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ADOPTION OF PRECISION AGRICULTURE

ADOPTION OF PRECISION AGRICULTURE TECHNOLOGIES IN ETHIOPIAN AGRICULTURAL CONTEXTS: A REVIEW
#9445

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ABSTRACT

In the coming decades, world agriculture will need to under-go a major transformation to meet the future demands of a growing population. Adoption of precision agriculture by smallholder farmers is still at a nascent stage and is limited by several factors. Smallholder farmers suffer from low farm productivity and yields as well as lack of access to inputs, credit, and markets; the lack of digital infrastructure like Internet and electricity; lack of awareness and digital skills among farmers; and societal barriers like gender. Thus, the main objective of this study is to determinants of adoption of PAT and to build a conceptual framework that consolidates the determinants of adoption of PAT by Ethiopian farmers. It can help to precisely level land, correct seeding, and application of the right amount of fertilizer, irrigation water, and pesticide based on the plant need. Digital technologies are making precision agriculture solutions increasingly affordable and accessible to even smallholder farmers in developing countries. These include mobile phones, remote sensing using satellites and unmanned aerial vehicles (UAVs), and sensors and the Internet of things (IoT) - all enabled by advances data processing and analytics.

Keywords: Artificial Intelligence, Digital Agriculture, Precision Agriculture

INTRODUCTION

Over the past few decades, agricultural production has progressed from the machinery age to the information age with the growing use of precision agriculture (Reichardt and Jürgens, 2009). FAO (2018) by 2050, the food industry will have to face the daunting challenge of feeding about 10 billion people by almost doubling its food supply in a sustainable way.

The Ethiopian land holding is less than one hectare in the highlands and a bit more in Afar, Gambelia, and Somali Regions. Hence, adoption of precision farming may be difficult, as the technology requires large farms of at least 60 hectares. However, the current system of cluster-based farming for a single commodity (several hundred farmers clustered to grow a single crop variety) may open the possibility of adoption for site-specific input application (Berhanu M., 2019)

Ethiopia Is Importing 30% of Wheat, 70% of Sugar and Rice, and 85% of the Vegetable Oil annual Demand from Abroad. This has brought a Huge Burden for the Economy Which Otherwise Would Have Been Used for Development. Hence The Government of Ethiopia has A Project to Intensify the Productivity of Wheat in the Highlands and Increase the Area of Wheat Production in the Lowlands of Afar, Wabe Shebelle and Omo Valleys Using Irrigation (Agegnehu et al., 2017).

In Ethiopia, since large- and small-scale farmers are using furrow (Agegnehu et al., 2016) and flood irrigation that resulted (Zeleke et al., 2010) Ethiopia has been one of the countries affected by soil sanity in the world (IFPRI, 2010). Adoption of precision agriculture by smallholder farmers in Ethiopia is still at a nascent stage and is limited by several factors. In addition to high costs, other key barriers include the lack of digital infrastructure like Internet and electricity, lack of awareness and digital skills among farmers, and societal barriers like gender. Finally, lack of digital skills and literacy among smallholder farmers remains a major barrier in leveraging the potential of digital technologies. Shortage of land per household is severe and land degradation is widespread in the highlands of Ethiopia. The fertilizer rate and type used for many crops is based on blanket recommendation with limited site-specific information (Agegnehu et al., 2016; Zeleke et al., 2010). This paper provides a synthesis of the level, practice, and future perspective of precision agriculture as well as the need and benefit of introducing the technology into the Ethiopian agriculture production system.

MATERIALS AND METHODS

Study area and the data

The study was conducted in the Haramaya University; & Adama science and Technology University, Oromia Regional state, Ethiopia. Haramaya, and Adama district and data on precision and non-precision farming's were collected Using structured interview schedule, both qualitative and quantitative primary data were gathered from FRG participant farmers and nonparticipant farmers. Interview schedule and group discussions have been conducted to gather information of demographic characteristics, socioeconomic, institutional dimensions to find out the determinant factors of adoption of precision Agriculture during the year 2020/21.

A secondary Data Search was conducted through the Web of Science (Apps. web of knowledge.com), Google Scholar (scholar.google.com), AGRIS (agris.fao.org), Research Gate (https://www.researchgate.net), Ethiopian Journal of Agricultural Sciences, The Ethiopian Society of Soil Science (www.esss.org.net), and Libraries of the Ethiopian Institute of Agricultural Research and National Soils Research Center. Several Publications that Provide Empirical Evidence on Precision Agriculture were reviewed in this paper.

Data Analysis

Collected data was analyses with the help of ANOVA, & SWOT Analysis.

Table 1. Determinants of Precision Agricultural Technology Adoption.

Categories	Variables
Socioeconomic Factors	Age, Education, Family Size, Activity Experience, Ability to obtain and process information, network, credit, risk aversion, producer organization level, farm management
Agro-Ecological factors	Land domination, farm specialization, total area, revenue, variable rate fertilizer application, livestock sales, asset / liability ratio, value of production, yield, corporate structure, income, and farm profitability, quality of soil, % of primary crop of the total area, % of the total area harvested area, % of the farm area divided by municipal area, activity / non-agricultural employment, and others.
Institutional Factors	Distance from the fertilizer distributors, Region, using of future contracts, development pressure and distance to the main market.

RESULTS AND DISCUSSION

Table 2. Distribution of non-FRG member's respondents by adoption Category of precision technologies.

Adoption Category	N	percent	Adoption index score	Mean	SD	F	P
Non-Adopter	50	65.8	0.00-0.000	0.00000			
Low-Adopter	22	28.9	0.01-0.30	0.4670	0.06858		
High-Adopter	4	5.2	0.31-1	0.0956	0.00762		
Total	76	100	0.00-1	0.2212	0.22124	34.47***	0.000

Table 3. Distribution of FRG member's respondents by adoption Category precision technologies.

Adoption Category	N	percent	Adoption index score
High	54	100	1
Total	54	100	

Table 4. Education statuses of sampled respondent.

Adoption Category	Illiterate	Read & write	1-4	5-8	9-10	>10	Total	χ^2	P
Non-Adopter	18	12	10	3	6	1	50		
Low-Adopter	2	2	8	5	2	3	22		
High-Adopter	3	6	9	16	10	14	58		
Total	23	20	27	24	18	18	130	17.25a	0.004

Table 5. Non-FRG Land holding of sampled respondents.

Land in hectare	Adoption Category	N	Mean	SD	t	P
	Non-Adopter	50	0.36	0.351		
	Low –Adopter	22	0.66	0.182		
	High-Adopter	4	1.0	0.204		
	Total	76	0.480	0.237	17.65***	0.000

***, significant at 1% probability level.

Table 6. FRG members Land holding of sampled respondents.

Land in Categories hectare	Adoption	N	Mean	SD	t	P
Total land holding	High-Adopter	54	0.86	0.246		
	Total	54	0.86	0.246	26.09***	0.000

***, significant at 1% probability level.

Table 7. Variable Coefficient.

Variable Coefficient	Estimated	Standard error	T	P=value
AGE	- 0.0013105	0.9966604	- 0.03	0.897
EDU	0.185146	0.0857708	1.88**	0.040
LANHO	0.1023712	0.0271121	2.81***	0.000
LIVSTO	0.0002305	0.0268286	0.01	0.881
ACESSAGRES	3257437	.0772683	3.38***	0.000
ACESSEXT	2543525	- 0.543362	4.12***	0.000
FRGM.	292717	0.428348	3.05***	0.000
Constant	-215274	1224055	-1.56	0.064
sigma	.3226762	.0316416	-	-
Log likelihood function=21.045534				
ANOVA best fit measure =0.4244				
P=0.000				

Source: Model output, ***, **,* represents 1%, 5% and 10% level of significant.

Table 8. Respondents' opinion on precision agriculture adoption @ Haramaya University.

Challenges of precision adoption	Total number of respondents	No. of respondent's Face challenges	% of respondent's Face challenges
Behavioural factors	200		
Lack of technology awareness /knowledge		158	79.31
Rigidity to adopt new technology /believe in old traditional factors		184	92.11
Reference group influence		120	60.09
Lack of awareness of government/ institutional support		127	64.03
Economic factors	200		
Higher initial cost		186	93.10
Higher operational cost		133	66.99
Lack of institutional and government assistance		151	75.86
Technology factors	200		
Complexity of technology usage		155	77.83
Limitation of technology use		164	82.75
Lack of installation/ training assistance		173	86.69
Availability and accessibility in sale		160	80.29

Table 1. Reasons for adoption and constraints to adoption of precision farming.

Reasons	**Mean Garrett's score**	**Rank**
Lack of finance and credit facilities	73	1
Drip installation and water-soluble fertilizers are expensive	65	2
Lack of knowledge about precision farming technologies	54	3
Labour scarcity	53	4
Farmers' perception on yield impact of low quantity of inputs	51	5
Lack of water availability and pumping efficiency	44	6
Lack of technical skill to follow precision farming recommendations	42	7
Market tie-ups lead to low price fixation for the produce / unprofitable negotiations	41	8
Inadequate training and demonstrations and weak research – extension – farmer relationship	41	9
Inadequate size of landholdings for adoption of precision farming	27	10

Table 10. Crosstab for land size versus age of sample respondents.

land size * age of respondents * I think I would adopt PA Cross tabulation					
I think I would adopt PA		Age of respondents			Total
	land size - acres/ha	26-35	36-50	Above 50	
Neutral	6-9		1		1
	Total		1		
Agree	less than 1			1	1
	2-5		11	11	22
	6-9	2	10	12	24
	10-12			5	5
	13 and above	1		1	2
	Total	3	21	30	54
Strongly Agree	2-5	2	14	13	29
	6-9	8	29	35	72
	10-12	1	9	25	35
	13 and above	0	2	7	9
	Total	11	54	80	145
Total	less than 1	0	0	1	1
	2-5	2	25	24	51
	6-9	10	40	47	97
	10-12	1	9	33	43
	13 and above	1	2	8	11
	Total	14	76	110	200

DISCUSSION

These are varieties, fertilizer application rate, chemical spraying, cultivation frequency, the sample respondent's adoption index scores were categorized in to three adopter groups namely non-adopter, low and high adopter the actual adoption index score ranges from 0 to 1. Adoption index score of 0 point implies non-adoption of the overall improved technologies production package. Statistical analysis of ANOVA indicated that there was significant variation (F= 34.47, P=0.000) among the adoption index score between the three categories at 1% level of significant which indicates difference of adoption of precision technology packages among sampled non- FRG (Table 1). As indicated in Table 3, non-adopter accounts for 65.8% with the mean adoption index of 0.0000. This indicated that non adopter was not practicing any of the recommended package and the technologies in the production year of 2020. Next to non-adopters, low adopters constituted about 28.9 %. They have mean adoption index of 0.4670 while high adopters constituted about 5.2% with mean adoption index were 0.0956.

CONCLUSIONS

Agriculture being the socio-economic backbone of the nation necessitates the implementation of Precision Agriculture to accelerate food productivity at a reduced cost, achieve food security, safety, and sustainability, and conserve the environment. It is still only a concept in Ethiopia and requires strategic assistance from both public as well as private sectors for successful adoption. Precision agriculture a way of research for revolutionizing agriculture and is a systematic implementation of the best management practices into a site-specific system. The concept of 'doing the right thing, at the right time and the right place' is an intuitive appeal. It is a technically sophisticated system of farming and requires technical manpower with the know-how of modern-day machines. Furthermore, we analyzed the influence over factors as socioeconomic, agro ecological, behavioral, information sources, perception by the farmer and technological in the adoption of PAT. The framework built is purely conceptual and it can be tested through application of field research with farmers. Based on the studies analyzed we were able to build up some propositions relating the determinants identified in the studies analyzed with the probability of farmers adopt or not PAT, which may indicate pathways for development of future studies.

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ANALYSE DE LA VARIABILITE SPATIALE DES RENDEMENTS DE MAÏS (*ZEA MAYS* L.) DANS LES REGIONS DES SAVANES ET CENTRALE AU TOGO #9510

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RESUME

L'agriculture de précision s'impose au Togo. Une étude a été menée dans 5 préfectures du Togo, dont 2 dans la région des Savanes (Oti et Kpendjal) et 3 dans la région Centrale (Sotouboua, Tchamba et Tchaoudjo) avec un total de 20 producteurs en 2021. L'objectif a été d'analyser la variabilité spatiale du rendement en grain du maïs (variété Ikenne) au sein de chaque région sous deux pratiques de gestion agricoles incluant : la pratique paysanne (le producteur opère comme il en a l'habitude) et la pratique dite optimale avec $N_{120}P_{60}K_{70}$ ha^{-1} et de bonnes pratiques principalement en termes d'entretien de la culture et de la gestion de l'application des engrais. Chaque producteur a disposé d'une surface de deux (02) ha divisée en deux parties (champs) égales dont une pour la pratique paysanne et l'autre pour la pratique dite optimale. Neuf carrés de rendement ont été posés dans chaque hectare à la récolte et les coefficients de variation des rendements sous les différentes pratiques ont été déterminés dans chaque région.

Les résultats ont montré une grande variabilité spatiale du rendement en grain de maïs au sein d'un même champ dans chaque région. Les coefficients de variation moyens ont été environ de 37% et 58% sous la pratique paysanne et environ de 21% et 30 % sous la pratique optimale, respectivement pour les préfectures de l'Oti et de Kpendjal dans la région des Savanes. Pour la région Centrale, les coefficients de variation moyens ont été environ de 44%, 39% et 27% sous la pratique paysanne et environ de 18%, 20% et 20% sous la pratique améliorée, respectivement pour les préfectures de Sotouboua, Tchamba et Tchaoudjo. Les coefficients de variation moyens au niveau régional ont été typiquement de 48 et 25 % respectivement sous les pratiques paysanne et améliorée dans les Savanes, et de 37 et 19 % respectivement sous les pratiques paysanne et améliorée dans la région Centrale. L'ensemble des résultats démontre que la variabilité du rendement en grain de maïs à l'échelle du champ est évidente avec une magnitude qui est fonction de la pratique agricole. Les coefficients de variation ont été différents suivant les régions indiquant ainsi que la recommandation de formules de fertilisation devrait être spécifique à chaque région.

Mots clés : Maïs, variabilité spatiale, rendement, coefficient de Variation ; Régions des Savanes et Centrale

ABSTRACT

Precision agriculture is gaining ground in Togo. A study was conducted in 5 prefectures of Togo, including 2 in the Savannah region (Oti and Kpendjal) and 3 in the Central region (Sotouboua, Tchamba and Tchaoudjo) with a total of 20 producers in 2021. The objective was to analyze the spatial variability of grain yields of maize (Ikenne variety) within each region under two agricultural management practices including: the farmer's practice (the producer operates as he is used to) and the so-called optimal practice with N120P60K70 ha-1 and good practices mainly in terms of crop maintenance and fertilizer application management. Each farmer was given an area of two (02) ha divided into two equal parts (fields), one for the farmer's practice and the other for the so-called optimal practice. Nine yield squares were placed in each hectare at harvest and the coefficients of variation of yields under the different practices were determined in each region.

The results showed high spatial variability in corn grain yield within a field in each region. The average coefficients of variation were about 37% and 58% under the farmer's practice and about 21% and 30% under the optimal practice, respectively for the Oti and Kpendjal prefectures in the Savannah region. For the Central region, the average coefficients of variation were about 44%, 39% and 27% under the farmer's practice and about 18%, 20% and 20% under the improved practice, respectively for the prefectures of Sotouboua, Tchamba and Tchaoudjo. The average coefficients of variation at the regional level were typically 48% and 25% under the farmer and improved practices in the Savannah region, and 37% and 19% under the farmer and improved practices in the Central region. Taken together, the results demonstrate that variability in maize grain yield at the field level is evident with a magnitude that is a function of farming practice. The coefficients of variation were different among regions indicating that the recommendation of fertilization formulas should be specific to each region.

Keywords: Maize, spatial variability, yield, coefficient of variation, Savannah and Central Regions

INTRODUCTION

En Afrique subsaharienne (ASS), la fertilité des sols varie dans l'espace et dans le temps, de l'échelle du champ à celle de la région, et est influencée à la fois par l'utilisation des terres et par les pratiques de gestion des sols des petits exploitants agricoles (Guimaraes Couto *et al*., 1997, Brejda *et al*., 2000, Earl *et al*., 2003, Godwin and Miller, 2003, Ncube *et al*., 2009). Cette variabilité spatiale des caractéristiques physiques, chimiques et morphologiques des sols est un fait établi depuis de longues années (Burrough, 1993). Comprendre la variabilité de la fertilité des sols, sa distribution et les causes de la variabilité observée est important pour aborder les stratégies d'utilisation durable des terres (Ebanyat, 2009, Musinguzi *et al*., 2016). Elle est due soit aux facteurs intervenant dans la formation des sols, soit au type d’utilisation et de gestion des terres (Kotto-Same *et al*., 1997). Elle a pour corollaire la variabilité de la fertilité des sols, ce qui induit une variabilité spatiale dans les rendements des cultures. La quantification précise à différentes échelles permet des pratiques rentables telles que la gestion spécifique au site ou l'agriculture de précision qui, d'autre part, aideraient à résoudre les problèmes de pollution et de dégradation des sols (Uzielli *et al*., 2006, Ngandeu Mboyo *et al*., 2008).

Afin d'adapter une gestion corrective des terres efficace et spécifique au site dans l’optique de promouvoir une agriculture de précision au Togo, il est nécessaire d'analyser et de comprendre les causes de la variabilité spatiale des rendements à l’échelle d’une parcelle. Dans les pays en développement d'Afrique subsaharienne, l'utilisation efficace des engrais est affectée par la variabilité des sols (Musinguzi *et al*., 2016).

Les rendements des cultures sont généralement limités en raison de l'exploitation des nutriments et de l'appauvrissement de la fertilité des sols dû à une application inadéquate ou inexistante d'engrais (Prabhavati *et al*., 2015). Les sols ne sont pas seulement assoiffés mais aussi affamés (Wani, 2008). Or l’un des défis majeurs, pour les scientifiques, les gouvernements et autres parties prenantes dans la région, est que la production alimentaire devrait augmenter de 70% en l'an 2050 pour répondre aux besoins caloriques nécessaires à la population (Liniger *et al*., 2011). Au Togo plus précisément dans les régions des Savanes et Centrale, plus de 80% des sols sont pauvres en éléments nutritifs (ITRA, 2021). Dans ces régions, la question de la sécurité alimentaire semble se limiter à la disponibilité spatio-temporelle et à l'accessibilité du maïs pour les ménages. Durant les deux décennies, le rendement moyen en maïs grain dans ces régions est presque constant et très faible par rapport au rendement potentiel (5t ha^{-1}) et n'excédant pas 2 t ha^{-1} contre une population en perpétuelle croissance exponentielle (DSID, 2021).

La présente étude s'inscrit dans un programme de recherche-développement visant à analyser la variabilité spatiale du rendement en grain du maïs et de comprendre les causes de cette variabilité afin de juger urgent de déterminer la fertilité endogène du sol et ainsi développer des stratégies techniquement, économiquement et socialement justifiée pour sa gestion et améliorer la productivité du maïs.

MATERIEL ET METHODES

Site de l'expérimentation

L'étude a été conduite dans les régions des savanes (latitude : 10,423868 ; longitude : 0.409638) et centrale (latitude : 8.95792029 ; longitude : 1.25795939) au Togo. Le climat est de type Soudano-guinéen avec une saison pluvieuse qui va de mai à octobre et une saison sèche de novembre à avril. Au cours de la période de l'essai, la quantité de pluie enregistrée a été de 539,9 mm en 36,5 jours et 1007,2 mm en 68,3 jours respectivement pour les préfectures de Kpendjal et Oti de la région des Savanes et de 1369,3 mm en 86 jours, 1307,3 mm en 86 jours, 1269,9 mm en 79 jours respectivement pour les préfectures de Sotouboua, Tchaoudjo et Tchamba de la région Centrale. Les sols dominants sont de types ferrugineux tropicaux lessivés (Lamoureux, 1969).

Matériel végétal

La variété de maïs Ikenne 9449-SR a été utilisée au cours de l'expérimentation. Il s'agit d'une variété composite, obtenue par CIMMYT / IITA, introduite au Togo en 1980 et cultivée dans toutes les régions du pays. Le cycle semis-maturité (50%) varie de 100 à 105 jours. Cette variété a une taille moyenne de 2,10 m et une hauteur d'insertion d'épis de 90 cm. Son grain est dûr de couleur blanchâtre. Elle présente un bon recouvrement de l'épi, une bonne résistance à la sécheresse, au virus de la striure et à la verse. Le rendement moyen de la variété Ikenne est de 5 Mg ha^{-1} (CEDEAO-UEMOA-CILSS, 2016).

Conduite de l'essai

L'essai a été mené de juin à novembre 2021 dans les régions des Savanes (Oti et Kpendjal) et Centrale (Tchaoudjo, Tchamba et Sotouboua) au Togo suivant un dispositif expérimental complètement aléatoires. Dix producteurs ont été choisis dans chaque région. Chaque producteur a disposé d'une surface de deux (02) ha divisée en deux parties (champs) égales dont une pour la pratique paysanne (le producteur opère comme il en a l'habitude) et l'autre pour la pratique dite optimale avec $N_{120}P_{60}K_{70}$ ha^{-1} et de bonnes pratiques principalement en termes d'entretien de la culture et de la gestion de l'application des engrais constituant ainsi les traitements.

Collecte et analyse des données

Les rendements en grain de maïs et les coefficients de variations ont été déterminé pour chaque traitement. Neuf carrés de rendements ont été posé d'une superficie de 3,84 m^2 soit 2,4 m de long et 1,6 m de large. Pour la détermination des carrés de rendements, chaque hectare est divisé en six parties égales du côté de sa longueur comme de sa largeur. Trois lignes ont été retenues, dont la ligne médiane et les lignes à chaque extrême en laissant une tranche des 1/6. Les carrés résultent des croisements des trois lignes de par la longueur et la largeur. Le rendement a été calculé par extrapolation à partir du poids des grains secs issus des plants récoltés et sur la base de la densité de peuplement pour chaque pratique par hectare. Les données obtenues ont été traitées à l'aide du tableur Excel pour déterminer l'écart type (σ) ainsi que la moyenne (µ). Le coefficient de variation (CV) a été calculé à travers cette formule ci-dessous :

$$CV = \frac{\sigma}{\mu} * 100$$

RESULTATS ET DISCUSSION

Les rendements en grain de maïs et les coefficients de variations sont résumés en annexe 1 et 2 ci-après. Les rendements calculés ont servi de déterminé les coefficients de variations qui ont présenté différentes amplitudes.

Pour les préfectures de la région des Savanes (Oti et Kpendjal), les coefficients de variations ont été environ de 21 et 37 % respectivement pour les pratiques améliorée et paysanne pour la préfecture de l'Oti et de 30 et 58% respectivement pour les pratiques améliorée et paysanne pour la préfecture de kpendjal ; en moyenne de 25 et 48% pour la région des Savanes.

Pour les préfectures de la région centrale (Tchaoudjo, Tchamba et Sotouboua), les coefficients de variations ont été environ de 20 et 27 % respectivement pour les pratiques améliorée et paysanne pour Tchaoudjo, de 20 et 39% respectivement pour les pratiques améliorée et paysanne pour la préfecture de Tchamba et de 18 et 44 % respectivement pour les pratiques améliorée et paysanne pour la préfecture de Sotouboua ; en moyenne 19 et 37% pour la région Centrale.

Les coefficients de variations obtenues sous les pratiques paysannes sont plus élevés que ceux obtenus sous les pratiques améliorées pour les cinq préfectures montrant ainsi une grande variabilité spatiale des rendements en grains de maïs sous les pratiques paysannes. Les coefficients de variation obtenus sous les pratiques améliorées comme paysanne ont variés également selon les préfectures.

Malgré l'application des mêmes technologies sur les pratiques dite améliorées, le rendement moyen a varié par parcelle d'une même préfecture. En considérant également, la moyenne préfectorale et régionale, le rendement moyen a également varié d'une préfecture à l'autre et d'une région à l'autre. Nous observons les mêmes scénarii sur les pratiques paysannes.

Alors il ressort de nos résultats que la variabilité spatiale des rendements est fonction des pratiques de gestion de cultures, de la fertilité endogène du sol et du climat. Ces résultats sont similaires à ceux d'Uzielli *et al*. (2006) pour qui la variabilité de la fertilité des sols induit une variabilité spatiale des rendements des cultures. Ils corroborent également ceux de Earl *et al*. (2003), Ncube *et al*. (2009) qui ont déclaré que la fertilité des sols varie dans l'espace et dans le temps, de l'échelle du champ à celle de la région, et est influencée à la fois par l'utilisation des terres et par les pratiques de gestion des sols des petits exploitants agricoles. Pour Jabro *et al*. (2010) la variabilité spatiale des propriétés du sol est un problème mondial majeur et contribue aux différences observées dans la croissance, les rendements et la qualité des grandes cultures.

La meilleure interprétation des résultats est que la gestion de la variabilité spatiale des rendements en grain du maïs nécessite une connaissance préalable de la fertilité endogène des sols, du climat et des pratiques de gestion techniquement, économiquement, socialement justifiées et respectueuse de l'environnement.

D'où l'urgence de promouvoir l'agriculture de précision au Togo, qui est un système intégré de gestion des cultures qui utilise divers outils et technologies pour évaluer et surveiller la variabilité spatiale des sols et des cultures et pour mettre en œuvre des applications spécifiques au site, qui est déjà dans de nombreux pays développés comme une pratique courante plutôt que comme une innovation (Rachid *et al*., 2020).

CONCLUSION

L'adoption de l'agriculture de précision dans les pays subsahariens, dont le Togo, devient un besoin urgent pour une production végétale respectueuse de l'environnement. Les résultats de la présente étude, dont l'objectif était d'analyser la variabilité spatiale des rendements en grain du maïs, montrent que cette variabilité est fonction des pratiques de gestion des cultures, de la fertilité endogène des sols et du climat. L'adoption de bonnes pratiques de gestion de culture permet de réduire une grande partie de cette variabilité. La détermination de la fertilité endogène du sol reste prioritaire dans la gestion de la variabilité spatiale des rendements.

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ANNEXE

Annexe 1. Tableau résumant les rendements et les coefficients de variation pour la région des Savanes.

Région	Préfecture	Producteur	Traitement	Rendement Mgha^{-1}	Coefficient de variation (%)
Savanes	Oti	1	Améliorée	3,97	22
		1	Paysanne	1,45	44
		2	Améliorée	4,53	20
		2	Paysanne	2,46	48
		3	Améliorée	3,97	18
		3	Paysanne	3,11	28
		4	Améliorée	4,92	17
		4	Paysanne	2,56	30
		5	Améliorée	3,38	26
		5	Paysanne	2,33	36
	Moyenne Oti		Améliorée	**4,15**	**20,6**
			Paysanne	**2,38**	**37,2**
	Kpendjal	6	Améliorée	3,14	26
		6	Paysanne	1,67	45
		7	Améliorée	2,22	39
		7	Paysanne	0,82	87
		8	Améliorée	2,75	27
		8	Paysanne	1,20	40
		9	Améliorée	2,90	27
		9	Paysanne	0,66	53
		10	Améliorée	2,89	29
		10	Paysanne	0,92	66
	Moyenne Kpendjal		Améliorée	**2,78**	**29,6**
			Paysanne	**1,05**	**58,2**
Moyenne Savanes			Améliorée	**3,47**	**25,1**
			Paysanne	**1,72**	**47,7**

Annexe 2. Tableau résumant les rendements et les coefficients de variation pour la région Centrale.

Région	Préfecture	Producteur	Traitement	Rendement $Mgha^{-1}$	Coefficient de variation (%)
Centrale	Tchaoudjo	1	Améliorée	2,77	35
		1	Paysanne	1,87	19
		2	Améliorée	4,18	13
		2	Paysanne	1,89	14
		3	Améliorée	3,56	10
		3	Paysanne	2,05	35
		4	Améliorée	4,65	22
		4	Paysanne	1,77	41
	Moyenne Tchaoudjo		Améliorée	**3,79**	**20**
			Paysanne	**1,90**	**27,25**
	Tchamba	5	Améliorée	4,79	25
		5	Paysanne	1,62	59
		6	Améliorée	3,72	17
		6	Paysanne	1,91	44
		7	Améliorée	3,93	18
		7	Paysanne	2,45	15
	Moyenne Tchamba		Améliorée	**4,15**	**20**
			Paysanne	**1,99**	**39,33**
	Sotouboua	8	Améliorée	5,56	11
		8	Paysanne	2,84	29
		9	Améliorée	3,82	22
		9	Paysanne	2,70	31
		10	Améliorée	2,96	21
		10	Paysanne	0,63	72
	Moyenne Sotouboua		Améliorée	**4,11**	**18**
			Paysanne	**2,05**	**44**
Moyenne Centrale			Améliorée	**4,02**	**19,33**
			Paysanne	**1,98**	**36,86**

VARIABILITY IN YIELD RESPONSE OF MAIZE TO N, P AND K FERTILIZATION TOWARDS SITE-SPECIFIC NUTRIENT RECOMMENDATIONS IN TWO MAIZE BELTS IN TOGO
#9512

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ABSTRACT

Savannah and central regions are the major maize production zones in Togo, but with maize grain yields at a threshold of only 1.3 Mg ha^{-1}. We use a participatory approach to assess the importance of the major three macro elements (N, P and K) for maize cropping in the two regions to further allow for site-specific and scalable fertilizer recommendations. Thirty farmers' fields served as pilot sites, allocated within the two regions to account for spatial variability in soil inherent fertility and weather conditions. Five fertilization schemes were applied to maize crop at each site as a replicate plot of 10 m x 10 m (100 m^2). The fertilization schemes were derived from a nutrient omission-based approach and consisted of the following treatments: T1, control, no fertilizer application; T2, full NPK fertilization at 120 kg N ha^{-1}, 60 kg P ha^{-1} and 70 kg K ha^{-1} ($N_{120}P_{60}K_{70}$); T3 ($N_0P_{60}K_{70}$); T4 ($N_{120}P_0K_{70}$); T5 ($N_{120}P_{60}K_0$). Fertilizer P and K rates were applied two weeks after maize planting together with half of N fertilizer rate, and the remaining half of N was applied 40 to 45 days after planting. Maize grain yields were determined by harvesting a sub-plot of 16 m^2 delimited at the center of each plot of 100 m^2. Mean yield data in the Savannah Region ranged from 0.56 to 4.57 and 0.32 to 3.02 Mg ha^{-1} for the Tandjouare and Tone districts, respectively. In the Central Region, mean grain yields were between 1.60 and 3.70 and 1.05 and 3.46 Mg ha^{-1} for the Tchaoudjo and Sotouboua districts, respectively. The fertilization treatment-based ranking of the yield data clearly indicated that all the three macro nutrients (N, P and K) are needed for maize production in the two regions with a priority-based ranking being N > P > K. However, the data set showed significant variability in yields within and across region, indicating that site-specific fertilizer recommendation is needed at a district-scale to maximize nutrient use efficiency and to realistically fulfill crop nutrient need.

Keywords: Maize cropping, mineral fertilizer, site-specific fertilizer recommendation, nutrient use efficiency, Togo

INTRODUCTION

Improving agricultural productions has become a growing concern in Togo because the sector is the primary engine of the country's economy with a contribution of over 40% to the GDP and more than 20% to the export gains (DSID, 2015). Furthermore, agriculture employs over 65% of the active population with 3.6 million ha of arable land representing 60% of the country's total area. Maize is the number one cereal food crop and produces 68% of the agriculture-based contribution to the country's GDP (FAO, 2021; DSID, 2015;). Food security is termed as maize grain availability (Detchinli, 2017) called ***Queen Grain***. Moreover, maize cropping occupies 700,000 hectares, which represents 40% of the total food crop area with a yearly grain production of typically 900,000 t (DSID, 2022), most of which comes from the

Savannah and Central regions known as the country's maize belts. Nevertheless, maize grain yield in the country is typically in a threshold of 1.3 t ha^{-1}, which is very low compared to the potential yields of 5 to 6 t ha^{-1} for the major used varieties (ITRA 2007).The low maize yield primarily results from the use of pan-territorial and very aged (1980's) fertilizer recommendations (Sanou et al. 2017which can also lead to environmental pollution (Ezui, 2010). Other problems faced by maize cropping include the complexity of the country's agro ecology and land degradation. Relatively recent exploratory studies (IFDC, 2012) showed noticeable variability in maize grain yield response to major nutrients across the different regions of the country. This indicates that maize production improvement in the country requires that fertilizer recommendations be updated on a site-specific basis. In other words, the production system should operate on a precision nutrient management basis with practices that are technically, socially, and economically justified and sustainable.

The objective of this study was to assess variability in yield response of maize to macro elements N, P and K fertilization in two maize belts in Togo. The aim was to determine the need level of each of the three elements (N, P and K) in maize production and asses the priority order of the need to further catalyze the development of precision site-specific nutrient management recommendations for maize cropping.

MATERIAL AND METHODS

Study sites

The study was conducted in two regions known as maze belts of the country including the Savannah region and the Central region (Fig. 1). The soils of the Savannah region are ferruginous tropical soils with organic matter content, pH $_{(H2O)}$ and sum of exchangeable bases ranging from 0.43 to 1.72%, 5.8 to 6 and 7 to 20 meq, respectively. The climate has a monomodal rainfall regime with an mean of 1200/yr and provides one maize crop typically from June to September. The Central region has clayed-vertisols with organic matter content and pH $_{(H2O)}$ between 0.55 and 2.08% and 5.4 and 8.0, respectively, and a monomodal rainfall regime climate with an average of 1200/yr and provides one maize typically from June to September.

Participatory nature and design of the study

In each of the two regions, fifteen (15) farmers were selected in two districts (Fig. 1) to host the experiment as a replicate. Farmers were strategically selected for capacity building and high technology adoption potential purposes and for serving as pilot sites for the region. At each pilot site, five plots of 10 m x 10 m (100 m^2) each were laid out and the following five fertilization treatments were applied on the basis of the principle of omission trials: T1: control, no fertilization; T2, N omitted from the full NPK (PK); T3: P omitted from the full NPK (NK); T4: K omitted from the full NPK (NP); T5: full NPK (120 kg N ha^{-1}, 60 kg P ha^{-1} and 70 kg K ha^{-1}).

Soil and crop management

At each site, Ikenne, the most used maize variety in the regions was planted at the scheme of 0.8 m x 0.4 m and thinned to 2 plants/hill making it to a potential population density of 62,500 plants/ha. Maize crop was manually weeded three times and treated as needed to EMACOT 50 MG to fight army worms. Fertilizer application consisted of the application in point-placed mode of $N_{120}P_{60}K_{70}$ kg ha^{-1}, with half of the N rate (60 kg N ha^{-1}) and full rates of P and K applied approximately 15 to 21 days after maize planting and the remaining half of N applied 40 to 45 days after maize planting. Fertilizers N was applied as urea (46% N), and P and K were applied as triple superphosphate (TSP 46% P2O5) and potassium chloride (KCl 60% K2O), respectively.

Data collection and analysis

Mean maize grain yield for each fertilization treatment in each district was measured by harvesting an area of 16 m2 (3.2 m x 5 m) in the middle of the 100 m^2 treatment plot. Harvested maize grain was sun-dried at about approximately 14% moisture content. The yield data set was subjected to analysis of variance (ANOVA) using the GENSTAT software version12.0 and mean yield values were discriminated with the Duncan test at a p value of 0.05.

RESULTS AND DISCUSSION

Mean maize grain yield data are presented in Table 1. For the Savannah region, the data set indicated that yield trends as linked to fertilization treatments are in general identical in the two districts of the region. The fertilization treatment-based ranking of the data clearly indicated that all the three macro nutrients (N, P and K) are needed for maize production in the two districts with the ranking of their importance being N > P > K. However, the data showed that fertilization treatment-based grain yields were constantly higher in the Tandjouare district than those in the Tone district (Tables 1). This indicates that site specific nutrient management is required in the region at the district-scale to realistically fulfill crop nutrient need thereby maximizing nutrient use efficiency.

In the Central region, the yield trends as linked to fertilization treatments are similar in the two districts except in Tchaoudjo where mean yield under T1 (control) was numerically higher than that under T2=PK (Table 1). This change in the yield general trend in Tchaoudjo presumably resulted from cropping history (use of cow dung two years prior to the experiment) at two pilot sites. Like the Savanah Region, the fertilization treatment-based ranking of the data (Table 1) indicated that all the three macro nutrients (N, P and K) are needed for maize production in the two districts with the ranking of their importance being N > P > K. Unlike the Savannah Region, the data set showed that fertilization treatment based mean grain yields were reasonably similar for the two districts of the Central Region. This suggests that recommended fertilization schemes towards maximizing nutrient use efficiency to enhance maize production may reasonably apply for the two districts of the region.

On a regional basis, although the yield trends were similar with respect to fertilization treatment and the ranking of the importance of the three nutrients was N > P > K, mean maize grain yields were higher in the Central region as compared to those in the Savannah region. This further highlights the variability in yield response to nutrient across regions. Results of this study corroborate those of IFDC (2012) and Mawussi et al. (2015) in terms of both yield trends and nutrients' importance in the Plateau, Central and Savannah regions of Togo. However, results from several studies in the Maritime region (Sika, 2022; Tagba, 2022, William, 2021) agree with our results in terms of yield variability in response to N, P and K, but are against our results in terms of nutrients' importance because their ranking was N > K > P.

Table 1. Mean maize grain yield (Mg ha^{-1}) under fertilization treatment at district and regional scales.

Region	District	Fertilization Treatment					LSD
		T1=control	T2=PK	T3=NK	T4=NP	T5=NPK	
Savannah	**Tandjouaré**	0.56**c**	0.83**c**	3.18**b**	3.44**b**	4.57**a**	**0.6282**
	Tone	0.32**b**	0.52**b**	1.06**b**	2.39**a**	3.02**a**	**0.785**
Regional Mean		**0.44**	**0.68**	**2.12**	**2.91**	**3.80**	
Central	**Tchaoudjo**	1.55**c**	1.32**c**	2.34**b**	3.34**a**	3.73**a**	**0.5964**
	Sotouboua	1.05**c**	1.09**c**	1.33**c**	2.83**b**	3.46**a**	**0.5056**
Regional Mean		**1.30**	**1.20**	**1.83**	**3.08**	**3.59**	

CONCLUSION

Maize cropping in the Savannah and Central regions of Togo would not be an option without fertilizers N, P and K application. The gradient of the variability in yield response which prioritize fertilizer need was N > P > K. District-specific based nutrient recommendations may be required in the Savannah Region, but a region-based recommendation could be relevant for the Central Region. Findings from this study together with other information could be integrated with relevant decision support tools to develop nutrient recommendation schemes that are both agronomically and economically suitable in the regions.

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USING PRECISION TECHNOLOGIES TO MONITOR THE GRAZING ACTIVITIES OF GOAT IN A NORTH AFRICAN WOODLAND #9515

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ABSTRACT

In the North of Africa, browsing on natural pastures is the main source of feed for domestic goats. Livestock farming, particularly grazing goats, constitutes the prevalent agricultural activity in the mountainous areas of Morocco. Data on animal behavioral activities are essential for understanding their feeding and their interaction with the environment to define the optimal management intervention strategies. The recent development of precision farming technologies and the increasing availability of sensor technologies to monitor and record behavioral activities provide a real opportunity to extend our database and to understand the grazing behavior of animals. This work was conducted to understand the grazing activity of browsing goats in Northern Morocco by using the Global Positioning System (GPS) and accelerometers. Measurements were undertaken in oak cork rangeland during the three main grazing seasons (spring, summer, and fall). Grazing activity parameters were assessed using GPS collars and leg position sensors on eight experimental goats. The results showed that grazing time was higher in spring (57%) than in summer (39%) and fall (41%), respectively (p<0.001). The daily vertical distance traveled by goats increased from spring (about 0.3 km) to summer and fall (about 0.6 km), while greater daily horizontal distances were recorded over similar distances during summer-fall. The highest speeds were recorded during spring (0.198 m/s). Goats spent more time walking in fall than in spring and summer. The combination of an accelerometer and GPS collar provided the opportunity to monitor and understand the grazing activities of goats in a mountainous woodland in Northern Morocco. These results could provide useful and target information for herders and managers to enhance the grazing strategies of goats.

INTRODUCTION

In Northern Morocco, forest woodlands contribute largely to the feeding of goat herds (Chebli et al., 2018). These forest pastures constitute an important fodder reserve, guaranteeing a permanent source of fodder for goats during drought periods (Chebli et al., 2020). The grazing of animals on the rangelands is associated with very different daily activities from those of confined animals. Unfortunately, few studies have focused on the grazing activities of goats, especially in forest areas. To contribute to the spatio-temporal management of goats on rangeland, it would be essential to discover the relationship between goats and their environment.

Advances in the development and use of Global Positioning System (GPS) and sensor technology have provided useful near-real-time information on animal activity and behavior to increase livestock productivity and monitor the use of space. In this context, this study aimed to assess the potential for the adoption of smart grazing using GPS collars and accelerometers as a tool for monitoring goat grazing activities in the North African forest rangelands of Northern Morocco.

MATERIALS AND METHODS

This experiment was carried out at a goat farm located in the province of Chefchaouen. Goat grazing activity measurements were collected over three days of the three main grazing seasons (spring, summer, and fall). Winter was excluded from the study because the goats' herd is generally confined during this period.

Eight Alpine dairy goats were equipped with GPS collars and triaxial accelerometers. The GPS collar was used to estimate locomotion activities (traveled distance, speed, and altitudinal locomotion). The accelerometer was used to estimate the physical activities (animal lying or standing and the number of steps).

ArcGIS 10.x was used to calculate in meters (m) the (x,y) coordinate system for each fixed record from the GPS collars. The Euclidean geometry between two successive pairs of fixed locations L_1 (x_1, y_1) and L_2 (x_2, y_2) was used to calculate the horizontal distance.

A trial (calibration) was conducted to monitor the grazing activity of the experimental goats. Calibration was performed prior to experimentation over a period of 3 days in combination with direct visual observations of animal behavior. The data obtained was used to predict the grazing activities of each experimental goat using classification and regression tree analysis of data collected from electronic monitoring sensors.

Data analyses were performed using SAS software. Grazing activity data were analyzed according to the PROC MIXED procedure of SAS with the daily observation of each goat as the experimental unit. Parameters were compared across seasons (i.e., spring, summer, and fall). For all analyses, the level of significance was declared at $p<0.05$. In case of significant effect, the means were compared using Tukey's test.

RESULTS AND DISCUSSION

All behavioral variables showed significant differences within each measurement season ($p<0.01$). Fig. 1 shows the seasonal importance of activities of the experimental goats grazing in the studied forest rangeland. According to the classification and regression tree analysis, the percentage of time spent grazing (eating) was greater in spring (57%) than in summer (39%) and fall (41%). As reported by several authors (Safari et al., 2011; Chebli et al., 2020), the high forage availability recorded in the spring explains the increase in the time allocated to grazing. Conversely, the low forage availability recorded during the summer and fall could explain the longer time reserved for walking without grazing. During these two seasons, the plant species preferred and most selected by the goats are rare, which explains the long time devoted to the search for palatable vegetation. Walking activity is more related to the longer duration of forage search and selection by animals. The proportions of time spent lying were highest in summer (13%), followed by fall (11%) and spring (4%). In the studied forest rangeland, lying activity was more concentrated at the mid-day when the sun was highest. In summer, goats prefer to rest in the shade of trees to avoid the mid-day heat. Resting while standing was similar in all seasons (about 22%). Similarly, grazing animals are known to be more active during the early and late hours of the day but less active during mid-day due to heat and humidity.

The time reserved for locomotion activities was different according to the seasons ($p<0.001$, Fig. 2). According to the GPS collar data, the horizontal and vertical distances traveled by the experimental goats were significantly higher and similar during summer and fall. Similarly, the number of steps recorded the highest values during summer and fall (>7100 steps) compared to spring (5000 steps). The low availability of fodder leads to an increase in the time spent by the animals in search for palatable vegetation which, consequently, increases their locomotion activities such as the number of steps.

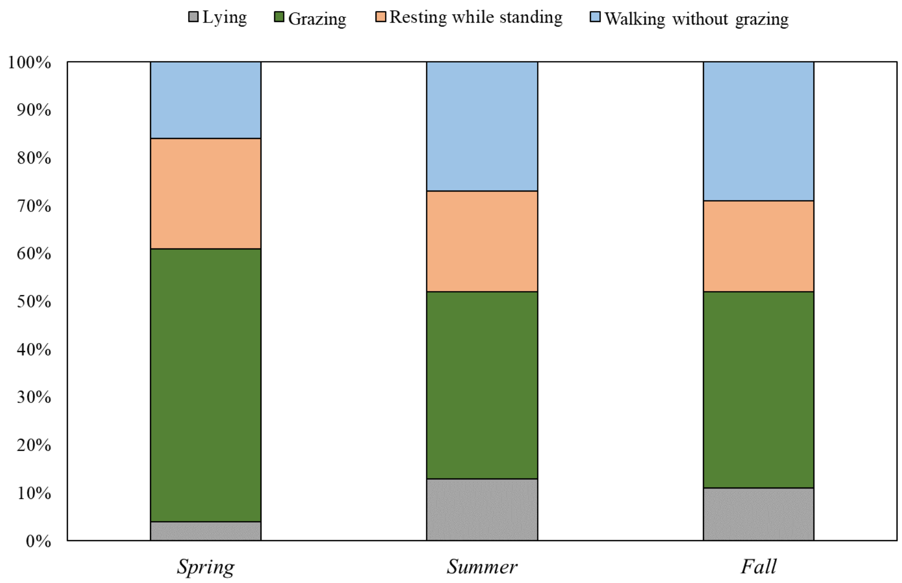

Fig. 1. Seasonal variation in grazing activities of dairy goats in a woodland of Northern Morocco.

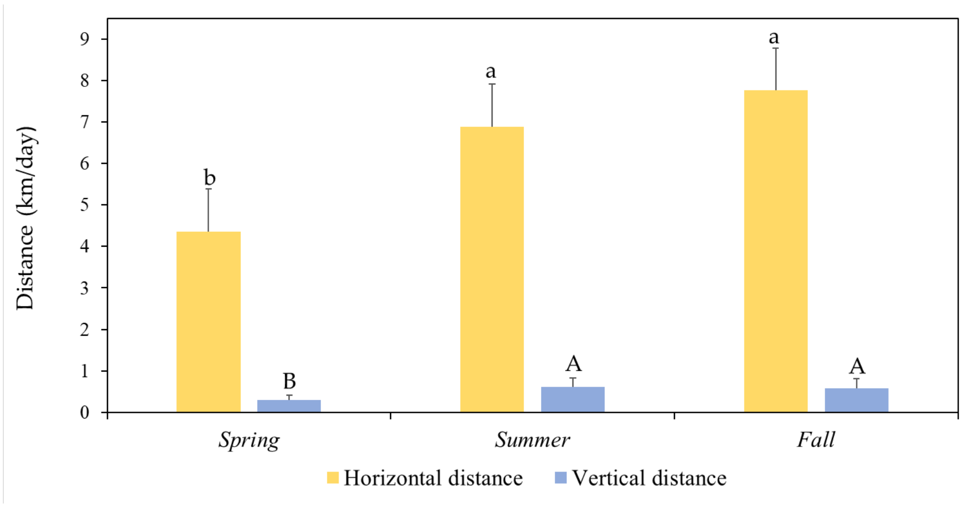

Fig. 2. Seasonal variation in displacement activity of dairy goats grazing in a woodland of Northern Morocco. The values of horizontal a-b or vertical A-B distances with different letters are significantly different ($p < 0.05$).

CONCLUSIONS

It could be confirmed that the grazing activities of goats mainly depend on the season. The combination of GPS collar and leg sensor technologies to monitor and record goat grazing activities provides useful information to understand the grazing behavior of goats grazing in the complex forest rangelands of Northern Morocco.

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FARMERS' PERCEPTION AND WILLINGNESS TO ADOPT DRONE TECHNOLOGY IN AGRICULTURE IN NIGERIA
#9537

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ABSTRACT

The application of drones, Unmanned Aerial Vehicles (UAVs), in agriculture has led to a paradigm shift in farming practices by reducing production costs and increasing operational efficiency and profitability. However, there is a paucity of empirical reports on the efficiency and profitability of UAV application to agriculture in Nigeria, limiting the contribution of Nigerian agriculture to the global scientific discourse on drone technology and advancement. This study investigates farmers' perception and willingness to adopt drone technology in agriculture in Nigeria. We employed a physical and online survey method to collect data from 96 respondents spanning 20 States across Nigeria. Data collected was analyzed using descriptive statistics and Binomial logistic regression. Results showed that 82.29% of the respondents were male, and more than 90% completed secondary school education. The average farming experience of households was 2.62 years, and the major crops grown were cassava, maize, and vegetables. All surveyed farmers have a mobile phone, with 98% using the internet and 43.62% producing on a small scale. The major income-generating activities of households included farming, trading, and agricultural processing in order of preference. The farmers' preferred mode of pesticide application was in the order of knapsack (manual) > motorized sprayer > tractor-mounted boom sprayer. 95% of respondents have heard about drones, and their major sources of awareness include social media (61.36%) and websites (19.32%). More than half of the respondents (51.06%) had witnessed a drone demonstration, 22.58% had operated a drone, and 38.3% of the respondent had sometimes employed the service of drone service providers. 98% and 94% of the surveyed farmers opine that drone technology can help overcome farming challenges and enhance agricultural productivity. Moreover, 92.7% of the respondents are willing to pay for the deployment of drone service on their farms, and those willing to engage in its long-term usage are relatively high (96.81%). Farmers prefer applying agrochemicals using drones (66.67%) over the conventional method (33%), with a bias for public-subsidized (22.83%), cooperative or cluster farming engagement (20.65%), and farmer pay (15.22%) drone service delivery model. More importantly, farmers' age and sexual orientation affect their willingness to accept drone technology in agriculture. Finally, we recommend the need for relevant policies to promote drone technology adoption in Nigerian agriculture as a pathway to enhancing efficient and low-cost sustainable food production. Farmers can achieve this by employing the services of drone service providers.

Keywords: agriculture, drones, technology, farmers, precision agriculture, Nigeria

INTRODUCTION

Increased agricultural production has the potential to unlock African prosperity and end hunger and poverty on the continent (African Development Bank, 2021). A vast majority of the African population is engaged in agriculture, contributing up to 60% to the GDP of many African countries through domestic and foreign trade of farm produce (The World Bank, 2021).

The merit of an improved agricultural livelihood system is a better living standard for Africans with increased income, food availability and access, and revenue for effective governance. However, crop and livestock productivity in Africa, especially Nigeria, is lower than global average. (FAO, 2022; Gidanmana, 2020). Increased production has only been seen with increased land cultivation, stocking more animals than effectively managing resources for optimum yield (Jayne & Sanchez, 2021). The consequences include inappropriate fertilizer application, wastage of irrigation water, and pests and weeds infestation, which deprives crops and animals of necessary nutrients and well-being to thrive and be productive. Hence, reduced yield and income become apparent. In the developed world, mechanized farming has been increasingly adopted for improved agricultural efficiency. For instance, the Unmanned Aerial Vehicle (UAV) has been widely employed for spray application of agrochemicals on farms. It helps to map the soil, plants, and animals effectively. It has also been used for fruit picking to prevent on-farm wastage, detecting, and monitoring pest and weed incidence and population, and inaccurate pesticide application for pest eradication. Drones are cost-effective technology for fertilizer delivery and animal feeding to enhance crop and animal growth and development (Doddamni et al, 2020; Kalmkar et al, 2020). UAVs gather data on biotic and abiotic factors for actionable insights on farm planning, production, allocating resources, and yield estimation or prediction that empower farmers with insight that prepares them to make better market decisions (Sylvester, 2018). In Africa and Nigeria especially, the adoption of mechanized technology is low. For instance, there are just 7,000 functional tractors for 28 million farmers in Nigeria (1:2:1,120) (Takeshima, 2016; TOHFAN, 2019), underlying the low farm productivity in the country. With the yearning for increased agricultural productivity, increasing the adoption of technology such as UAVs has become imperative. However, understanding the factors influencing the adoption of this technology is important for its successful deployment by drone services companies and policymakers. While external factors such as infrastructure, cost of technology purchase and operation have been highlighted to influence drone adoption by farmers, these restricting factors have also been reported by Skevas & Kalaitzandonakes, 2020. Therefore, this study seeks to understand farmers' perceptions and willingness to adopt drone technology in agriculture in Nigeria. Based on the information at our disposal, our research is the first to explore farmers' perceptions and willingness to adopt drone technology in Nigeria.

MATERIALS AND METHODS

Study area

The study was conducted in Moniya, Ibadan, South-West Nigeria where farmers were administered questionnaires at a farmers' field day to assess their perception and willingness to adopt drone technology in agriculture.

Study design

This study adopted a qualitative exploratory design as a research methodology and a semi-structured questionnaire approach distributed to farmers from the different geographical regions of Nigeria. The questionnaire was subdivided into thematic sections, including socio-demographic characteristics, farmers' perceptions of drone technology, and the factors underlying or impeding farmers' adoption of drone technology.

Sampling and data collection

We employed a purposive sampling method to collect data from 96 respondents, spanning 20 States across Nigeria. The study was conducted between September 20, 2022, and October 14, 2022.

Data analysis

Completed questionnaires were received in hard copy form or via Online format (Google form), coded, entered, and analysed using the Statistical Package for the Social Science (SPSS), version 25.0 for Windows (SPSS Inc., Chicago, Illinois, United States). The analytical approaches used were descriptive statistics such as percentages and frequencies. We examined the variables influencing farmer’s willingness to adopt drone technology in agriculture in Nigeria using the binomial logistics regression.

RESULTS AND DISCUSSION

Descriptive statistics

The result of the household survey indicates more male (82.29%) than female (17.71%) respondents, with 48.96% married and 51.04% single. 92.71% of the surveyed households completed tertiary education, 6.25% did not complete secondary education, and 1.04% completed primary education. The average farming experience of the respondents was 2.62 years, and only 29.03%, 9.68%, and 7.53% have been farming for 3, 4, and 5 years, respectively. The major crops grown by the households include cassava (13.04%), maize (13.04%), tomatoes (23.91%), and vegetables (21.74%).

All the respondents have mobile phones, with 98.6% accessing internet connectivity. The respondents' proportion of small, medium, and large-scale farmers was 43.62%, 39.36%, and 17.02%, respectively. Households using overhead irrigation (47.25%) were fewer than those depending on rain-fed agriculture (48.35%), and only 4.4% used both. The recorded income-generating activities include farming (62.86%), logistics (1.43%), trading (21.43%), processing/value addition (5.71%), and others (8.57%). The households' preferred method of pesticide application was a knapsack or manual (68.82%) and motorized backpack sprayers (16.13%).

The application of drones in agriculture includes crop irrigation, pest control, fertilizer application, and animal mustering, among others (Yinka-Banjo and Ajayi, 2019). A higher proportion of the surveyed households have heard about drones (95.74%), compared to 4.26% who are unaware of the technology. This result corroborates the report by Jemali et al. (2017), who reported that 81.4% of the respondents in their study had prior knowledge of drones. However, it is noteworthy that drone awareness differs from the ability to use or offer technical opinions about the technology (Smith et al., 2022). In this sense, understanding the public's awareness of drones can be a complex phenomenon. In this study, the major sources of drone information include social media (61.36%) and websites (19.32%). This concurs with the educational level of the respondents and their inclination toward using social media. A similar result has been reported in the USA (Aydin, 2019) concerning the prominence of the mainstream media as the main source of drone-related information. There was a slight difference in the respondent's experience regarding drone demonstrations and handling. 51.06% of the farmers have experienced drone demos, while 48.94% have yet to have the experience. Only 22.58% have operated a drone, and 77.42% lack the technical know-how to operate a drone. This differs from the report by Annor-Frempong and Akaba (2019) that only 2.8% (4) of farmers had experienced drone technology in a survey conducted in Ghana. Farmers who have experienced drone demonstrations could probably derive technical knowledge from the specialists, which may enhance drone adoption on their farms in the nearest future (Aydin et al., 2019; Hafeez et al., 2022).

Only 38.3% had employed the services of a drone company/expert. In Finland, Simula (2021) reported that 64% of 1 092 farmers were already or willing to use drone services. The low level of drone employment observed in this study may be related to the small and medium scale of farm production undertaken by the larger percentage of the respondents, which precludes investment in the technology. However, specialized education on precision agriculture could help increase the awareness and adoption of drones in the Nigerian agricultural sector (Uche and Audu, 2021). 92.7% of households are willing to pay for drone services. This corroborates the findings by Omega (2021) that farmers in Northern Ghana are willing to pay for drone services, albeit with varying payment capacities. Based on our results, the government and policymakers need to develop regulatory measures to ensure citizens' safety and privacy as the advocacy for drone use in Nigeria expands (Yawson and Frimpong-Wiafe, 2018).

Majority of the surveyed farmers (98% and 94%) opine that drone technology can help overcome farming challenges and enhance agricultural productivity respectively. Moreover, a higher proportion of the respondents (96.81%) are interested in leveraging drones over the long term, indicating a positive potential for drone piloting services in Nigeria (Simula, 2021). Moreover, the study showed that a large percentage of households (66.67%) prefer drone usage to the conventional method of farming (33.33%), and the most preferred drone service delivery was publicly subsidized service (22.83%), employing drone service as a cooperatives, association or cluster group (20.65%), and direct payment by individual farmers (15.22%). This points to a huge gap in the respondent's knowledge and awareness of the merits of drones in agriculture.

Table 1. Results of the relationship between farmer’s socioeconomic and operational activities and willingness to pay for drone technology in Agriculture in Nigeria.

Independent variables	Marginal effect	Coefficient	Std. err.	z	P>|z|
Age	0.009	.1542287	.0769273	2.00	0.045
Gender	0.147	1.582243	.922748	1.71	0.086
Type of agriculture	-0.031	-.5420138	.6522722	-0.83	0.406
Number of incomes	0.002	.0353492	.4656768	0.08	0.939
Education	-0.003	-.0571256	1.458888	-0.04	0.969
Membership of cooperatives	0.072	1.340747	1.228146	1.09	0.275
Credit access	-0.096	-1.12778	1.749141	-0.64	0.519
No. of crops grown	-0.001	-.0237238	.2796799	-0.08	0.932
constant		-2.933122	2.578271	-1.14	0.255

Note: Likelihood ratio chi square = 13.42 (df =), Chi-square probability = 0.0981, and Pseudo R^2 = 0.225. The reference category for gender = female.

Factors affecting farmer’s willingness to adopt drone technology in Nigeria

One of the merits of drone application in agriculture is improved productivity at a low cost. In this study, the farmer's age influenced their willingness to adopt drone applications in agriculture, and an increase in age increases the chances of adopting drone-driven precision agriculture. Our result supports the findings by Bai et al. (2022) and Michels et al. (2020) that farmers' age is a driver of drone adoption in farming areas. Like Michels et al. (2020), most of the respondents in our study are youths which may have contributed to their age influence on drone adoption. Another probable reason for the observed result is comfortability with the technology (Klauser et al., 2017).

Farmer's sexual orientation is perceived as less important in the adoption of precision agriculture (Paustian and Theuvsen, 2017), and farming is predominantly dominated by male households in Nigeria (Bello et al., 2021; Aminu et al., 2021). Studies on climate-smart adaptation strategies (e.g., Oyawole et al., 2020) and smart farming and AI (e.g., Foster et al., 2023) showed gender differences in farming technology adoption. We found that male farmers are 1.58 times more likely to adopt drones than their female counterparts. This concurs with

Zheng et al. (2019) and Paustian and Theuvsen (2017), who showed that male households are more inclined to adopt drones, partly due to the higher proportion of male-headed households among the respondents. Unlike Bai et al. (2022), education level did not impact drone adoption, and this may be related to convergence in the respondents' level of education. All other variables considered in the model did not influence drone adoption.

CONCLUSION

This research assessed farmers' awareness of the use and operations of drone technology in enhancing the efficiency of agricultural practices and contributing to sustainable livelihoods in farming areas. Farmers attest to the need for a shift from conventional agriculture to precision farming hinged on the deployment of drone services, thus exemplifying the importance of awareness of drone technology for easy adoption of drone services. Several limiting factors were identified, including the credit worthiness of farm holdings, aggregation of farmers into groups and incentivizing/subsidizing drone services on a public-private partnership, which, if addressed, would help to fast-track adoption at scale. Given the current realities of a race to achieve availability, accessibility, and affordability of safe and nutritious food for all, drone services are strategic in leapfrogging agricultural practices to feed into the overall agri-food systems transformation agenda. With self-sufficiency in food production on the continent of Africa, the findings from this research speak to the need to bridge the gap between technology and agriculture while placing youths in the centre stage to drive the process through R&D, SMEs, and Policy formulation to deliver on the Malabo Declaration, CAADP and AU Agenda 2063

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CLIMATE SMART AGRICULTURE

EVOLVING POTENTIALS FOR PRECISION CLIMATE-SMART AGRICULTURE IN SUB-SAHARAN AFRICAN COUNTRIES
#9421

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ABSTRACT

Progressively, there is increasing awareness on the significance of agriculture in both adaptation and mitigation to climate change. While adaptation has been typically highlighted in the most vulnerable countries, especially in Africa where the failure to adapt have been noted to exacerbate the dangers of food insecurity, there is limited effort at emphasizing mitigation as the ultimate resolution of the debacle. Climate-smart agriculture (CSA) is critical to achieving development irrespective of the attendant impacts of global warming, simultaneously ensuring food security through productivity and income growths, forcing resilient ecosystems thus boosting livelihoods and at the same time plummeting greenhouse gas emissions. Thus, CSA approach not only sustainably increases productivity but enhances adaptation and mitigations where possible, yet these benefits remain largely unexploited in the Sub-Saharan Africa (SSA), hence resulting in seemingly misplaced prospects, unrecognized impact, and gross inability to access climate finance. Whereas precision agriculture (PA) has enormous prospective for development in SSA, yet several social-economic and technological limitations abound for SSA countries. This is evident from the knowledge that more than half of these countries have not shown capacity to develop their potentials for precision climate-smart agriculture (PCSA). Therefore, there is need for more investigation on the low usage of precision agriculture as management strategy accounting for temporal and spatial variability to improve sustainability of agricultural production in Africa. Furthermore, the role of information and technology-based farm management systems to tackle variability in agriculture for optimum profitability and sustainability, needs further exploration. This study aims to acquire, interpret, and utilize as much spatial information as possible to enhance farming in SSA countries with the goal of reducing the climatic impacts associated with agricultural activities. This study estimates the mitigation potentials of PCSA agricultural practices using data from FAO, World Bank, IFAD, and other studies for evaluation. The study further shows emerging market countries, particularly in Sub-Saharan Africa, can possibly gain advantage from unconventional agribusiness technologies that mitigate the impacts of climate change from a country-by-country analysis. We also emphasis PCSA as the solution to feeding the SSA population that is growing faster than available land supply, while also ensuring the sustainable use of water and energy with the scientific plausibility of overcoming water scarcity due to drought by employing regional climate model forecasts towards 2100 for the adoption of climate smart technologies such as micro-irrigation, drip irrigation, and solar pumps etc. The role of agricultural extension through digital advisory services, as well as crop and soil monitoring, is also emphasized as a strategy to increase agricultural productivity and farmer income, make rural communities more resilient, and mitigate climate change. Finally, our findings identify land use and agricultural management practices with the largest mitigation potential, analyzed uncertainties in mitigation under different climate scenarios and provide recommendations to improve monitoring of mitigation benefits for PCSA project design and implementation in SSA.

INTRODUCTION

Agriculture is the most important economic sector in many sub-Saharan Africa (SSA) countries, contributing more than one-third of the gross national product (GNP) and employing more than two-thirds of the labour force (AfDB, 2020). Yet, the region has not invested enough into agricultural research and development, which is the reason for the reduction in agricultural productivity and growth as compared to other regions of the world (Fuglie *et. al.*, 2020). However, empirical evidence suggests that climate change will continue to have far-reaching consequences for agriculture which will disproportionately affect poor and marginalized groups in SSA who depend on agriculture for their livelihoods and have a low capacity to adapt (Zougmoré *et. al.*, 2018). Similarly, climate change may pose challenges in the region's quest to use agriculture as the mainstream opportunity to achieve food security as well as the poverty reduction targets entrenched in the sustainable development goals (Onafeso, Akanni, and Badejo, 2015). Regrettably, agriculture in SSA has remained primarily rainfall-dependent, with staple food production entirely from rain-fed farming systems (Bjornlund, Bjornlund, and Van Rooyen, 2020).

Climate-smart agriculture (CSA) including agricultural practices, restoration practices of degraded lands, forest and cropland regeneration practices, practices in the livestock sub-sector, water resources and use of weather and climate information services have been adopted across SSA (Ariom *et. al.*, 2022). Although, as the impacts of climate change vary from country to country, the CSA strategies adopted also varies significantly often influenced as well by numerous factors like financial preferences, role of policy legislation, access to climate information and farmers' knowledge levels. Besides, low inherent soil fertility combined with increased population pressure has led to soil degradation and nutrient depletion in most of the SSA countries (Drechsel, Kunze, and de Vries, 2001).

For sustainable agricultural growth to be achieved therefore, a more efficient use of resources must be employed, with the adoption of precision agriculture (PA) technologies considering temporal and spatial variability to improve sustainability of agricultural production (ISPA 2018). Progressing reasonably faster in the western countries with increasing affordability of onboard computing capacities, global navigation satellite system (GNSS), sensors, geo-information systems (GIS), geo-mapping, robotics, and emerging data analysis tools. The imminent challenge in the SSA countries is to evaluate crop health using performance *in situ* sensors, spectra radiometers, machine vision, multispectral and hyperspectral remote sensing, thermal imaging, and satellite imagery as it is being used by researchers and innovative farmers in other regions of the world (Khanal *et. al.*, 2020; Lowenberg-DeBoer *et. al*. 2021).

However, PA has enormous prospective for development in SSA, yet social-economic and technological limitations abound. More than half of SSA countries have not shown capacity to develop potentials for precision climate-smart agriculture (PCSA). This study aimed to acquire, interpret, and utilize as much spatial information as possible to enhance farming in SSA countries with the goal of reducing the climatic impacts associated with agricultural activities.

MATERIALS AND METHODS

We estimated the mitigation potentials of PCSA agricultural practices using data from FAO, World Bank, IFAD, and other studies for evaluation. The study further showed emerging market countries, particularly in SSA, can possibly gain advantage from unconventional agribusiness technologies that mitigate the impacts of climate change from a country-by-country analysis.

RESULTS AND DISCUSSION

SSA countries have adopted CSA to confront agricultural productivity challenges, build resilience to climate change, and reduce greenhouse gas (GHG) emissions, with extensive indication that the continent is disposed to precision agriculture (Barasa, Botai, Botai, and Mabhaudhi, 2021). Although, CSA research in Africa only began two decades ago, there has been several approaches involving low-tech precision farming to estimate millet yields successfully (Gandah, Stein, Brouwer, and Bouma, 2000). As impacts of climate change continues to manifest particularly as droughts and floods affecting agriculture, progress towards achieving potential solutions and increase productivity continues to promote CSA techniques and policy framework. Similarly, significant country level incorporation of agricultural practices and technologies with applicable indigenous knowledge and innovations encompassing the three pillars of CSA have also been widely reported among the few SSA countries that have taken the lead in advancing the research domain. Notwithstanding these progressions however, only few SSA countries (viz. Kenya, South Africa, Zimbabwe, and Mali) appeared to be forefront in global CSA implementation (Chandra, McNamara, and Dargusch, 2018).

In general, however, there is considerable evidence of some progress in CSA activities in East Africa, particularly in Kenya, Ethiopia, Uganda, Burundi, and Tanzania; in West Africa, particularly in Nigeria, Mali, and Ghana; and also in Southern Africa majorly in South Africa and Zimbabwe (https://ccafs.cgiar.org/resources/publications/csa-country-profiles). According to the World Bank data on Food production index, the SSA countries can do much better with PCSA as shown in Table 1 where only Southern Africa countries by region outperformed both the global average and that of the United States of America except for the decline in the recent decade. Quite noteworthy, however, the case is not the same for all other regions in SSA where values higher than both the global average and the United States of America indices have been observed. This implies that with improvements in PCSA, the SSA as a region have the potentials to outperform all other regions of the world in terms of Food production index.

Table 1. Food production index (2014-2016 = 100).

	1960	1970	1980	1990	2000	2010	2020
Northern Africa	18.40	24.58	36.17	48.96	66.12	91.42	**107.97**
Western Africa	26.90	31.23	33.98	43.98	61.47	91.97	**110.92**
Eastern Africa	40.61	52.10	59.97	73.36	78.04	**98.03**	**112.49**
Middle Africa	29.87	33.82	37.16	42.83	60.94	86.32	**109.23**
Southern Africa	**54.05**	**69.51**	**75.28**	**80.82**	**93.83**	**104.43**	99.00
USA	41.26	49.13	60.91	68.83	83.03	92.26	104.45
Global Average	52.05	61.35	71.26	75.65	80.91	92.76	107.79

Sustained progress in PCSA including optimization of existing resources such as land, soil and water to intensify productivity and improve agricultural processes as well as reducing the agrarian sector induced GHG emissions and ensuring sustainability through environmental quality protections are observable measure gradually shaping food production in SSA. Similarly, improved understanding in satellite positioning and navigation has made it possible to gather information required to apply decision-based precision agriculture in recent times. This ability to acquire on-farm information coupled with increased awareness of variability of soil and crop conditions by the farmers have been the main drivers of the recent advancement of precision agriculture (Stafford 2000). Further developments in PCSA expected in most SSA countries however includes adapting fertilizer application to variable soil conditions on large mechanized farmlands with the potentials to use automatic fertilizer application devices, autonomous farm machinery, and computer software for management of various production systems (Gebbers and Adamchuk (2010).

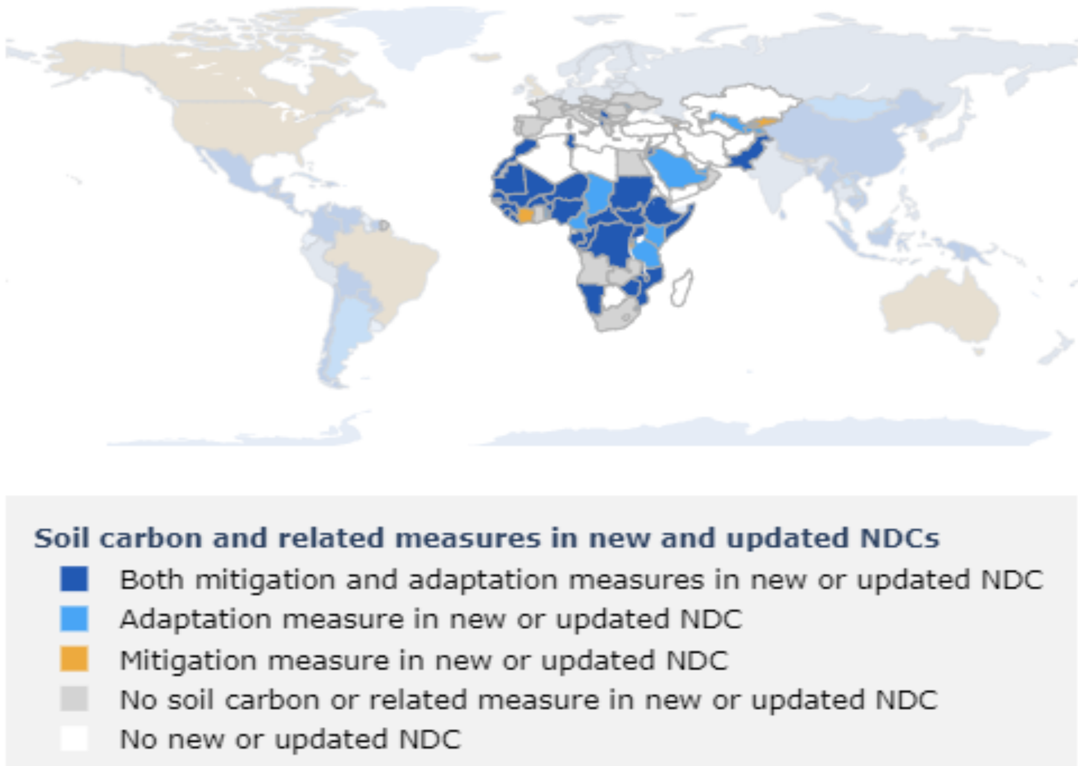

Fig. 1 Nationally Determined Contributions (NDCs) to COP 21 (Rose, *et. al*., 2021).

According to the Nationally Determined Contributions (NDCs) for climate action under the international agreement at the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in Paris in 2015 (COP 21), most of the SSA countries as of September 3, 2022, have updated commitments to both mitigation and adaptation measures. This shows another significant progress towards PCSA with evidence that SSA can do much better with improved international collaborations such as those funded by IFAD involving South Africa, Kenya, Tanzania, and Zimbabwe, with the USA, Germany, the Netherlands, and Australia. While these collaborations are well appreciated, it is imperative to include under-developed countries in the CSA subject matter. This will serve as a steppingstone to implementing the CSA concept, realizing its benefits, and, consequently, achieving the much-needed agricultural transformation in sub-Saharan Africa.

There is, therefore, the need for further investigation on the squat practice of precision climate smart agriculture as management strategy accounting for temporal and spatial variability to improve sustainability of agricultural production in SSA. Furthermore, the role of information and technology-based farm management systems to tackle variability in agriculture for optimum profitability and sustainability, needs further exploration.

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MANIPULATION OF ROW SPACING DID NOT AFFECT GROWTH AND YIELD OF CHIA IN TWO CONTRASTING ENVIRONMENTS IN KENYA
#9434

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ABSTRACT

Sustainability of agricultural production relies on a good management strategy in crop production. Optimal spacing is one of the major crop management systems in chia production required to increase yield and quality of chia seed. In this regard, this study explored the potential of different row spacing on the growth and yield of chia in Kenya. Two experiments comprising three spacing arrangements of 30 cm x 10 cm, 60 cm x 10 cm and 90 cmx 10 cm were carried out in Kabete and Nyeri in a randomized complete block design. In this study, all the assessed row spacing did not show any significant differences in growth and yields of chia in open fields. However, highest panicle length for both sites in two seasons was recorded at a spacing of 60cm by 10cm. In consideration of effective agricultural practices such as weeding, fertilization and irrigation, a spacing of 60cm by 10cm is recommended.

Keywords: Seeds, management, treatments, optimization, systems

INTRODUCTION

Chia (*Salvia hispanica* L.) is a crop in the Lamiaceae family, with its centres of origin being Mexico and Guatemala (Cahil, 2004). It is a relatively new crop in Kenya and is gaining popularity owing to its rich nutritional profile and its low cost of production thus making it more profitable in comparison to other crops to farmers. Most sub-Saharan Africans are characterized by diverse soil characteristics and experience diverse agro-climatic conditions. In this very soil dynamism, each soil has its optimal density of establishment as per the land equivalence ratio (Graves *et al.,* 2010). The adoption of chia as a pseudo-cereal across several sub-Saharan African countries such as Kenya calls for extensive studies on its agronomic suitability, especially on its spacing. This study establishes whether varying row spacing influences the growth and yield of chia in contrasting agro-ecological zones in Kenya.

MATERIALS AND METHODS

Chia was established in two study sites, Kabete and Nyeri in a randomized complete block design for two seasons. The treatments were three row spacings; 30cm × 10 cm, 60cm × 10cm, and 90cm × 10cm. In each plot, 5 plants were randomly selected and data on growth and development were assessed 15, 45, 80 and 100 days after sowing (DAS). Harvesting was 100 DAS whereby the number of panicles, and grain yield (g/plant) were determined.

RESULTS

The assessed row spacings did not show any significant differences in growth and yields of chia in open fields.

Table 1. Seed yield, number of panicles and number of branches of chia at physiological maturity under three row spacings in Kabete and Nyeri in two seasons.

KABETE						
	Season 1			Season 2		
Row spacing	Seed yield (g/plant)	No. of panicles	No. of branches	Seed yield (g/plant)	No. of panicles	No. of branches
30cm × 10cm	783.30a	28.00a	11.73a	2300a	13.40a	9.87a
60cm × 10cm	600.00a	28.60a	11.87a	2360a	17.93a	11.87b
90cm × 10cm	846.70a	40.13b	12.67b	2320a	18.13a	10.80ab
LSD	442.3	7.14	0.66	1017.1	4.76	1.2
P-value	0.37	0.002	0.01	0.99	0.09	0.001
NYERI						
	Season 1			Season 2		
Row spacing	Seed yield (g/plant)	No. of panicles	No. of branches	Seed yield (g/plant)	No. of panicles	No. of branches
30cm × 10cm	783.30a	31.80a	12.00a	702.45a	19.93a	13.80a
60cm × 10cm	600.00a	28.53a	11.60a	643.00a	24.00a	13.60a
90cm × 10cm	846.70a	31.33a	12.27a	894.50a	21.33a	13.07a
LSD	442.3	8.61	0.92	288.34	13.43	1.78
P-value	0.37	0.71	0.35	0.34	0.83	0.69

Means in the same column not having a common letter are significantly different based on the Tukey's LSD test ($P<0.05$).

DISCUSSION

Seed yield and number of panicles were not significantly different across the three row spacings in both sites. There was a significance difference on the number of branches across the three-row spacing for Kabete for the two seasons with a spacing of 90cm by 10cm recording the highest number of branches. In Nyeri however, there was no significance difference in number of branches across the three row spacings for the two seasons.

From the results, it is evident that manipulation of row spacing had no effect on growth and yield of chia. This can be attributed to the aspect of chia having low water requirement and its capability to adapt well in arid semi-arid regions (Ayerza, 1995). This therefore shows that when chia is planted in soils that have not been depleted of nutrients, its growth and yield will not be affected by the row spacing adopted. For this experiment, the available N% in the soil, was 0.25% and 0.13% for the clay-loam and clay soils of Kabete and Nyeri, respectively. This was optimal for effective production of chia and the crop only utilized enough for its growth and development. Although in these studies there were no significant differences on assessed parameters across the three treatments, in is important to make consideration of management practices that will not only contribute to good agricultural practices, but also economical and profitable to farmers. Further work is recommended on water use dynamics, water and nutrient use, and light use efficiency of chia.

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EFFECTS OF LEGUME BREAK CROPS ON YIELD, NITROGEN USE EFFICIENCY AND ECONOMY OF MAIZE PRODUCTION IN WESTERN OROMIA, ETHIOPIA
#9520

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ABSTRACT

Prolonged monocropping of maize lacking appropriate soil fertility management is affecting soil fertility and maize production in Western Oromia. The use of legume break crops improved performance of subsequent maize. The biological N_2-fixation of legumes as precursor crops reduced the amount of nitrogen fertilizer applied to maize. Higher mean grain yield of maize was obtained following faba bean without and with rhizobia inoculation than maize after maize. The total nitrogen uptake of different maize varieties was improved following leguminous break crops with application of lower amounts of nitrogen fertilizer. Higher agronomic nitrogen efficiency, fertilizer N recovery efficiency and nitrogen use efficiency of maize were obtained from 55 kg N ha^{-1} application as compared to 110 kg N ha^{-1} following legume break crops. Production of highland maize varieties following faba bean and soybean with half recommended rate of 55 kg N ha^{-1} improved mean maize grain yield has been recommended for maize production in western Ethiopia. Therefore, fertilizer management practices following legumes break that increase nitrogen use efficiency and improve yield of cereals will likely be more effective and desirable options for maize production. Further research can be undertaken on the interaction of nitrogen rates and legume break crops to determine economically optimum nitrogen rates for maize after legumes break crops and nitrogen use efficiency and economy of production in Ethiopia.

Keywords: break crops, legumes, nitrogen, maize

INTRODUCTION

The provision of food, fiber and fuel, climate regulation and carbon sequestration, will increasingly depend on the availability of healthy and sustainably managed soils (FAO, 2020). However, soil fertility depletion is considered as the major threats to food security in Ethiopia. Conventional agriculture (continuous cropping with low inputs) has certain limitations in terms of maintaining long-term soil fertility (Charpentier et al., 1999). Wu et al. (2003) reported that longer cultivation has further depleted the soil organic-matter content and fertility of these soils. Wakene (2001) reported that continuous monocropping with heavy applications of N and P fertilizers and intensive mechanized tillage practice lead to increased soil acidity, degradation of organic carbon and leaching of the exchangeable bases. Hence, decreasing productivity can be alleviated by different methods such as use of inorganic nitrogen and use of legumes in a cropping system. Well managed fertile soils are the foundation for sustainable food production and many essential ecosystem services.

Legumes contribute to the maintenance and restoration of soil fertility by fixing N_2 from the atmosphere (Giller and Wilson, 1991). Azam and Farooq (2003) reported symbiotic nitrogen fixation by legumes is the major natural process of adding nitrogen into the biosphere, amounting to about 35 million tons globally annually. Optimizing this symbiosis can increase crop yields and enhance soil fertility, whilst reducing the negative monetary costs and environmental impacts associated with nitrogen fertilizer use (Canfield et al., 2010; Hirel et al., 2007; and Peoples et al., 2009).

Quantities of N fixed in faba bean vary greatly but estimates of rates of fixation vary from 40 (Duc et al., 1988); 93% (Brunner and Zapata, 1984) to 120 kg N ha^{-1} (Danso, 1992) of crop N, and from 16 to 300 kg aboveground N per ha per crop. Khan et al. (2002) harvested plant parts and found that root-zone soil represented 39% of total plant N for faba bean. The soil N contents were improved 10.6 times more than the original soil N content (0.014%) from the plots where faba beans were grown (Fassile, 2010). Significant yield increases of faba bean from biological N_2-fixation of 82 kg N ha^{-1} of 1.4 t ha^{-1} grain yields were obtained (Beck and Duc, 1991); representing 35 to 69% increase due to the inoculation (Khosravi et al., 2001).

The input of fixed N from grain legumes may be a significant contributing factor in relation to sustaining productivity in smallholder systems (Sanginga, 2003). Lassaletta et al. (2014) suggested that an increase in the contribution of symbiotic N fixation would result in increasing NUE. Lo´pez-Bellido et al. (2006) found that nitrogen derived from the atmosphere (Ndfa) percentages ranged between 70 and 96%, and N_2-fixed between 39 and 144 kg N ha^{-1} in faba bean. The N agronomic efficiency and N fertilizer recovery efficiency of maize following grain legumes were on average 14 and 34% greater than of maize following maize and 12 and 20% greater than of maize following fallow, respectively (Yusuf et al., 2009). Therefore, estimating the biological nitrogen fixation by faba bean with and without rhizobia inoculation and determining its effects of nitrogen requirement of subsequent maize are potential for increased maize production. The objective this study was to determine the effects of faba bean precursor crop biomass incorporation on yields and nitrogen use efficiency of subsequent maize varieties in Tokke Kutaye, western Ethiopia.

MATERIALS AND METHODS

The experiments were conducted during the 2013 and 2014 cropping seasons on two farmers' fields in the humid highlands of Toke Kutaye in Oromia National Regional State, western Ethiopia. The area in Toke Kutaye lies between 8°9'8" and 8^{0}71ˀ21"N and 37°72' and 37^{0}42' E and located at the 2,262 and 2,322 meter above sea level, with mean annual rainfall of 1,045 mm (NMSA, 2014). It has a cool humid climate with the mean minimum, mean maximum, and average air temperatures of 8.9, 27.4 and 18.1°C, respectively. The experiment was conducted in 2013 and 2014 cropping season. The faba bean (variety Moti) in the highland were planted with and without rhizobia inoculation in the preceding cropping season as precursor crop. The rhizobia strain (FB-1035 for faba bean was used for the inoculation. Both precursor crops were planted, managed, and harvested following recommended agronomic packages and residues was incorporated in the field. In the second year (2014 cropping season), two maize hybrid varieties (Wenchi and Jibat) were sown with three levels of nitrogen on the two fields. Twelve treatment combinations were imposed with the main crop (maize). The maize hybrid was planted with three levels of nitrogen fertilizers onto plots of faba bean precursor crop biomass with and without rhizobia inoculation. The experiment was laid out in 2 x 2 x 3 factorial arrangement in randomized complete block design in three replications in 2014. The two types of faba bean field (with and without rhizobia inoculation) were used as factor A, the two maize varieties (Wenchi and Jibat) were used as factor B while the three levels of nitrogen (0, 55, 110 kg N ha^{-1}) were used as factor C, resulting in 12 treatment combinations.

The grain yield of maize varieties was recorded at physiological maturity and was adjusted to 12.5% moisture level (Birru, 1979; Nelson et al., 1985). The maize tissue samples were taken from the stalk and from grain at harvesting. The maize tissues and grains were subjected to wet digestion (Jones and Case, 1990). The N content of the plant tissue was determined by a Kjeldahl procedure according to Murphy and Riley (1962). The total N uptake was obtained by dividing the N concentration in the tissue to total dry biomass weight (kg ha^{-1}) of maize, whereas N agronomic efficiency (NAE) was obtained by dividing the grain yield to the applied N (Wu et al, 2011; Cleemput et al. 2008). The N use efficiency (UEN) is the total amount of N absorbed (including that present in the roots, often disregarded) per kg of applied N. The nitrogen physiological efficiency was calculated as total dry matter or grain yield produced per unit of N absorbed. N utilization efficiency was calculated as (Haegele, 2012). Apparent fertilizer N use (recovery) efficiency (ANRE) (equation 4) is the amount of fertilizer N taken up by the plant per kg of N applied as fertilizer, which was calculated as described by Azizian and Sepaskhah (2014), Cleemput et al. (2008), Craswell and Godwin (1984). Then, N harvest index (NHI) at maturity was calculated (Jones and Case, 1990) and an accumulation (kg N ha^{-1}) in the shoots or grains was calculated (Seleiman et al., 2013; Xu et al. 2006). Agronomic and nitrogen use efficiencies data analysed using statistical packages and procedures of Statistical Analysis System Computer Software. The mean separation was done using least significance difference procedure at 5 % probability level (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

The mean grain yields were significantly ($P<0.05$) higher for maize planted following faba bean precursor crop with the application of 55 and 110 kg N ha^{-1}. Significantly ($P<0.05$) higher (7718 and 5132 kg ha^{-1}) mean grain yield maize was obtained from application half recommended nitrogen fertilizer following faba bean precursor crop in Farm 1. and Farm 2 (Table 1). This indicates variation in fertility status of different farm fields.

The mean total nitrogen uptake of maize varieties was significantly ($P<0.05$) affected by application nitrogen fertilizer rates (Table 1). Higher total nitrogen uptake of maize was obtained from application both 55 and 110 kg N ha^{-1} in Farm 1 and Farm 2 as compared to control. Similarly, Beslemes et al. (2013) reported significant differences ($P<0.05$ and $P<0.01$) on total N uptake of maize with increased N fertilization levels. Maize that received 120 kg N ha^{-1} in addition to faba bean biomass also had higher grain N uptake (El-Gizawy, 2009). Increased N uptake with application of nitrogen as compared to without fertilizer indicates better improvement soil N status (and organic matter) following precursor crop biomass, leading to enhanced nitrogen uptake by maize.

The nitrogen agronomic efficiency of the two maize varieties varied among farms, maize varieties, and precursor crop biomass without/with rhizobia (Table 1). Significantly and non-significantly higher ($P<0.05$) nitrogen agronomic efficiency of maize was observed from maize planted following faba bean precursor crop biomass without rhizobia inoculation as compared to with inoculation in Farm 1 and Farm 2. This indicates faba bean precursor crop without rhizobia gave higher biological N_2-fixation due to effective native rhizobia.

Maize varieties showed significant ($P<0.05$) difference in nitrogen agronomic efficiency following faba bean precursor biomass in Farm 1 and 2, with significantly higher nitrogen agronomic efficiency achieved from Jibat maize variety as compared to Wenchi (Table 1). The result obtained match with better grain yield of Jibat maize variety from Farm 1 and 2 Table 2. Therefore, use of Jibat maize variety should be recommended for producers in the area.

Table 1. Effects of faba bean biomass, maize varieties and nitrogen rates on grain yield, Total nitrogen uptake, nitrogen agronomic efficiency and N use efficiency of subsequent maize in Toke Kutaye, western Ethiopia in 2014 cropping season.

Treatment	Farm 1				Farm 2			
	Grain yield, kg ha^{-1}	Total nitrogen uptake, kg ha^{-1}	Agronomic efficiency, Kg grain kg N applied^{-1}	Nitrogen use efficiency, kg N uptake kg N applied^{-1}	Grain yield, kg ha^{-1}	Total nitrogen uptake, kg ha^{-1}	Agronomic efficiency, kg grain kg N applied^{-1}	Nitrogen use efficiency, kg N uptake kg N applied^{-1}
Biomass of faba bean no inoculated with rhizobia	6988	698	43a	2.62b	4585	436	16.33	2.37a
Biomass of inoculated faba bean	7523	824	27b	5.32a	4272	408	14.94	1.47b
LSD (5%)	NS	NS	3.73	0.2864	NS	NS	NS	0.4922
Maize Varieties								
Wenchi	7351	698	30.81b	3.74b	4607	414	15.03a	2.32a
Jibat	7161	824	39.63a	4.20a	4249	429	12.79b	1.51b
LSD (5%)	NS	NS	3.73	0.2864	NS	NS	1.948	0.4922
Mineral N rates (kg ha^{-1})								
0	5934b	655b			3804b	329c		
55	7718a	815a	46.07a	4.94a	4349b	438b	16.745	3.09a
110	8115a	813a	21.32b	2.24b	5132a	498a	10.58	2.28b
LSD (5%)	1393	157.27	15.216	0.71	558	41.167	3.32	0.052
CV (%)	22.99	24.41	17.36	21.02	15.10	11.53	12.94	14.07

NS=non-significant difference, Numbers followed by same letter in the same column are not significantly different at 5% probability level.

The application of nitrogen fertilizer rates significantly ($P<0.05$) affected nitrogen agronomic efficiency of maize varieties following faba bean precursor crop biomass in Farm 1and 2 (Table 1). In both farms higher mean nitrogen agronomic efficiency of (46.07 and 16.75 kg grain kg N applied^{-1}) were obtained with application 55 kg N ha^{-1} as compared to 110 kg N ha^{-1}. Similarly, Amanullah and Alkas (2009) reported NAE was 28 kg (kg N)$^{-1}$ at an application rate of 60 kg N ha^{-1} but decreased to 23 and 19 kg (kg N)$^{-1}$ at application rates of 120 and 180 kg N ha^{-1}, respectively.

The nitrogen use efficiency of maize varieties was higher ($P<0.05$) following faba bean precursor crop with rhizobia inoculation as compared without rhizobia in Farm 1 but the opposite was observed in Farm 2. This indicates that Farm 1 and Farm 2 had differences in soil N fertility status (Table 1).

Maize varieties showed significant ($P<0.05$) difference in nitrogen use efficiency in both farms following faba bean precursor crop. Wenchi had higher mean nitrogen use efficiency following faba bean precursor crop with and without rhizobia inoculation in Farm 1 and 2 which entails matching of higher grain yield of Wenchi maize variety as indicated in Table 1. Even though not significantly different in grain yield, the result obtained matched with higher nitrogen use efficiency of maize varieties in both farms.

The application of nitrogen fertilizer significantly ($P<0.05$) affected nitrogen use efficiency of the maize varieties. Significantly higher nitrogen use efficiency was gained from maize varieties planted with 55 kg N ha^{-1} (as compared to 110 kg N ha^{-1}) following incorporation of faba bean precursor crop biomass in Farm 1 and farm 2, respectively. This implies that both maize varieties (Wenchi and Jibat) were efficient in using N under the lower mineral nitrogen input system, which could be affordable by resource poor smallholder farmers in the area. Goodroad and Jellum (1988) found higher nitrogen use efficiency was obtained when nutrient concentration was near the critical level, and this was true in the present situation whereby the total N levels in the present study sites were rated as being low to medium. The result agrees with results of Ortiz-Monasterio et al. (1997); Woldeyesus et al. (2004) who reported that N uptake efficiency was higher at lower rates of N application, but drastically decreased with further increases in the rate of the N.

Nitrogen physiological efficiency of subsequent maize in Toke Kutaye

Nitrogen physiological efficiency of maize varieties were significantly (P<0.05) affected faba bean biomass incorporation, maize varieties, and nitrogen rates application in Farm 1 and 2 (Table 2). Higher nitrogen physiological efficiency of 30.19 and 17.49 kg grain kg N uptake^{-1} were achieved from of maize planted following incorporation of faba bean precursor crop without prior rhizobia inoculation in Farm 1 and Farm 2 (Table 2). This indicates the presence competitive indigenous rhizobia strains in the soil. The result did not match with grain yield variation following faba bean precursor crop biomass incorporation in Table 2.

The maize varieties used showed significant (P<0.05) difference in nitrogen physiological efficiency (Table 2) The mean nitrogen physiological efficiency of 21.89 kg grain kg N uptake^{-1} was attained from Jibat maize variety in Farm 1 following faba bean precursor crop. Wenchi maize variety had higher maize nitrogen physiological efficiency of 17.23 kg grain kg N uptake^{-1} in Farm 2 following faba bean precursor crops. Likewise, Eivazi and Habibi (2013) found variation in nitrogen physiological efficiency between single cross maize varieties, which is true for three-way crosses of Wenchi, and Jibat hybrid maize varieties currently used for the study.

The nitrogen physiological efficiency of both maize varieties significantly (P<0.05) affected by nitrogen fertilizer rates in Farm 1 and 2 (Table 2). Significantly higher nitrogen physiological efficiency at the higher nitrogen fertilizer rate (following faba bean precursor crop). Similarly, Beslemes *et al*. (2013) found significant differences for faba bean green manure management and N fertilization on the N physiological efficiency of maize. The N physiological efficiency of maize following legumes increased significantly with increasing nitrogen rates **(**Yusuf, *et al*., 2009)**.** Higher mean nitrogen physiological efficiency attained with application 110 kg N ha^{-1} as compared 55 kg N ha^{-1} implies increasing N uptake as N supply increases and it suggests that higher grain yield could be achieved at higher N rate (Yusuf, *et al*., 2009). In contrary, Barbieri *et al*. (2008) reported that physiological efficiency of maize decreased with increasing rates of nitrogen fertilizer application. Further research will be needed to improve the nitrogen physiological efficiency by matching application rate and timing with plant demands.

Fertilize N (recovery) use efficiency of subsequent maize in Toke Kutaye

The fertilizer N (recovery) use efficiency of maize varieties were significantly (P<0.05) affected faba bean biomass incorporation, maize varieties, and nitrogen rates application in Farm 1 and 2 (Table 2). Higher fertilizer N (recovery) use efficiency of 532 and 237% maize varieties were obtained from Farm 1 and Farm 2 following incorporation faba bean precursor crop biomass with rhizobia inoculation and without, respectively (Table 2). Miller and Heitchel (1995) reported that N recovery following green manure crops might vary due to the amount of N fixed, mass of plant material incorporated, rate of decomposition and immobilization of legume N in the soil. N fertilizer recovery efficiency (REN) was significantly after legumes than after natural fallow or maize (Yusuf *et al*., 2009) to the tune of 34 and 20% greater than that of maize following maize and fallow, respectively (Yusuf *et al*., 2009). The N recovery fraction was enhanced by 10-15% after faba bean cover cropping, for sandy and clayey soil (Beslemes *et al*., 2013). Ladd (1981) showed 23 and 4% recovery of N in wheat following incorporation of medic residues the first and second year, respectively. Maize plants were observed to recover only 17-25% of the N from alfalfa residues (Harris and Hesterman 1987) implying the need for supplemental mineral N. In contrary, Carsky *et al*. (1999) reported lower REN values in maize following soybean genotype than maize following natural fallow.

Cassman *et al*. (2002) stated that when soil-N content is increasing, the amount of sequestered N contributes to higher nitrogen use efficiency (NUE) of the cropping system, and the amount of sequestered N derived from applied N contributes to higher N fertilizer recovery efficiency.

Table 2. Effects of faba bean biomass, maize varieties and nitrogen rates on Nitrogen physiological efficiency, Fertilize N (recovery) use efficiency, shoot and grain N accumulation, and N harvest index of subsequent maize in Toke Kutaye, western Ethiopia in 2014 cropping season.

Treatment	**Farm 1**				
	Nitrogen physiological efficiency, kg grain kg N uptake^{-1}	Fertilize N (recovery) use efficiency, %	Shoot N accumulation, kg ha^{-1}	Grain N accumulation, kg ha^{-1}	N Harvesting index, %
Biomass of faba bean no inoculated with rhizobia	30.19b	262b	6.31b	8.86	0.59
Biomass of inoculated faba bean	9.8b	532a	6.64a	9.67	0.59
LSD (5%)	3.016	40.45	0.003	NS	NS
Maize Varieties					
Wenchi	14.15b	374b	7.32a	9.02	0.55b
Jibat	21.89a	420a	5.63b	9.52	0.63a
LSD (5%)	3.016	40.45	0.003	NS	0.044
Mineral N rates, kg ha^{1}					
0			5.06b	7.00b	0.58
55	12.89b	494a	6.42ab	9.82a	0.62
110	22.84a	339b	7.93a	10.98a	0.57
LSD (5%)	8.45	145	1.639	1.6954	NS
CV (%)	22.36	22.14	18.92	21.61	14.67
Treatment	**Farm 2**				
	Nitrogen physiological efficiency, kg grain kg N uptake^{-1}	Fertilize N (recovery) use efficiency, %	Shoot N accumulation, kg ha^{-1}	Grain N accumulation, kg ha^{-1}	N Harvesting index, %
Biomass of faba bean no inoculated with rhizobia	17.49a	237a	5.20a	6.03	0.53
Biomass of inoculated faba bean	12.86b	147b	5.05b	5.98	0.54
LSD (5%)	3.3737	14.58	0.0032	NS	NS
Maize Varieties					
Wenchi	17.23a	231a	5.59a	5.90	0.52b
Jibat	13.12b	152b	4.66b	6.11	0.56a
LSD (5%)	3.3737	14.58	0.0032	NS	0.0225
Mineral N rates, kg ha^{1}					
0			4.22b	4.76c	0.53b
55	10.20b	229a	5.75a	5.95b	0.52b
110	14.64a	154b	5.43a	7.30a	0.58a
LSD (5%)	3.47	47.16	0.4546	0.6243	0.052
CV (%)	24.47	15.91	7.95	12.28	8.18

NS=non-significant difference, Numbers followed by same letter in the same column are not significantly different at 5% probability level.

The maize varieties showed significant (P<0.05) difference with fertilizer N (recovery) use efficiency in both farms. Jibat maize variety had higher fertilizer N (recovery) use efficiency in Farm 1 but Wenchi maize variety had higher efficiency in Farm 2 following faba bean precursor crop biomass. This implies both maize varieties had different fertilizer N (recovery) use efficiency in different locations. The variation in fertilizer N (recovery) use efficiency of maize varieties was also reported Eivazi and Habibi (2013).

The nitrogen fertilizer rate at 55 kg N ha^{-1} significantly (P<0.05) higher on fertilizer N (recovery) use efficiency of maize varieties in both farms (Table 2). The N recovery gradually decreased with increase N as was also observed by others (El-Gizawy, 2005; 2009; Berenger *et al*. 2009). This implies the response to fertilization was very poor, but analysis of grain yield and N uptake showed significant differences between all fertilizer rates (Yusuf *et al*., 2009). Therefore, the wide adoption of maize varieties following faba bean precursor crop is desirable for increased maize yields under smallholder farms with application half recommended N fertilizer rate in the region.

Shoot and grain N accumulation, and N harvest index of subsequent maize in Toke Kutaye

Shoot N accumulation of maize varieties was significantly (P<0.05) affected using faba bean precursor crop with and without rhizobia inoculation in both farms (Table 2). This might be due to differences the fertility status and historic management practices applied to the two farms.

The maize varieties showed significant (P<0.05) difference in mean shoot N accumulation in Farm 1 and Farm 2 following incorporation of faba bean precursor crop. Wenchi variety gave higher shoot N accumulation as compared to Jibat maize variety in both farms had been planted with faba bean precursor crop. The shoot N content of maize was varied between hybrid maize varieties (Uribelarrea *et al*., 2009).

Application of nitrogen fertilizer rates significantly (P<0.05) affected shoot N accumulation of maize varieties (Table 2). Significantly higher shoot N accumulation of maize varieties were obtained with higher N fertilizer rates application. Similarly, Moser (2004) found that shoot N concentration increased as the rate of N application increased in tropical maize varieties. Increase of nitrogen rates showed significant difference for shoot N accumulation of maize varieties (Uribelarrea *et al*. (2009). Similarly, nitrogen fertilizer application rates significantly influenced shoot N yield and increased with increases in N rate (Kidist, 2013; Muurinen, 2007; Woldeyesus *et al*., 2004).

Grain N accumulation of maize varieties was significantly (P<0.05) affected by N fertilizer application but non-significant the use of faba bean precursor crop with and without rhizobia inoculation in both farms and maize varieties (Table 2). The mean grain N accumulation of maize varieties increased significantly (P<0.05) as the rates of nitrogen fertilizer increased from 0 to 110 kg N ha^{1}, indicating direct influence of nitrogen application on seed development due to its role in amino acid and nucleic acid synthesis, both of which contain nitrogen. Maize planted after faba bean that received 120 kg N ha^{-1} also gave higher grain N uptake (El-Gizawy, 2009). Likewise, variation due to nitrogen application rate was observed for grain N concentration (Uribelarrea *et al*. (2009). Therefore, application of recommended nitrogen fertilizer could increase grain N accumulation of maize varieties.

N harvest index of maize varieties was significantly (P<0.05) affected by maize varieties and application N fertilizer rates (Table 2). The maize varieties used significantly (P<0.05) varied with N harvest index of maize following faba bean precursor crop in both farms (Table 2). There was variation in N harvest index between farms, maize varieties, precursor crop and application of nitrogen rates. This implies that different sites will vary in this characteristic. The application of nitrogen fertilizer rates following faba bean precursor crop significantly

(P<0.05) increased N harvest index of both maize varieties in Farm 2 but non-significant (P<0.05) for Farm 1 (Table 2). Kidist (2013) also found that nitrogen fertilizer application rates significantly influenced nitrogen harvest index of maize.

CONCLUSION

Higher agronomic efficiency, fertilizer N (recovery) use efficiency and nitrogen use efficiency of maize were obtained from 55 kg N ha^{-1} application as compared to 110 kg N ha^{-1}, which matched with higher grain yields of maize. Improved yields of maize following faba bean precursor crop without and with rhizobia inoculation and applying half recommended rate of nitrogen fertilizer (55 kg N ha^{-1}) in high altitude areas of western Ethiopia. Therefore, fertilizer management practices following legumes precursor crop biomass incorporation that increase nitrogen use efficiency and improve yield of maize will likely be more effective and desirable options for the area. The results from this series of studies suggest possibilities for further research work on optimum nitrogen rate, interaction of faba bean precursor crop biomass incorporation with nitrogen rates in the production of maize in other areas of western Ethiopia.

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ECONOMICS

RECOMMANDATION DE FORMULES DE FERTILISATION SITE-SPECIFIQUE POUR LA PRODUCTION DU MAÏS (*ZEA MAYS* L.) DANS LA REGION DES SAVANES AU TOGO
#9511

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RESUME

Dans le contexte actuel de la dégradation des terres agricoles et des difficultés de disponibilité et d'accès aux intrants agricoles en particulier les engrais, la maximisation de l'efficience d'utilisation des nutriments en nutrition des plantes devient plus que jamais une nécessité. Nous avons conduit en 2020 sous culture de maïs (*Zea mays* L.), des essais soustractifs à base de l'azote (N), du phosphore (P) et du potassium (K) dans les préfectures de Tandjouaré et de Tône de la région des savanes au Togo. L'objectif a été de déterminer la fertilité endogène des sols de ces préfectures en termes de rendement en grain de la culture, avec pour but de faire des recommandations de formules de fertilisation site-spécifiques à partir de rendements ciblés. Cinq traitements de fertilisation définis suivant le principe de soustraction d'élément ont été appliqués : le témoin absolu – $N_0P_0K_0$ (T_1), $N_0P_{60}K_{70}$ (T_2), $N_{120}P_0K_{70}$ (T_3), $N_{120}P_{60}K_0$ (T_4) et $N_{120}P_{60}K_{70}$ (T_5) kg ha^{-1} et la variété Ikenne de maïs a été utilisée. Les essais ont été conduits de façon participative incluant huit producteurs à Tandjouaré et sept producteurs à Tône servant chacun de répétition pour chacun des cinq traitements de fertilisation avec une parcelle élémentaire de 10 m x 10 m. Sur la base des rendements moyens obtenus sous chaque traitement dans chaque préfecture, des rendements ciblés ont été déterminés en tenant compte du rendement potentiel de la variété Ikeenne. Les formules de fertilisation pour obtenir l'écart entre les rendements ciblés et ceux mesurés sur les traitements zéro N, zéro P et zéro K ont été calculées. Les résultats ont révélé que les rendements moyens variaient de 0,52 à 4,25 et de 0,32 à 3,02 Mg ha^{-1}, respectivement à Tandjouaré et Tône et ont montré que le gradient de besoin prioritaire en nutriment de maïs était de N > P > K dans les deux préfectures. A Tandjouaré, l'obtention des rendements en grain de 3, 3,5, 4 et 4,5 Mg ha^{-1} est sujette aux formules de fertilisation $N_{92}P_0K_0$, $N_{112}P_{10}K_0$, $N_{132}P_{18}K_{16}$ et $N_{152}P_{26}K_{29}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondants de 16, 13, 11 et 10. Dans la préfecture de Tône, l'obtention des rendements en grain de 2,5, 3, 3,5, 4 et 4,5 Mg ha^{-1} est sujette aux formules de fertilisation $N_{79}P_{24}K_0$, $N_{99}P_{32}K_{16}$, $N_{119}P_{41}K_{30}$, $N_{139}P_{49}K_{43}$ et $N_{159}P_{57}K_{56}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondants de 9, 8, 12, 7 et 6.

Mots clés: Maïs, recommandation de formule de fertilisation, essais soustractifs, Région des Savanes du Togo, RVC

ABSTRACT

In the current context of agricultural land degradation and difficulties in availability and access to agricultural inputs, particularly fertilizers, maximizing nutrient use efficiency in plant nutrition is becoming more necessary than ever. In 2020, we conducted subtractive trials based on nitrogen (N), phosphorus (P) and potassium (K) under maize (*Zea mays* L.) in the prefectures of Tandjouaré and Tône in the Savannah region of Togo. The objective was to determine the endogenous fertility of the soils in these prefectures in terms of crop grain yield, with the aim of making recommendations for site-specific fertilization formulas based on targeted yields. Five fertilization treatments defined according to the element subtraction principle were applied: the absolute control - N0P0K0 (T1), N0P60K70 (T2), N120P0K70 (T3), N120P60K0 (T4) and N120P60K70 (T5) kg ha-1 and the maize variety Ikenne was used. The trials were conducted in a participatory manner with eight farmers in Tandjouaré and seven farmers in Tône, each serving as a replication for each of the five fertilizer treatments with a 10 m x 10 m plot size. Based on the average yields obtained under each treatment in each prefecture, target yields were determined considering the potential yield of the Ikeenne variety. Fertilization formulas to obtain the difference between the target yields and those measured on the zero N, zero P and zero K treatments were calculated. Results revealed that average yields ranged from 0.52 to 4.25 and 0.32 to 3.02 Mg ha^{-1}, respectively, in Tandjouaré and Tône and showed that the gradient of priority maize nutrient requirement was N > P > K in both prefectures. In Tandjouaré, grain yields of 3, 3.5, 4, and 4.5 Mg ha-1 were obtained using the fertilizer formulas N92P0K0, N112P10K0, N132P18K16, and N152P26K29 kg ha-1, respectively, with corresponding value/cost ratios of 16, 13, 11, and 10. In Tône prefecture, grain yields of 2.5, 3, 3.5, 4, and 4.5 Mg ha-1 are achieved using the fertilizer formulas N79P24K0, N99P32K16, N119P41K30, N139P49K43, and N159P57K56 kg ha-1, respectively, with corresponding value/cost ratios of 9, 8, 12, 7, and 6.

Keywords: Maize, fertilizer recommendation, nutrient omission trials, Savannah Region of Togo, RVC

INTRODUCTION

l'Afrique sub-saharienne est particulièrement vulnérable aux menaces jumelles de la dégradation des ressources naturelles et de la pauvreté, le changement climatique reste une préoccupation majeure donnant lieu à de nouveaux défis (Liniger *et al*., 2011). Un des défis majeurs, pour les scientifiques, les gouvernements et autres parties prenantes dans la région, est que la production alimentaire devrait augmenter de 70% en l'an 2050 pour répondre aux besoins caloriques nécessaires à la population (Liniger *et al*., 2011). Le déficit alimentaire ainsi que la pauvreté en particulier des populations rurales résultent principalement de la baisse de la fertilité des sols et il est démontré qu'aucune issue de sortie du cycle infernal de la famine et de la pauvreté n'est possible à moins que la tendance actuelle de la dégradation des sols est renversée (IFDC, 2005). Wheeler *et al.* 2000 ont démontré que la variabilité climatique a des impacts directs et indirects sur la production agricole. Par ailleurs, la vulnérabilité des systèmes culturaux et de la production végétale à la variabilité climatique conduit à des risques économiques et de sécurité alimentaire (Hatfield *et al*., 2011). Plusieurs approches telles que l'utilisation des rendements de culture et des analyses spatiales des systèmes agraires (Amouzou *et al*., 2013 ; Sogbedji *et al*., 2017) ont été utilisées pour comprendre les implications potentielles des trois principales entités (sol, climat et végétal) du système agricole pour plusieurs composantes du système de production alimentaire. Les résultats issus de telles approches ont montré qu'il devient plus urgent que jamais pour le secteur agricole de s'adapter à ces différentes entités. L'adaptation durable à ces entités est synonyme de composer simultanément avec leurs impacts respectifs, ce qui peut être fait avec succès en adoptant des technologies plus versatiles et plus résilientes vis-à-vis d'elles. Les options potentielles d'adaptation doivent nécessairement opérer sur la base de l'interface sol-climat-végétal

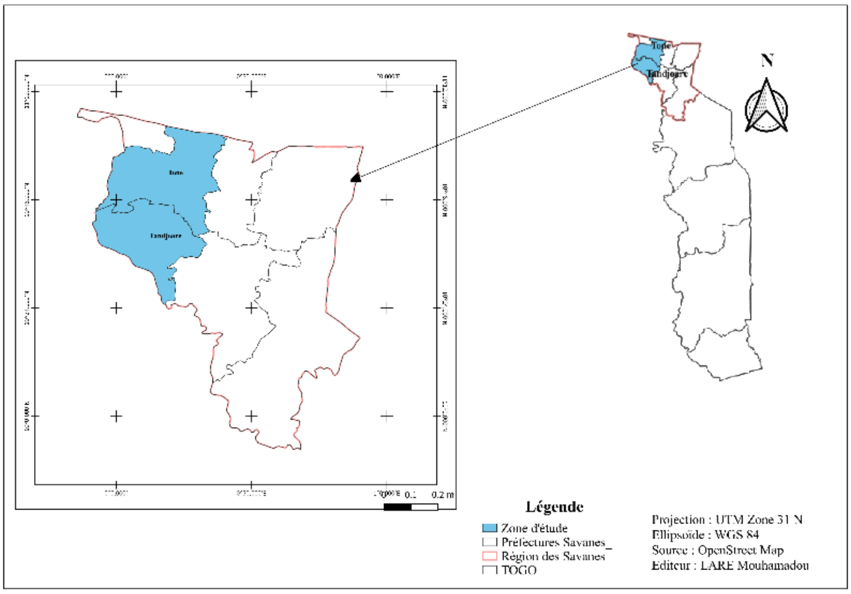
(Sogbedji, 2020). De telles options font sévèrement défaut dans le secteur agricole togolais et particulièrement dans la région des Savanes. Dans cette région, la culture de maïs constitue l'activité principale pour près de 90% de la population, les sols sont parmi les plus dégradés avec un rendement moyen en maïs grain n'excédant pas 2 t ha^{-1}, ce qui est en deçà du potentiel génétique de la culture d'au moins 5 t ha^{-1} (Akata, 1992, DSID, 2019, ITRA 2021). Des résultats de simulation sur la dégradation des sols au Togo permettent de dire que les sols dégradés passeraient de 15 % en 1995 à plus de 40 % en 2035 avec près de 16 % de sols fortement dégradés contre 2 % en 1995 (Brabant *et al.*, 1996). Plusieurs chercheurs ont souligné la nécessité d'actualiser les doses d'engrais recommandées après avoir rappelé le caractère obsolète des recommandations d'engrais en Afrique subsaharienne. Ces recommandations obsolètes qui sont des recommandations pan-territoriales ne tiennent compte ni de la dégradation des sols, ni de la diversité des agroécosystèmes et des pratiques culturales (Igue *et al*., 2013, Blanchard *et al*., 2014, Detchinili *et al*., 2017).

La présente étude s'inscrit dans un programme de recherche-développement visant à déterminer la fertilité endogène des sols de ces préfectures en termes de rendement en grain de la culture, avec pour but de faire des recommandations de formules de fertilisation site-spécifiques à partir de rendements ciblés.

MATERIEL ET METHODES

Site expérimental

L'étude a été conduite dans la région des savanes (Tandjouaré et Tône) du Togo. C'est la région la plus septentrionale du Togo. Le climat dans la région est de type Soudano-sahélien avec une saison pluvieuse qui va de mai à octobre et une saison sèche de novembre à avril. La pluviométrie y est de 850 à 1400 mm avec une très variabilité interannuelle (De Witte, 2013). Cette région connait également des périodes de fortes températures en mars et avril (38°) et des périodes de faibles températures entre novembre et janvier (19 °) (Lamsaïf, 2014) avec une importante évaporation surpassant les 2000 mm d'eau par an. Les sols dominants sont de types ferrugineux tropicaux lessivés (Lamoureux, 1969).



Carte de la zone d'étude

Matériel végétal

La variété de maïs Ikenne 9449-SR a été utilisée au cours de l'expérimentation. Il s'agit d'une variété composite, obtenue par CIMMYT / IITA, introduite au Togo en 1980 et cultivée dans toutes les régions du pays. Le cycle semis-maturité (50%) varie de 100 à 105 jours. Cette variété a une taille moyenne de 2,10 m et une hauteur d'insertion d'épis de 90 cm. Son grain est dûr de couleur blanchâtre. Elle présente un bon recouvrement de l'épi, une bonne résistance à la sécheresse, au virus de la striure et à la verse. Le rendement moyen de la variété Ikenne est de 5 Mg ha^{-1} (CEDEAO-UEMOA-CILSS, 2016).

Conduite de l'essai

L'étude a été conduite de juin à novembre de 2020 dans les préfectures de Tandjouaré et de Tône au Togo. Cinq traitements de fertilisation définis suivant le principe de soustraction d'élément ont été appliqués : le témoin absolu – $N_0P_0K_0$ (T_1), $N_0P_{60}K_{70}$ (T_2), $N_{120}P_0K_{70}$ (T_3), $N_{120}P_{60}K_0$ (T_4) et $N_{120}P_{60}K_{70}$ (T_5) kg ha^{-1} et la variété Ikenne de maïs a été utilisée. Les essais ont été conduits de façon participative incluant huit producteurs à Tandjouaré et sept producteurs à Tône servant chacun de répétition pour chacun des cinq traitements de fertilisation avec une parcelle élémentaire de 10 m x 10 m.

Collecte et analyse de données

Les rendements en maïs grains ont été déterminés sous chaque traitement en récoltant les épis de la surface utile. Les grains récoltés ont été pesé pour chaque traitement à l'aide d'une balance électronique. Sur la base des rendements moyens obtenus sous chaque traitement dans chaque préfecture, des rendements ciblés ont été déterminés en tenant compte du rendement potentiel de la variété Ikenne. Les formules de fertilisation pour obtenir l'écart entre les rendements ciblés et ceux mesurés sur les traitements zéro N, zéro P et zéro K ont été calculées. La dose de chaque élément a été calculée à travers cette formule :

$$\text{Dose de Fertilisant} = \frac{\text{Rendement ciblé} - \text{Rendement Zéro}}{\text{EI} * \text{TR}}$$

EI : Efficience Interne
TR : Taux de Recouvrement
D'après JANSSEN et al (1990), on a : EI (N) : 50 Kg Grains/Kg de N absorbé, EI (N) : 400 Kg Grains/Kg de P absorbé et EI (K) : 75 Kg Grains/Kg de K absorbé
Pour les sols argileux, le taux de recouvrement (TR) est : TR(N)= 0,5, TR(P)= 0,15, TR(K)= 0,5
Le Ratio Valeur Cout (RVC) a été calculé à travers cette formule pour chacune des formules de fertilisation :

$$\text{RVC} = \frac{\text{Revenu total de l'option}}{\text{Coût total des engrais}}$$

RESULTATS ET DISCUSSION

Les rendements en grains de maïs enregistrés sont résumés en annexe 1 et 2 ci-après. Les résultats de l'étude révèlent que les rendements moyens ont variés de 0,52 à 4,25 et de 0,32 à 3,02 Mg ha^{-1}, respectivement à Tandjouaré et Tône et montrent que le gradient de besoin prioritaire en nutriment de maïs est de N > P > K dans les deux préfectures. Les résultats ainsi obtenus corroborent ceux de (Maba *et al.*, 2007, Mawussi *et al.*, 2015) qui ont également trouvé les mêmes scénarii sur les sols ferrugineux tropicaux.

Sur la base des résultats des essais soustractifs, les formules de fertilisation développées pour obtenir l'écart entre les rendements ciblés et ceux mesurés sur les traitements zéro N, zéro P et zéro K ont fait l'objet de débat et vient confirmer les études de Igue *et al.* (2013), Blanchard *et al.* (2014), Detchinili *et al.* (2017), Lare et Sogbedji (2020) sur la nécessité d'actualiser les formules de fertilisation. Pour la préfecture de Tandjouaré, l'obtention des rendements en grain de 3, 3,5, 4 et 4,5 Mg ha^{-1} est sujette aux formules de fertilisation $N_{92}P_0K_0$, $N_{112}P_{10}K_0$, $N_{132}P_{18}K_{16}$ et $N_{152}P_{26}K_{29}$ kg ha^{-1}, respectivement, avec des Ratios Valeur Coût (RVC) correspondants de 16, 13, 11 et 10. Pour la préfecture de Tône, l'obtention des rendements en grain de 2,5, 3, 3,5, 4 et 4,5 Mg ha^{-1} est sujette aux formules de fertilisation $N_{79}P_{24}K_0$, $N_{99}P_{32}K_{16}$, $N_{119}P_{41}K_{30}$, $N_{139}P_{49}K_{43}$ et $N_{159}P_{57}K_{56}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondants de 9, 8, 12, 7 et 6.

Il ressort que tous les Ratios Valeurs Couts (RVC) calculés sur la base des formules de fertilisation développées sont supérieurs à la valeur seuil 2 fixée par la FAO en 2005. Pour la préfecture de Tandjouaré, plus le rendement ciblé est faible, plus le RVC est élevé. Par contre dans la préfecture de Tône, le meilleur RVC est obtenu pour un rendement ciblé de 3,5 $Mgha^{-1}$. Les doses des éléments nutritifs obtenues pour les panoplies de rendements ciblés corroborent les travaux de Ziadi *et al.* (2006), Mustapha (2012) pour lesquels la fertilisation azotée joue un rôle essentiel sur la croissance des végétaux et le rendement des cultures et qu'elle contribue à augmenter la production agricole tout en ayant un impact sur la qualité des produits récolté. Pour Batamoussi *et al.* (2014), l'azote constitue le principal élément limitant le rendement des cultures céréalières.

Les formules de fertilisation ainsi développées nécessitent une validation sur le terrain afin de confirmer et ou d'infirmer leurs performances agronomiques et économiques pour une production optimale et durable surtout dans le contexte actuel de changement climatique et de dégradation des ressources de base.

L'interprétation des résultats montre la nécessité pour chaque cite spécifique sa formule de fertilisation en fonction de l'objectif du producteur dans le strict respect de l'environnement et des réserves nutritives natives du sol. La pauvreté des terres agricoles a rendu l'utilisation des fertilisants, surtout minéraux, indispensable à la production (Sanou *et al.*, 2018).

CONCLUSION

La faible productivité du maïs au Togo est plus qu'une réalité malgré l'effort des chercheurs, des scientifiques, des parties prenantes et du gouvernement. L'agriculture de précision devient alors une urgence au Togo pour faire face à ce défi. Suite à l'objectif de développer des formules de fertilisation site spécifique pour les préfectures de Tandjouaré et de Tône, les résultats ont présenté différente amplitude et sont économiquement rentable avec des RVC supérieurs au seuil 2. Toutes fois, ces formules nécessitent une validation en milieu réel afin de confirmer ou d'infirmer leurs performances.

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ANNEXE

Annexe 1.

Préfecture	Traitement	Rendement Moyen en Mg ha^{-1}
Tandjouaré	Témoin absolu	0.52
	$N_0P_{60}K_{70}$	0.70
	$N_{120}P_0K_{70}$	2.92
	$N_{120}P_{60}K_{70}$	3.40
	$N_{120}P_{60}K_{70}$	4.25
Tône	Témoin absolu	0.32
	$N_0P_{60}K_{70}$	0.52
	$N_{120}P_0K_{70}$	1.06
	$N_{120}P_{60}K_{70}$	2.39
	$N_{120}P_{60}K_{70}$	3.02

Annexe 2.

Préfecture	Rendement ciblé	Formule de fertilisation	RVC
Tandjouaré	3	$N_{92}P_0K_0$,	16
	3,5	$N_{112}P_{10}K_0$,	13
	4	$N_{132}P_{18}K_{16}$	11
	4,5	$N_{152}P_{26}K_{29}$	10
Tône	2,5	$N_{79}P_{24}K_0$	9
	3	$N_{99}P_{32}K_{16}$,	8
	3,5	$N_{119}P_{41}K_{30}$,	12
	4	$N_{139}P_{49}K_{43}$	7
	4,5	$N_{159}P_{57}K_{56}$	6

MAXIMISATION DE L'EFFICIENCE D'UTILISATION DES NUTRIMENTS : RECOMMANDATION DE FERTILISATION A LA CARTE POUR LE MAÏS SUR LES FERRALSOLS DU SUD-TOGO
#9519

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RESUME

L'amélioration de la nutrition des plantes à travers l'agriculture de précision devient incontournable pour l'optimisation de l'entreprise agricole et la protection de l'environnement. Nous avons conduit pendant la grande saison culturale de 2020 et 2021, sous culture de maïs (*Zea mays* L.), des essais soustractifs à base de l'azote (N), du phosphore (P) et du potassium (K) à la station d'expérimentations agronomiques (SEAL) de l'Ecole Supérieure d'Agronomie de l'Université de Lomé, Togo. L'objectif a été de déterminer la fertilité endogène du site en termes de rendement en grain de la culture pour faire des recommandations de formules de fertilisation à la carte (site-spécifiques) à partir de rendements ciblés. Cinq traitements de fertilisation ont été appliqués suivant le principe de soustraction: le témoin absolu – $N_0P_0K_0$ (T_1), $N_0P_{60}K_{60}$ (T_2), $N_{140}P_0K_{60}$ (T_3), $N_{140}P_{60}K_0$ (T_4) et $N_{140}P_{60}K_{60}$ (T_5) kg ha^{-1}. Chacun des traitements de fertilisation a été croisé avec quatre variétés de maïs dans un dispositif expérimental en bloc aléatoire complet à parcelles divisées (Split-splot) à trois répétitions avec la fertilisation en parcelle principale (4 m x 2,5 m) et la variété de maïs en sous-parcelle (2,5 m x 2 m). Les formules de fertilisation pour obtenir l'écart de rendement entre les rendements ciblés et ceux mesurés sur les traitements zéro N, zéro P et zéro K pour chaque variété ont été déterminées à travers le taux de recouvrement et l'efficience interne de chaque nutriment. Les rendements moyens ont varié de 1,01 à 4,91, 1,13 à 4,92, 0,78 à 4,86 et 0,67 à 3 Mg ha^{-1}, respectivement pour les variétés Obatanpa, Sotubaka, Ikenne et Tzee, et ont clairement indiqué que le gradient de besoin prioritaire en nutriment de maïs était de N > K > P pour le site. Pour la variété Sotubaka, les rendements en grain ciblés de 3,5, 4,0, 4,5 et de 5 Mg ha^{-1} sont obtenus avec des formules de fertilisation $N_{20}P_0K_0$, $N_{40}P_0K_{19}$, $N_{60}P_0K_{32}$ et $N_{80}P_0K_{45}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondant typiquement à 89, 36, 26 et 21. Pour la variété Obatanpa, l'obtention des rendements en grain de 4,0, 4,5 et de 5 Mg ha^{-1} est sujette aux formules de fertilisation $N_{25}P_0K_{15}$, $N_{45}P_0K_{28}$ et $N_{65}P_0K_{41}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondants de 32, 32 et 14. L'obtention des rendements en grain de 3, 3,5, 4,0 et 4,5 Mg ha^{-1} pour la variété Ikenne, nécessite des formules de fertilisation $N_{37}P_0K_{18}$, $N_{57}P_0K_{31}$, $N_{77}P_0K_{45}$ et $N_{97}P_0K_{58}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût y afférents de 29, 21, 17 et 15. Pour la variété Tzee, les rendements en grain de 2,5, 3,0 et de 3,5 Mg ha^{-1} sont obtenus par les formules de fertilisation $N_{32}P_0K_{07}$, $N_{52}P_0K_{21}$ et $N_{72}P_8K_{34}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondants de 35, 21 et 15.

Mots clés : Maïs, formule de fertilisation, essais soustractifs, ferralsols, ratios valeur/coût

ABSTRACT

The improvement of plant nutrition through precision agriculture becomes unavoidable for the optimization of the agricultural enterprise and the protection of the environment. We conducted during the major cropping season of 2020 and 2021, under maize (*Zea mays* L.), omission trials based on nitrogen (N), phosphorus (P) and potassium (K) at the station of agronomic experiments (SEAL) of the Higher School of Agronomy of the University of Lome, Togo. The objective was to determine the endogenous fertility of the site in terms of grain yield of the crop towards site-specific fertilizer recommendations based on targeted yields. Five fertilization treatments were applied: the control - $N_0P_0K_0$ (T_1), $N_0P_{60}K_{60}$ (T_2), $N_{140}P_0K_{60}$ (T_3), $N_{140}P_{60}K_0$ (T_4) and $N_{140}P_{60}K_{60}$ (T_5) kg ha^{-1}. Each of the fertilizer treatments was crossed with four maize varieties in a three-replicate split-split randomized block design with the fertilization scheme as main plot (4 m x 2.5 m) and the maize variety in the sub-plot (2.5 m x 2 m). Based on measured average yields, target yields were determinedand fertilization schemes to obtain the yield difference between target and measured yields on the zero N, zero P and zero K treatments for each variety were determined using the recovery rate and the internal efficiency of each nutrient. Measured average yields ranged from 1.01 to 4.91, 1.13 to 4.92, 0.78 to 4.86, and 0.67 to 3 Mg ha^{-1}, respectively for Obatanpa, Sotubaka, Ikenne, and Tzee varieties, and clearly indicated that the priority gradient of maize nutrient requirement was N > K > P for the site. For the variety Sotubaka, grain yields of 3.5, 4, 4.5, and 5 Mg ha-1 are obtained with fertilizer formulas $N_{20}P_0K_0$, $N_{40}P_0K_{19}$, $N_{60}P_0K_{32}$ and $N_{80}P_0K_{45}$ kg ha^{-1}, respectively, with value/cost ratios typically corresponding to 89, 36, 26, and 21. For the Obatanpa variety, achieving grain yields of 4, 4.5, and 5 Mg ha-1 is subject to the fertilization formulas $N_{25}P_0K_{15}$, $N_{45}P_0K_{28}$ and $N_{65}P_0K_{41}$ kg ha^{-1}, respectively, with corresponding value/cost ratios of 32, 32, and 14. For the variety Ikenne, obtaining grain yields of 3, 3.5, 4 and 4.5 Mg ha-1 requires fertilization formulas $N_{37}P_0K_{18}$, $N_{57}P_0K_{31}$, $N_{77}P_0K_{45}$ and $N_{97}P_0K_{58}$ kg ha^{-1}, respectively, with related value/cost ratios of 29, 21, 17 and 15. For the variety Tzee, grain yields of 2.5, 3, and 3.5 Mg ha-1 are obtained by the fertilization formulas $N_{32}P_0K_{07}$, $N_{52}P_0K_{21}$ and $N_{72}P_8K_{34}$ kg ha^{-1}, respectively, with corresponding value/cost ratios of 35, 21, and 15.

Keywords: Maize, fertilizer recommendation, omission trials, ferralsols, value/cost ratio

INTRODUCTION

Le maïs représente une des majeures cultures dans le système agroalimentaire au Togo car, il occupe près de 51 % des céréales cultivées et se positionne comme la principale culture céréalière devant le riz (DSID, 2015 ; FAO, 2021). En outre, la culture du maïs occupe 700 000 hectares, ce qui représente 40 % de la superficie totale des cultures vivrières, avec une production annuelle de grains de 900 000 tonnes (DSID, 2022). Nonobstant la grande importance de la maïsiculture dans le système alimentaire, les rendements moyens au niveau des exploitants agricoles au Togo, tournent autour de 1,3 t ha^{-1} qui largement en deçà du potentiel génétique des différentes variétés de la culture. Cette faiblesse résulte de la persistance des systèmes de productions traditionnelles en place qui ne permettent pas de valoriser le plein potentiel des variétés améliorées introduites (ITRA, 2007). Ces systèmes sont entre autres, caractérisés par l'utilisation de formules de fertilisation pan-territoriales occasionnant par ailleurs la dégradation progressive de la ressource de base, la perte de la fertilité des sols, une nette diminution des rendements des cultures suivies d'une baisse de la rentabilité économique des productions agricoles (Sanou et Soule, 2017 ; Detchinli *et al.*, 2017). Un rapport de la FAO évoque également que la pandémie à la Covid19 a entraîné de sévères répercussions dans le domaine agricole notamment sur la disponibilité des intrants d'où un effet régressif sur les productions agricoles (FAO, 2021). Les producteurs sont alors confrontés à une problématique qui est celle de produire en quantité mais aussi en qualité suffisante pour satisfaire les besoins des populations tout en préservant la qualité de la ressource de base. Le développement du secteur agricole passera donc par l'application des principes de l'agriculture de précision. Il s'agit de prendre en compte la restauration des ressources naturelles c'est-à-dire que les éléments nutritifs exportés par les cultures doivent alors être restitués au sol (Dagbénonbakin *et al.*, 2015). A cet effet, la connaissance des quantités d'éléments minéraux exportés par les cultures constitue un facteur primordial dans l'accroissement des rendements du maïs. Selon Dagbénonbakin *et al.* (2015), pour concevoir de nouvelles stratégies de fertilisation, il faut disposer d'une bonne connaissance de l'état de fertilité initiale des sols. Certains travaux ont montré l'importance de la mise en place des essais soustractifs, car ils permettent de déterminer les doses optimales et économiquement rentables de fertilisants minéraux en vue d'une application efficiente des stratégies de fertilisation. Ces essais doivent prendre en compte les éléments nutritifs exportés par les cultures en vue d'atteindre les potentiels de rendement des différentes variétés de semences agricoles vulgarisées et de reconstituer les éléments nutritifs du sol (Detchinli et Sogbedji, 2014 ; ITRA, 2007). Pour une nette amélioration des rendements en grain de maïs au Togo, il faut une utilisation optimale et efficiente de la fertilisation minérale en maïsiculture (Mawussi *et al.*, 2015). Face à cette situation, le défi de la recherche agricole sera de déterminer des besoins prioritaires de la culture du maïs en fonction des principaux nutriments minéraux que sont l'azote (N), le phosphore (P) et le potassium (K).

MATERIEL ET METHODES

Site expérimental

L'étude a été conduite à la Station d'Expérimentations Agronomiques de l'Université de Lomé à Lomé, Togo. Le climat est de type tropical guinéen offrant deux saisons culturales : une grande saison de mi-mars à mi-juillet et une petite saison de septembre à novembre. Les précipitations annuelles varient de 800 à 1200 mm et la température moyenne annuelle est entre 24 à 30°C. Le sol est de type ferrallitique communément appelé « terres de barres ». Le sol est bien drainé et possède un faible taux de matière organique (< 10 $g.kg^{-1}$). Sa teneur en potassium (K) est inférieure à 2 $cmol.kg^{-1}$; il a un contenu en phosphore total (P total) variant de 250 à 300 mg kg^{-1}, une capacité d'échange cationique de 3 à 4 $méq.kg^{-1}$, un pH de 5,2 à 6,8 (Tossah, 2000). Le contenu sableux est approximativement de 800 $g.kg^{-1}$ dans l'horizon de 0 à 20 cm et décroît à moins de 600 $g.kg^{-1}$ à partir de 50 à 120 cm de profondeur (Lamouroux, 1969). Le site expérimental a une pente de moins de 1 %.

Conduite de l'essai

L'étude a été conduite d'Avril à août de 2019 et de 2020. Cinq traitements de fertilisation définis suivant le principe de soustraction d'élément ont été appliqués : le témoin absolu – $N_0P_0K_0$ (T_1), $N_0P_{60}K_{60}$ (T_2), $N_{140}P_0K_{60}$ (T_3), $N_{140}P_{60}K_0$ (T_4) et $N_{140}P_{60}K_{70}$ (T_5) kg ha^{-1}. Chacun des traitements de fertilisation a été croisé avec quatre variétés (Ikenne, Sotubaka, Obatanpa et Tzee) de maïs (Tableau 1) dans un dispositif expérimental en bloc aléatoire complet à parcelles divisées (split-plot) à trois répétitions avec la fertilisation en parcelle principale (4 m x 2,5 m) et la variété de maïs en sous-parcelle (2,5 m x 2 m). Les semis ont eu lieu les 07 et 08 avril respectivement pour les années 2020 et 2021. Les cultures ont été désherbées manuellement et EMACOT a été utilisé pour lutter contre la Chenille Légionnaire d'Automne (CLA).

Tableau 1. Caractéristiques des varieties de maïs utilisées pour l'étude.

Variétés de maïs	Cycle (jour)	Couleur du grain	Rendement potentiel (Mg ha^{-1})
IKENNE	100 -105	Blanche	5
SOTOUBAKA	100 - 110	Jaune	6
TZEE	80 - 85	Blanche	3,5
OBATANPA	95 - 105	Blanche	6

Collecte et analyse de données

Les rendements en maïs grains ont été déterminés sous chaque traitement en récoltant les épis de la sous-parcelle y afférente. Les grains récoltés ont été pesé pour chaque traitement à l'aide d'une balance électronique après séchage jusqu'à un taux d'humidité d'approximativement de 14 pourcent. Sur la base des rendements moyens obtenus sous chaque traitement, des rendements ciblés ont été déterminés en tenant compte du rendement potentiel de la variété de chaque variété. Les doses de chacun des trois éléments N, P et K à appliquer pour obtenir l'écart entre les rendements ciblés et ceux mesurés sur les traitements zéro N, zéro P et zéro K ont été calculées. La dose de chaque élément a été calculée à travers formule suivante :

$$\text{Dose de Fertilisant} = \frac{\text{Rendement ciblé} - \text{Rendement Zéro}}{\text{EI} * \text{TR}}$$

EI : Efficience Interne ; TR : Taux de Recouvrement

D'après JANSSEN *et al* (1990), on a : EI (N) : 50 kg grains/kg de N absorbé, EI (N) : 400 kg grains/kg de P absorbé et EI (K) : 75 kg grains/kg de K absorbé.

Pour les sols argileux, le taux de recouvrement est : TR(N) = 0,5 ; TR(P) = 0,15 ; TR(K) = 0,5.

Le ratio valeur coût (revenu total de l'option/coût des engrais appliqués, RVC) a été calculé.

RESULTATS ET DISCUSSION

Les résultats révèlent que les rendements moyens ont varié de 1,01 à 4,91, 1,13 à 4,92, 0,78 à 4,86 et 0,67 à 3 Mg ha^{-1}, respectivement pour les variétés Sotubaka, Obatanpa, Ikenne et Tzee, et ont clairement indiqué que le gradient de besoin prioritaire en nutriment de maïs sur les sols ferralitiques est de N > K > P dans le contexte pédoclimatique de la culture. Les résultats ainsi obtenus sont en désaccords aux résultats de Kodjo et al. (2013) qui ont démontré que le gradient de besoin prioritaire en nutriment de maïs sur les sols ferralitiques est de N > P > K.

Sur la base des résultats des essais soustractifs, les quantités d'engrais générées pour obtenir l'écart entre les rendements ciblés et ceux mesurés sur les traitements zéro N, zéro K et zéro P ont varié selon les variétés et confirment les études de Igue *et al*. (2013) et Blanchard *et al*. (2014) sur la nécessité d'actualiser les formules de fertilisation dans l'optique d'apporter à la plante son besoin en nutriments exigeant pour sa croissance et son développement optimale. Pour la variété Sotubaka, les rendements en grain de 3,5, 4, 4,5 et de 5 Mg ha^{-1} sont obtenus avec des formules de fertilisation $N_{20}P_0K_0$, $N_{40}P_0K_{19}$, $N_{60}P_0K_{32}$ et $N_{80}P_0K_{45}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondant typiquement à 89, 36, 26 et 21. Pour la variété Obatanpa, l'obtention des rendements en grain de 4, 4,5 et de 5 Mg ha^{-1} est sujette aux formules de fertilisation $N_{25}P_0K_{15}$, $N_{45}P_0K_{28}$ et $N_{65}P_0K_{41}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondants de 32, 32 et 14. Pour la variété Ikenne, l'obtention des rendements en grain de 3, 3,5, 4 et 4,5 Mg ha^{-1} nécessite des formules de fertilisation $N_{37}P_0K_{18}$, $N_{57}P_0K_{31}$, $N_{77}P_0K_{45}$ et $N_{97}P_0K_{58}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût y afférents de 29, 21, 17 et 15. Pour la variété Tzee, les rendements en grain de 2,5, 3 et de 3,5 Mg ha^{-1} sont obtenus par les formules de fertilisation $N_{32}P_0K_{07}$, $N_{52}P_0K_{21}$ et $N_{72}P_8K_{34}$ kg ha^{-1}, respectivement, avec des ratios valeur/coût correspondants de 35, 21 et 15.

Tous les RVC calculés sur la base des formules de fertilisation développées sont supérieurs à la valeur seuil 2 fixée par la FAO en 2005 pour qu'une formule de fertilisation soit rentable et donc recommandable. Pour les quatre variétés, plus le rendement ciblé est faible, plus le RVC est élevé. Les doses des éléments nutritifs obtenues avec un accent sur l'azote pour les différentes gammes de rendements ciblés ont corroboré les résultats de travaux antérieurs (Ziadi *et al*. 2006 ; Batamoussi *et al.* 2014) qui ont indiqué que l'azote constitue le principal élément limitant le rendement des cultures céréalières.

Tableau 2. Recommandation de formule de fertilisation et RVC y afférent.

Variété	Rendement ciblé (Mg ha^{-1})	Recommandation (kg ha^{-1})	RVC
Sotubaka	3,5	$N_{20}P_0K_0$	89
	4,0	$N_{40}P_0K_{19}$	36
	4,5	$N_{60}P_0K_{32}$	26
	5,0	$N_{80}P_0K_{45}$	21
Ikenne	3,0	$N_{37}P_0K_{18}$	28
	3,5	$N_{57}P_0K_{31}$	21
	4,0	$N_{77}P_0K_{45}$	17
	4,5	$N_{97}P_0K_{58}$	15
Tzee	2,5	$N_{32}P_0K_7$	32
	3,0	$N_{52}P_0K_{21}$	21
	3,5	$N_{72}P_8K_{34}$	15
Obatampa	4,0	$N_{25}P_0K_{15}$	32
	4,5	$N_{45}P_0K_{28}$	32
	5,0	$N_{65}P_0K_{41}$	14

CONCLUSION

Il est nécessaire de développer pour chaque variété de maïs, sa propre formule de fertilisation en fonction de l'objectif du producteur et sur la base des réserves nutritives natives du sol. En absence d'azote dans la formule de fumure minérale, on enregistre les plus faibles rendements de maïs alors que l'absence de phosphore n'affecte pas le rendement en grain du maïs. Par ordre décroissant, le besoin en azote se révèle le plus important suivit de celui du potassium : N>K>P. Les principes de base de l'agriculture de précision s'impose alors aujourd'hui pour une production optimale et durable. Les formules de fertilisation développées sur la base des rendements ciblés ont été économiquement rentables. Des essais agronomiques sont nécessaires pour apprécier la validité des formules de fertilisation de la présente étude.

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EDUCATION AND ENGAGEMENT INNOVATIONS

PROMOTING PRECISION AGRICULTURE EDUCATION IN SUB–SAHARAN AFRICA: UNDERSTANDING THE ENABLERS AND THE BURDENS #9403

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ABSTRACT

Adopting Precision Agriculture tools and strategies can significantly accelerate agricultural transformation in sub–Saharan Africa (SSA) but burgeoning population and minimal technology advancement has slowed down SSA's progress toward attaining food and nutritional security. Climate change and the COVID-19 pandemic have increased the need for more resilient, productive, and profitable agriculture to ensuring food and nutrition security. Precision agriculture offers innovative approaches to harnessing soil and water resources in a more efficient and economic ways to increase crop yields in an environmentally friendly manner. With almost 60 percent of the region's population under the age of 25, education of youth in precision agriculture is crucial. This review paper focuses on the enablers and burdens of precision agriculture education in Africa. The paper presents a summary of ideas and findings from literature review, focus group discussion and key informant interviews. The study showed that Precision agriculture Education. if strategically implemented, can grow very rapidly, leading to increased enrolment and skills development as well as increased youth involvement in SSA African agriculture leading to higher crop yields and farmer incomes. The dominant enablers identified included Africa's youthful population and increasing growth in telephony and access to the internet, whiles the most important constraints included lack of infrastructure and limited knowledge and skills in PA technology. We conclude that if policy makers, local authorities, and managers of educational institutions in SSA stimulate PA integration into existing curriculum and create the needed enabling environments for PA growth at different levels in agricultural training institutions, SSA agricultural production systems will yield food and nutritional security outcomes, whiles creating jobs and enhancing livelihoods of the rural poor.

INTRODUCTION

Education is the surest way to overcome Africa's socio-economic development challenges. FAO (2007) pointed out that there a direct link between food security and education of rural youth, and that education can also help to improve farmers' livelihoods. In most parts of Africa, agriculture education is not prioritised and so it is often viewed as the preserve for underachievers. Furthermore, the quality of agriculture education is SSA is often low, and there is limited availability of well-motivated and highly skilled faculty, especially in poorly endowed or in less prestigious universities and colleges (FAO/UNESCO, 2003; World Bank, 2008). Precision Agriculture offers enormous potential to accelerate agricultural transformation in sub–Saharan Africa (SSA). Integrating PA into existing agricultural training institutions eventually increase agricultural productivity and profitability, contributing to sustainable development, through food security and increased farmer incomes. Investments in PA skill training and education is likely to empower Africa's youth with new knowledge and sharpen their skills for highly paid jobs. Romanov et al. (2016) opined that PA allows agriculturalists to observe, evaluate and control farming operations. Paustian and Theuvsen

(2017) and Swinton & Lowenberg-DeBoer (1998) reported that PA offers a lot of economic and environmental benefits through accelerated transformation of Africa's agrifood systems for shared prosperity and enhanced livelihoods. However, global adoption of PA is low, particularly in developing nations (Paustian & Theuvsen, 2017). Agriculture a major course in many African universities, but the number of students interested to pursue agriculture continues to decrease across the region. The declining numbers of agriculture students raises concern and so the underlying causes need to be identified so that the challenges could be addressed accordingly. Integration of PA into existing agricultural education in Africa can attract more youth, significantly increase enrolment, and promote capacity development for a more productive agricultural industry. However, the success of PA education in Africa is dependent on curriculum re-engineering, outreach, and tailored skill training, which requires skilled faculty, availability of ICT and internet facilities and an enabling policy environment. This paper presents an overview of the perceptions of faculty, undergraduate and postgraduate students from two Ghanaian universities about PA education in Africa. The paper further examines enablers and barriers to precision agricultural education in Africa.

MATERIALS AND METHODS

The study involved a desk review of literature including FAO and World Bank reports, a focus group discussion (FGD) and a survey involving faculty, postgraduate and undergraduate students randomly selected from two Ghanaian public universities: the University of Cape Coast and the Technical University of Cape Coast, respectively. The literature review was followed by a focus group discussion and survey using a semi-structured questionnaire information to facilitate triangulation of results. The survey involved undergraduate students, postgraduate students and faculty from agriculture or agriculture-related departments qualitative and quantitative data. Data obtained from the study was analysed and presented mainly as descriptive statistics (frequency, percentage, and mean values).

RESULTS AND DISCUSSION

Demographics of the respondents

The results showed that about 76% of the students were male. This is in accordance with an IFPRI (International Food Policy Research Institute) study, which concluded that women are underrepresented in Africa's agricultural research and higher education (Beintema and Di Marcantonio, 2010).

Table 2. Demographic of the respondents.

Gender		Designation		Highest level of Education			Number of years of university education university	
Male	Female	Faculty	Students	PhD	MSc	BSc	>5 years	< 5 years
530	170	70	630	30	70	600	60	640

The survey revealed that most of the respondents had no or very limited knowledge about PA. However, most of the respondents (students and faculty alike) agreed that the impact of PA on Ghana's agricultural industry will grow as new ideas and opportunities spread. Furthermore, majority of the respondents had no knowledge about the components of PA education, with only 14% claiming to know what they are.

Perceptions of PA Education in SSA

The respondents showed a high level of consensus on their perceptions of PA education in Africa. Responses to specific questions asked during the FGD are summarized in Table 2.

Table 3. perceptions of PA education in sub-Saharan Africa.

Perception	Yes	No	Don't Know
Is PA critical for accelerated transformation of the agrifood systems, and shared prosperity and enhanced livelihoods in Africa	83%	17%	-
There is inadequate skilled PA faculty, tools, and facilities in Ghanaian universities	87%	13%	-
There is limited financial commitments and regulatory policies towards integrating PA into existing program in universities	86%	14%	-
The extension services in Ghana lacks the capacity, skills, and competencies to promote PA services	60%	22%	18%
There is lack of equipment and logistics to stimulate PA Education and outreach in Ghana	70%	9%	21%
The media is interested and adequately psyched to promote PA education and outreach in Ghana	39%	27%	44%
Promotion of PA education and outreach is low because of a disjoint existing between academia, industry, and the media	59%	10%	31%
The success of PA education in Ghana is highly dependent on curriculum reengineering to include PA technology and skills training	59%	4%	37%

The study showed that there is a general perception that PA education can accelerate development of Africa's agrifood sector, but that there is inadequate skilled PA faculty, tools and facilities in SSA universities, Further, it was generally perceived that there is limited financial commitments and regulatory policies towards integrating PA into existing program in SSA universities.

Enablers, Barriers, and opportunities for PA Education in SSA

The study indicated a widely agreed perception that efficient curriculum, as well as provision of ICT and Geosciences equipment and logistics can stimulate PA education in SSA. Furthermore, most of the respondents agreed that PA education hinges on curriculum reengineering and vavilability of ICT and internet facilities. Although mobile technology penetration and internet access is growing steadily in SSA it is still expensive, and combined with limited and unreliable electricity supply, low ICT literacy levels and lack of financial resources to secure the use of ICTs (World Bank, 2011), integration of PA into existing education can be hindered. The focus group discussion revealed that Ghana has a youthful population, who are keen to pursue technology-based education. But the main challenge facing PA education is limited access to PA information and education, which highly limits the acquisition of knowledge and skills and development of entrepreneurial skills. Regarding opportunities, the study indicated that the youth are enthusiastic to be empowered with modern PA technologies" (MIJARC/IFAD/FAO, 2012). Furthermore, increasing availability of smartphones and expanding internet access coupled with increasing access to secondary and tertiary education is likely to stimulate interest in PA education.

The way forward

While the challenges identified are complex and interwoven, a strategically structured PA education that ensures access to the right information through integrated training approaches and provide solutions through adoption of modern agricultural practices and deployment of ICT offers a great potential to increase agricultural productivity and profitability. Results from the FGD showed that each category of respondents had different priorities in terms of what would promote accelerated PA education in Ghana. The FGD showed that faculty prioritised training, infrastructure, and industry-academia linkages; postgraduates were more interested in PA research while undergraduate students were more inclined towards PA skills, scholarships, and skilled faculty.

Transitioning traditional farming to digital agriculture in an era of fast technology growth and dynamic agricultural economy, agricultural universities in SSA need to adapt their curricula and integrate improved technology, communication, and entrepreneurial skills. However, IUCEA (2015) and other organizations across Africa repeatedly show that regardless of the need for technical skills, employers place much greater importance on ‘soft skills’ (Kalufya and Mwakajinga 2016; Ngalomba , 2018). Thus, it is crucial to train agriculture graduates in ways that enable them to continually adapt to a complex and changing ecosystem, by providing them opportunities that ensure their inclusion in networks that promote co-learning and sharing of scientific, technical and market information. Building the skills of both educated and uneducated youth to work along the agricultural value chain has the potential to solve the problem of youth unemployment and, at the same time, increase agricultural productivity. Rapid technological evolution requires a culture of continuous learning and an agricultural education and training system properly focused on both how to learn and what to learn. Such a system must employ innovative e approaches that will position agriculture graduates to lead change, to be adaptable and efficient. Universities should enhance the skills of graduates in ways that will empower them to respond to rapidly changing technological, environmental, and structural conditions. They must be innovative and capable of adapting their PA knowledge and skills to complex and changing food systems.

The integration of PA technologies in higher education offers the potential to equip agriculture graduates with the needed skills that will make them employable in a rapidly expanding agricultural industry. Although PA education and training as crucial to optimize PA’s contribution to agricultural development, most universities in Africa will find it hard to stay ahead of the rapid advances in technology associated with PA adoption. Therefore, it is critical to assess and prioritise the PA-training needs of students studying in agricultural universities in Ghana. In accordance with Mondal and Basu (2009), we suggest that significant attention should be given information technologies, such as global information systems (GIS), global positioning systems (GPS), remote and proximal sensing, robotics, and variable rate technology (VRT), that are needed detect and manage spatial and temporal variability. In terms of skills and technical knowledge required for PA education in Ghana, Presently, the wide array of precision agriculture technologies (PAT) including GNSS technology, Geographic Information Systems, yield monitors, soil sampling tools, remote sensing tools, farm management applications, and variable rate application technologies are available (Paustian & Theuvsen, 2017; Robertson et al., 2012)

PA Education is a potentially effective approach to teaching agricultural skills and providing capacity-building trainings for agriculture graduates, but it should be done in ways that will always transmit the necessary skills, and result in good employment outcomes. There is often a mismatch between the kind of training offered and the requirements of the labour market in an evolving agricultural sector (Kalufya and Mwakajinga, 2016)., Thus, there is an urgent need to strengthen existing universities to establish linkages with the key players in SSA’s agricultural industry. Linking universities with industry is critical to identify knowledge and skills that meet the needs of industry, facilitate participatory research, and enhance results dissemination to solve local problems. It is equally important to connect universities with labour market opportunities and to strengthen partnerships with employers to ensure that the PA skills that will be developed in graduates respond to labour market needs so that they become employable.

CONCLUSION

Although, efforts to transition traditional agriculture training to PA education in Ghana' will not come easily, responses offered during the FGD and interviews offer a glimmer of hope that there are workable solutions to overcome the challenges faced by young women and men trying to engage in agriculture as a source of sustainable livelihood. The study concludes that a PA education that builds the technical knowhow and skills of SSA youth, while enabling access to financial services, and niche markets and opportunities to actively participate in policy dialogue and developmental agenda setting is likely to increase youth's involvement in the agricultural sector, resulting in increased productivity and profitability. Thus, PA education should be integrated existing undergraduate and postgraduate agricultural programme, focusing on skill training in data science, geographic information systems (GIS), remote sensing, and artificial intelligence. Finally, governmental policies in SSA should emphasize training and re-training of faculty, support staff, as well as provision of ICT and internet infrastructure and funds for successful implementation of PA education in agricultural universities across SSA.

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ON-FARM EXPERIMENTATION

LIME AND PHOSPHORUS EFFECTS ON SOIL ACIDITY AND MALT BARLEY PHOSPHORUS USE EFFICIENCY IN WELMERA DISTRICT, CENTRAL HIGHLANDS OF ETHIOPIA
#9389

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ABSTRACT

In Ethiopia, about 43% of total arable land affected by soil acidity. Furthermore, phosphorus (P) deficiency is a major constraint to increase crop yields. Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase P availability in soils. Therefore, appropriate rate of lime and P fertilizer is an important strategy for improving crop growth in acidic soils. Accordingly, an experiment was undertaken to study lime and P effects on soil acidity and phosphorus use efficiency in 2018 in Welmera district, Oromia National Regional State in central highlands of Ethiopia. Acidic fields that have not been previously reclaimed with lime since last five years were selected, soil sampled and analyzed. Six rate of lime (0, 1.56, 2.34, 3.12, 3.9 and 4.68 t ha^{-1}) and three rates of P (0, 16.5 and 33 kg ha^{-1}) arranged in factorial randomized block design in three replications. The soil pH increased, and exchangeable acidity reduced after amending the soil with lime. Lime and P fertilizer applied have greatly contributed for the soil chemical acidity Improvement and better improvement of phosphorus use efficiency; it is recommended that, application of 2.34 t lime ha^{-1} with 16.5 kg P ha^{-1} fertilizer is good combination in Welmera District.

Keywords: Acid soil, soil pH, yield, exchangeable acidity.

INTRODUCTION

Soil acidity is contributing to crop yield reduction in the country in general, and that of barley production that is expanding in scope and magnitude. About 43% the total arable land affected by soil acidity across different regions of Ethiopia (Behailu, 2015). Acidity related soil fertility problems are major production constraints reducing the productivity of the major crops grown in the country (IFPRI, 2010). Low soil pH severely affects nutrient solubility and particularly enhances phosphorus sorption and precipitation with Al and Fe (Takow *et al.,* 1991 and Hue, 1992). Soil P deficiency is another major constraint to increase yields of barley and wheat in tropical and subtropical regions (Stangel and von Uexhull, 1990). To maintain production levels, P must be added to the soil plant system as mineral fertilizer to replenish what is removed with harvested crop parts (Vlek *et al.*, 1997). However, under acidic conditions applied phosphorus reacts with Fe and Al oxides/hydroxides to form insoluble phosphates, which can’t be accessed by plants (Kamprath, 1984).

Liming of acid soils can increase soil pH, P availability and alleviate Al toxicity to plants and thus maintain a suitable environment for growth of a variety of crops (Lollato *et al.*, 2013; Geremew *et al.*, 2015; Mamedov *et al.*, 2016; Getachew *et al.,* 2017; Geremew *et al.*, 2020c). Efforts to ameliorate the deleterious effects of soil acidity must therefore be accompanied by measures to increase available P in soils. Appropriate rate of lime and P fertilizer are therefore an important strategy for improving malty barley productivity on acid soils. Furthermore, there is scarce research information available on the effect of lime and P fertilizer on malt barley P use efficiency. Therefore, the objective was to study lime and P effects on soil acidity and PUE at Welmera District, Central Highland of Ethiopia.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted in 2018 production year in Oromia National Regional State in Welmera District of Holeta Agricultural Research Center (HARC), Robgebeya (RG) and Watabacha Minjaro (WM), found 40, 52 and 25 km, respectively, Northwest of Addis Ababa on the main road to Ambo.

Soil Sampling and analysis

Fields that have not been previously reclaimed with lime since last five years were selected. Soil samples were collected at depth of 0-15 cm at randomly marked sampling points and composited to (0.5 kg), similarly, were collected on plot bases at harvesting and air-dried, ground, and sieved. The soil was analysed following standard procedures for; pH (Van Reeuwijk, 1992), organic carbon Walkley and Black (1934), the total nitrogen (TN) Kjeldahl method (Bremner and Mulvaney, 1982). Available P using the standard Bray-II (Bray and Kurtz, 1945), Exchangeable bases (Ca, Mg and K) and CEC (Okalebo *et al.*, 2002). Exchangeable acidity (Ac) and exchangeable Aluminum (exAl) Rowell (1994) method.

Experimental design, treatments, and experiment setup

The treatments comprise six rates of lime (0, 1.56, 2.34, 3.12, 3.9 and 4.68 t ha^{-1}), the lime rates set were based on Geremew *et al.* (2020 a). Three rates of P (0, 16.5 and 33 kg ha^{-1}) combined in factorial RCBD with three replications. The lime source used was $CaCO_3$; with the purity 95.5% relative neutralizing value 85.6. The plot size was 2 by 2.5 m^2 having 10 rows with 20 cm between rows. The lime was applied 30 days before sowing by broadcasting uniformly on the plots; P was applied by banding at planting and malt barley variety IBON143/3, developed at HARC from ICARDA germplasm and released in 2012 used.

Plant sampling and analysis

Data collection on yield was undertaken as method set by Anderson *et al.* (2002). The sampled malt barley grain and straw were chopped, ground, and then dried until constant weight was attained to determine P contents of the total biomass. For phosphorus analysis, dried and grounded parts of the plants were digested at a temperature of 480^0 C. Finally, phosphorus use efficiency (PUE) was determined as described by Fageria *et al.* (1997).

Data analysis

Collected data were subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS, 2003). The difference among significant treatment means were tested using least significant difference (LSD) at 5% level of significance. Before combined analyses test of homogeneity of error variance and normality was checked.

RESULTS AND DISCUSSIONS

The pre plant analysis result indicated that soil reaction was strongly acidic at HARC (4.95) and RG (4.66) and very strongly acidic at WM (4.49) as per soil acidity rate set by Tekalign *et al.* (1991). The concentration of exAl was at toxic level to plants mean value 1.66

cmol(+)kg^{-1} soil. The soil OC was very low, 1.69% and TN was moderate, 0.19% (Tekalign *et al.*, 1991), while AP was low, 7.49 mg kg^{-1} as rated by Jones (2003). Soil CEC at all sites was moderate, 19.4 cmol(+)kg^{-1}soil according to Hazelton and Murphy (2007).

Exchangeable Ca was moderate at all sites mean value 5.03 cmol(+)kg^{-1} soil, while Mg was moderate at HARC (2.27 cmol(+)kg^{-1}) and RG (1.91 cmol(+)kg^{-1} soil) and low at WM (0.91 cmol(+)kg^{-1} soil). Exchangeable K content was high with mean value of (1.32 cmol(+)kg^{-1} soil) according to rating by FAO (2006). Generally, the analysis result indicates that OC and available P contents of soils of all the experimental sites were low and the soil reaction acidic.

Selected soil chemical properties after harvesting

The results of soil analysis after crop harvest are depicted in Fig. 1 and 2. The exchangeable acidity (Ac) and exAl after harvesting. The pH of the soil and AP of the soil increased with application of lime at all sites. Contrary to this the soil Ac and Al decreased with increased application of lime. The lowest Ac and exAl were recorded for plots treated with lime at the rate of 4.68 t ha^{-1} at all sites after harvesting. The exchangeable Al recorded was comparable with lime applied at the rates of 3.12 and 3.9 at RG. Increased application of lime and P fertilizer contributed for increased AP in all the study area, but application of P fertilizer at the rates of 33 kg ha^{-1} resulted in the highest AP after harvesting at HARC, RG and WM but was comparable to 16.5 kg ha^{-1} P applied. (Fig. 2).

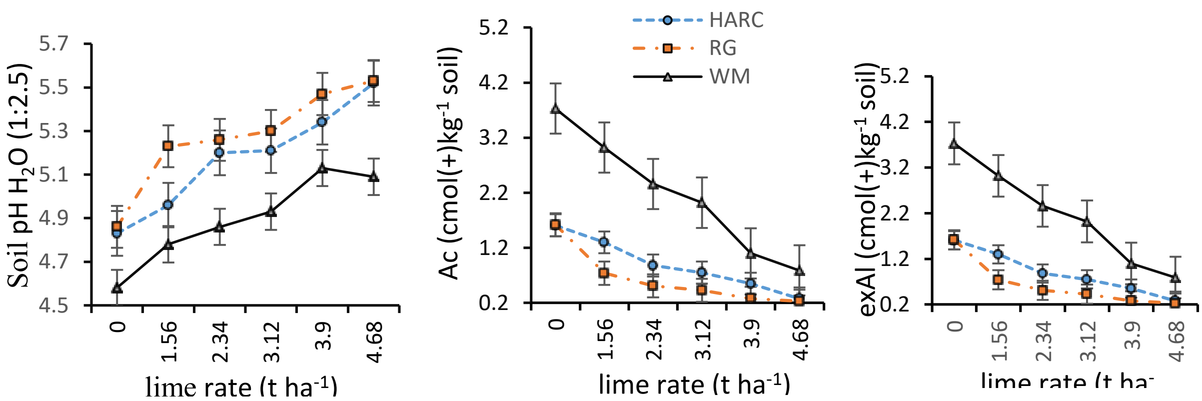

Fig. 1. Soil reaction and exchangeable acidity as affected by application of lime exchangeable Al.

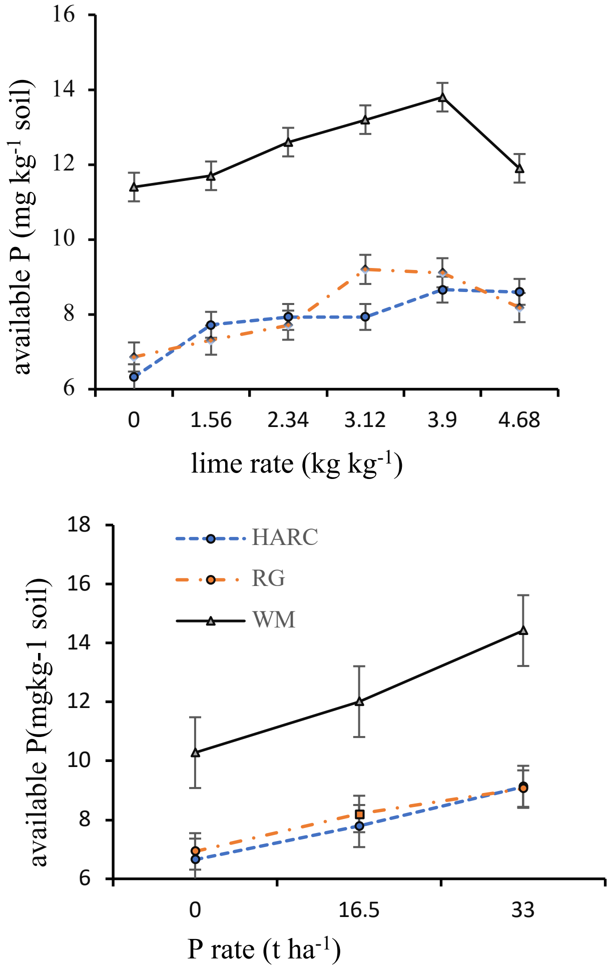

Fig. 2. Soil available phosphorus as affected by application of lime. HARC-Holeta Agricultural Research Center, RG-Robgebeya, WM-Watabacha Minjaro, Ac-Exchangeable Acidity, exAl- Exchangeable aluminum.

Soil reaction increased with increased application of lime whereas the exchangeable acidity and aluminum deceased. This indicates that applied lime has neutralized the acidity and increased pH, lowered the Ac and exAl. Getachew *et al.* (2017) found that amelioration of soil acidity with lime amendment which facilitates detoxification of Al and Mn activity. Detoxification of Al can be achieved by increasing soil pH which in turn certainly results in decrease of Al solubility thereby minimizes its toxic effect on plants (Geremew et al., 2020b). Peter (2017) also reported that application of lime significantly reduced the Ac compared to plots that were not treated by lime.

Phosphorus use efficiency

The phosphorus use efficiency increased with increased rate of lime up to 2.34/16.5 and 3.9/16.5 (t ha^{-1} by kg ha^{-1}) at HARC and RG, respectively. At WM, independent application of lime and P fertilizer affected phosphorus use efficiency of malt barley. Statistically superior PUE were recorded on plots treated with lime and P fertilizer at the rates of 2.34 t ha^{-1} and 16.5 kg ha^{-1}, respectively compared to the higher rates of P fertilizer (Table 1).

Table 1. Phosphorus use efficiency of malt barley as affected by the interaction of lime by phosphorus.

	Lime rate (t ha^{-1})												Lsd	Mean
	---0---		**---1.56---**		**---2.34---**		**---3.12---**		**---3.9---**		**---4.68---**			
	Phosphorus rate (kg ha^{-1})													
	16.5	33	16.5	33	16.5	33	16.5	33	16.5	33	16.5	33		
HARC	13.8^{cd}	23.4^{bc}	21.3^{bc}	22.1^{bc}	51.7^{a}	37.61^{ab}	37.6^{ab}	25.5^{bc}	36.0^{ab}	34.4^{abc}	52.3^{a}	33.6^{abc}	20.7	22
RG	7.5^{ef}	12.4^{def}	11.8^{def}	19.4^{cde}	29.6^{abc}	17.7^{cde}	38.5^{ab}	11.16^{def}	43.3^{a}	12.9^{def}	42.1^{a}	26.0^{bcd}	15.3	15

Means with the same letter in the same row are not significantly ($p \leq 0.05$) different from each other. HARC-Holeta Agricultural Research Center, RG-Robgebeya, Lsd-List significant difference.

The P use efficiency (PUE) of malt barley per unit of P application was decreasing but increasing with increased application of lime (Table 1). Lower PUE was recorded at higher P rates under all lime rates applied at all sites. Similarly, Rahim *et al.* (2010); Shabnam and Iqbal (2016) noted that elevated P application has significantly reduced the phosphorus use efficiency of crops; which is attributed to reductions in P utilization efficiency of the plant as reported by Sandana and Pinochet (2014). Furthermore, Bolland (1992) indicated that when plants are exposed to stress, P uptake is reduced, and phosphorus use efficiency increased.

CONCLUSIONS

Application of lime improved soil acidity status of the soil. The pH of the soils increased, while Ac and exAl decreased with liming. Lime and P fertilizer applied have greatly contributed for improvement of soil acidity and phosphorus use efficiency of malt barley and recommended that, 2.34 t ha^{-1} lime by 16.5 kg ha^{-1} P fertilizer are good combination in Welmera District.

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FINE-TUNING SPECIALTY FERTILIZATION STRATEGIES TO LOCAL WHEAT PRODUCTION THROUGH ON-FARM EXPERIMENTATION IN NIGERIA #9536

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ABSTRACT

Wheat specialty fertilizer validation trial was conducted in 8 Local Government Areas (LGAs) of Kano State, Nigeria on farmers field. The specialty fertilizer validation project is implemented to improve the productivity and profitability of small-scale wheat smallholder farmers. Four treatments - absolute control (AC), local control (LC), OCP1 and OCP2 were replicated four times in a RCBD on a plot of 25m^2. The AC was based on the indigenous nutrient supply from the soil (no application of fertilizer); the LC was the generic recommendation of (120:40:40 kg/ha using NPK 15:15:15); OCP 1 was a specialized formulation for wheat with N, P, K, Ca, Mg and S; and OCP 2 was another specialized formulation with micronutrients (B, Zn and Mo) formulated from soil mapping projects from 300 farmer's fields. The test crop was Norman Borlaug breeder's seed. In each LGA, apart from the farmers visual observation of yield during the brown field day, a 1m-by-1m quadrant was used to harvest and estimate yield, while a portion of the grain and stover were collected for nutrient uptake analysis. The highest grain yield (3787 kg/ha) was observed with the OCP2 fertilizer formulation treatment; a similar trend was observed when the data was pooled across LGAs. The result of total above ground biomass (kg/ha) showed that OCP1 and OCP2 gave the highest biomass of 10,026 and 10,092 respectively, while the least biomass was observed with the absolute control plot. Application of N, P, K with other macro and micronutrients has good profit potential in Nigeria since a reduced amount of the N (100 kg) less than the generic recommendation (120 kg N) gives higher yield due to the introduction of other nutrients (Mg, S, Zn, B and Mo). Additional information is needed to determine which deficiencies of Mg, S, Zn, B and Mo are most important. Wheat grain yield responses to applied nutrients tended to be greater in soils with medium to high clay content. Apart from soil nutrient deficiency, the synergistic effect of some macro and micronutrients with N, P and K will greatly influence yield of wheat.

Keywords: Wheat, specialty fertilizer, on-farm experimentation, yield, OCP

INTRODUCTION

Wheat (Triticum aestivum L.) is an important rainfed crop of Nigeria and Sub-Saharan Africa with both large and small-scale production (Abubakar et al 2018, Nziguheba et al. 2016) but production is far less than the regional demand. Mean yields are low, often with inadequate nutrient availability as a constraint (Tittonell and Giller 2013), but numerous other biotic, abiotic, and management constraints are also important. Wheat is a crop of major interest in Nigeria as it is the main component of bread and other wheat-based products such as cakes, biscuits, macaroni, spaghetti, pasta, etc. In Northern Nigeria, because of high temperature, the local climatic conditions have not been favorable for optimum growth and yield of wheat. Accordingly, the climatic potential for wheat production generally decreases equator-wards due to consistently high temperature and humidity (Oche, 1998). Thus, production is presently restricted to areas between latitudes 10-140N (covering the Sudan and Sahel savanna zones), during the cold harmattan period between the months of November and February, under irrigation (Abbas, 1988). According to Anonymous (2006) the increasing consumption and demand for wheat in Nigeria was largely due to increase and expansion in bread and pasta industries, and for the manufacture of crackers, noodles etc. Presently, domestic wheat demand in the country is far more than local production; consequently 90-95% of wheat consumed is imported from the United States of America. For example, the country imported 4.3 million tons of wheat in 2007 as against 3.8 million tons in 2006.

Increasing wheat production in Nigeria requires prior investigation of the crop's requirements. In places with relatively low technology as obtainable in developing countries, a naturally favorable environment is paramount for optimum production. Fertilizer is commonly used for wheat production, but rates of application are low and the recommendations are generalized and inadequately based on field research results. Fertilizer recommendations are not sufficiently profit oriented and do not consider farmers' financial ability for fertilizer use (Rware et al. 2016). Farmers who face severe financial constraints need high returns on their investment at low risk.

(CIMMYT 1988, Miko et al 2006) and often find better opportunities to use their limited monetary resources than for fertilizer application to wheat at the recommended rates (Jansen et al. 2013). Farmers' fertilizer use decisions need to aim for maximization of net return to nutrient application (Wortmann and Kaizzi 2016). Much research has been done globally on wheat response to applied nutrients, but this has little relevance in the dry lands of Nigeria where numerous unmitigated constraints result in a median grain yield of less than 2 tons ha^{-1}

Fertilizer application can often be profitable for wheat production in northern Nigeria, but responses vary. Optimization of fertilizer use for profit maximization requires robust information of the nature of wheat response to different nutrients in different recommendation domains. The objectives of this research were to: quantify the yield response of wheat to N, P and K; test 2 new fertilizer formulations for wheat and to diagnose the importance of secondary and micronutrient on wheat productivity.

MATERIALS AND METHODS

Study area

The study areas are within the Sudan savanna agro ecological zone. The experiments were conducted on farmer's fields across 8 local government areas of Kano state, the communities are Bagwai, Bunkure, Garun Malam Dambatta, Garko, Kura, Takai Warawa and the research farm of Bayero University Kano (BUK). These fields represent the major wheat producing communities of Kano state.

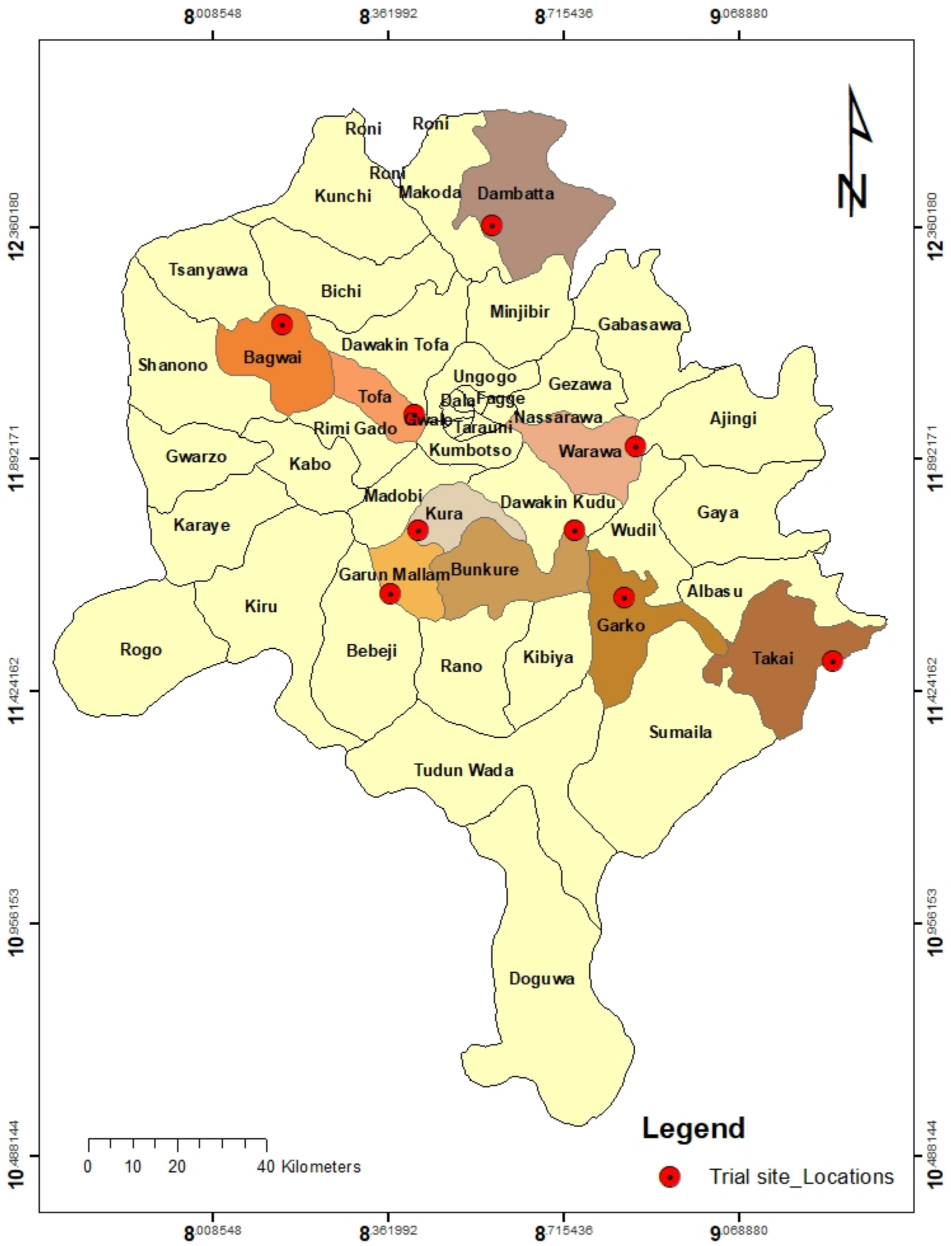

Fig 1. Map of Kano State showing the study area.

Agronomic practices

A basin of 5m x5m was prepared for the 4 treatments and replicated 4 times. The seeds are drilled within this basin for ease of irrigation. Wheat is sown in a row spacing of 22.5 cm and a planting depth of between 5 and 6 cm for good germination and density. The field trials were managed by the farmers at various LGAs based on the normal farmers' practices including irrigation.

Treatments and experimental design

The treatments were arranged in a Randomized complete Block Design (RCBD) replicated across communities. There were four treatments as follows:

i. Absolute Control (AC)- no fertilizer application

ii. Local Control (LC) – Generic recommendation of N, P and K
iii. OCP 1- Specialized OCP wheat formula 1 (N, P, K, Mg and S)
iv. OCP 2 - Specialized formula 2 (N, P, K, Mg, S, Zn, B and Mo

The AC was based on the indigenous nutrient supply from the soil (that is no application of fertilizer). The LC was based on the generic recommendation of (120:40:40 kg/ha using NPK 15:15:15), while the OCP 1 was based on the specialized formulation for wheat with magnesium (Mg) and sulphur (S) applies at the rate of 100 kg N 100 kg P_2O_5, 50 kg K_2O, 8 kg Mg, 5 kg S per hectare. OCP 2 was another specialized formulation for wheat with magnesium (Mg), sulphur (S) and micronutrients (B, Zn and Mo) applied at the rate of 100 kg N 100 kg P_2O_5, 50 kg K_2O, 8 kg Mg, 5 kg S, 3 kg Zn, 1 kg B and 1 kg Mo per hectare.

The wheat variety used was Norman Borlaug breeder's seed sourced from LCRI. Fertilizer was applied once during sowing for OCP 1 and OCP 2. Top dressing with urea was only done for the local control plot at 24 days after sowing. All agronomic data collection were done by the field officer. The wheat specialty fertilizer formulations were developed based on spatial soil analysis of the entire wheat belt of Kano state. Recommendations were generated based on wheat nutrient demand and amount of plant available nutrient in the soil.

Data analysis

Data Generated were subjected to Analysis of variance to see the effect of fertilizer treatment and communities alongside their interactions. Means were separated using Tukey HSD on GenStat version 17 software. The software JMP was used to create bar charts.

RESULTS AND DISCUSSION

It was observed that the soils in Dambatta, Bagwai, Garun Mallam, Kura and Warawa trial sites are having high sand content of more than 50 % and low clay content of less than 16 % (Table 1). The particle size distribution of soils in BUK, Bunkure, Garko and Takai are best for wheat production, this is because wheat does better in a medium clay soil as reported by Athanase et al (2018). It was observed that the mean pH in water value across the study sites were categorized as slighlty acidic (NSPFS, 2005). There was a very low variability in pH across the farms. This pH values are within the acceptable range for availability of most of the essential nutrients needed by majority of plants. The average total nitrogen across the study area were categorized as low (NSPFS 2005). The low nitrogen content of the soils was because of the sandy nature of the soil. The mean organic carbon across the farms was categorized as low (NSPFS 2005). The available phosphorus across the farms fell under the low fertility class according to NSPFS (2005). The exchangeable potassium across the farms is rated as medium according to Esu (1991). The exchangeable calcium, magnesium and sodium across the farm are shown on Table 1. Calcium and sodium were rated as low, while magnesium was also rated as low according to Esu (1991). The average effective cation exchange capacity of the farms was categorized as low (Esu, 1991). The low effective cation exchange capacity implied low nutrient holding capacity of the soil which necessitates proper nutrient management in terms of fertilizer application timing to coincide with active period of the wheat nutrient demand.

Grain yield of wheat varied significantly ($p<0.001$) across the different fertilizer treatments and across communities (Table 2). Among the fertilizer treatments, OCP1, OCP2 and local control (LC) produce significantly higher yields than the absolute control (AC). Although not statistically different, OCP2 gave higher grain yield than both OCP1 and LC. The difference in yield among the OCP fertilizer formulations may be because of addition of micronutrients (Zn, B and Mo), a similar observation was made by Athanase et al 2018 on wheat and Bello et al (2019) on maize. Among the farming communities, the highest grain yield (3984 kg/ha) was observed in Garko followed by Takai (3700), this high response may not be unconnected to the low sand and medium clay content of the two communities as shown on Table 1, a similar observation was made by Abubakar et al (2000). The effect of total above ground biomass as affected by fertilizer treatment is shown on Table 2, it will be observed that the highest total biomass OCP2 gave the highest total biomass (10,092 kg/ha) which is statistically at par with OCP1 and LC, a similar trend with grain yield. Among communities, Takai gave the highest above aground biomass (12,247 kh/ha) while the lowest was observed in Kura. For both grain yield and total biomass, there is a similar trend of yield increase with the introduction of a new macro or micronutrient from LC through OCP1 and OCP2. With the aforementioned trend, the probability of response to an added nutrient may be increasing in the region, likely to gradual limiting nutrient depletion and mitigation of other constraints to allow higher yields and greater responses to applied nutrients (Zingore 2011, Wortmann et al. 2017). The effect of fertilizer formulation on plant height at maturity and number of spikelet at maturity is shown on Table 3 with a similar trend like yield and biomass. Number of tillers per plant (Table 3), days to emergence (Fig. 4) and days to maturity were not statistically different among the fertilizer formulations, a similar observation was made by Miko et al 2006.

Table 1. Physical and Chemical properties of Soils across the study area.

Soil Parameter	BUK	Bagwai	Bunkure	Danbatta	Garko	Garun Malam	Kura	Takai	Warawa
Sand (%)	40.04	73.21	28.84	67.83	44.94	64.37	75.28	34.57	52.35
Silt (%)	36.39	15.26	26.99	16.94	17.56	23.85	15.52	34.26	37.99
Clay (%)	23.57	11.53	44.17	15.23	37.50	11.78	9.20	31.17	9.66
pH (1:1)	5.92	5.99	5.99	6.00	5.86	6.12	6.44	6.14	6.12
EC Us/cm	95.85	132.95	137.65	135.36	117.84	111.79	130.38	82.52	109.49
O.C (%)	0.59	0.65	0.55	0.59	0.76	0.58	0.58	0.64	0.59
N (%)	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06
P (mg/kg)	3.48	5.51	5.87	3.60	4.62	5.79	4.60	4.58	6.59
Ca (cmol/kg)	1.99	2.29	2.23	2.58	2.22	2.19	2.02	2.87	2.37
Mg (cmol/kg)	0.65	0.77	0.68	0.71	0.69	0.64	0.77	0.67	0.85
K (cmol/kg)	0.17	0.23	0.23	0.19	0.20	0.20	0.23	0.22	0.17
Na (cmol/kg)	0.08	0.08	0.10	0.09	0.09	0.09	0.08	0.10	0.09
EA (cmol/kg)	0.12	0.33	0.27	0.25	0.29	0.20	0.16	0.17	0.40
ECEC (cmol/kg)	3.00	3.70	3.44	3.80	3.40	3.27	3.19	4.02	3.85
Zn (mg/kg)	14.09	11.48	7.13	7.24	9.75	8.25	15.15	7.17	11.94
Cu (mg/kg)	2.01	2.05	2.27	2.60	2.35	2.21	2.56	2.11	1.82
Mn (mg/kg)	29.17	21.11	19.29	19.70	20.26	19.03	28.26	18.72	17.87
Fe (mg/kg)	176.05	170.90	193.81	167.71	180.66	230.42	187.39	218.87	195.28
S (mg/kg)	9.04	10.41	8.44	9.48	10.28	9.63	10.58	8.96	9.53
B (mg/kg)	0.63	0.67	0.76	0.59	0.70	0.71	0.72	0.70	0.58

Table 2. Effect of Fertilizer formulation and location on grain yield and total biomass of wheat in Kano.

Parameter	Grain Yield kg ha^{-1}	Total Biomass kg ha^{-1}
Fertilizer Formulation		
Absolute Control (AC)	1608b	4712b
Local Control (LC)	3442a	9430a
OCP 1	3462a	10026a
OCP 2	3787a	10092a
SED	175.1	552.6
F Prob.	<0.001	<0.001
Community		
Bagwai	2589c	6159c
BUK	3172bc	7834bc
Bunkure	3841ab	9949ab
Danbatta	3562ab	10228ab
Garko	3984a	10388ab
Garun Malam	2709c	8334bc
Kura	1103d	3347d
Takai	3700ab	12247a
Warawa	3012bc	8600bc
SED	262.7	828.9
F. Prob.	<0.001	<0.001
Interaction		
Fert Formulation x Community	NS	NS
SED	525.4	1657.8
F prob.	0.245	0.524

Table 3. Effect of fertilizer formulation and location on plant height, number of tillers and number of spikelet of wheat in Kano.

Parameter	Plant Height at Maturity cm	Number of Tillers m^{-2}	Number of Spikelet m^{-2}
Fertilizer Formulation			
Absolute Control (AC)	61.42b	377	315.1b
Local Control (LC)	83.58a	370	342.8ab
OCP 1	86.81a	487	367.6a
OCP 2	85.97a	389	364.9a
SED	1.661	71.6	18.56
F Prob.	<0.001	0.327	0.019
Community			
Bagwai	84.62ab	351	315.8bc
BUK	77.88b	381	354.2ab
Bunkure	85.56ab	425	391.4ab
Danbatta	84.94ab	439	405.1a
Garko	82.88ab	471	353.6ab
Garun Malam	69.12c	578	330.9ab
Kura	57.88c	310	241.1c
Takai	87.19a	371	341.4ab
Warawa	84.94ab	426	395.1ab
SED	2.492	107.4	27.85
F. Prob.	<0.001	0.427	<0.001
Interaction			
Fert Formulation x Community	NS	NS	NS
SED	4.984	214.7	55.69
F prob.	0.096	0.310	0.755

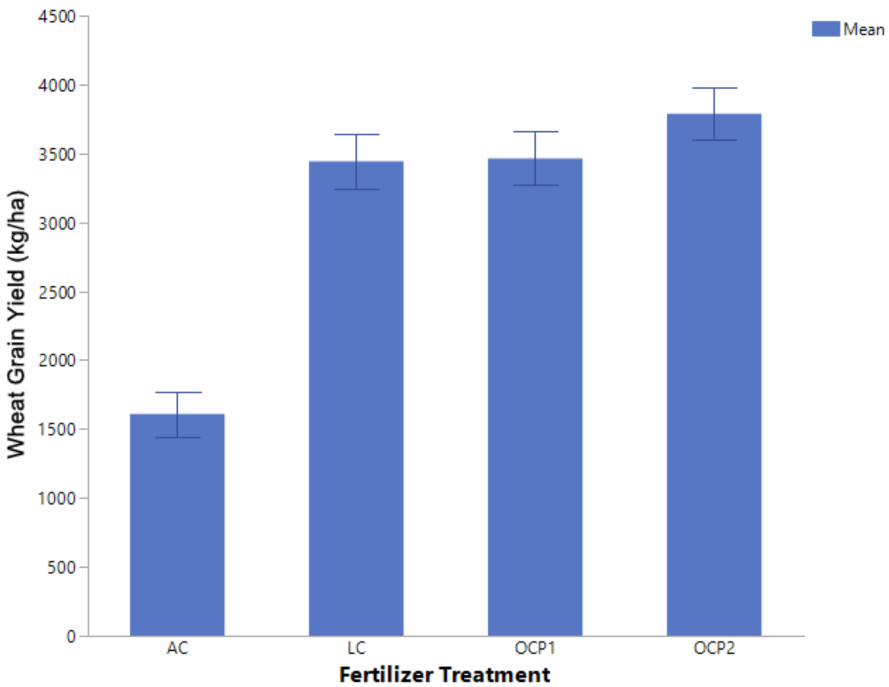

Fig. 2. Effect of Different Fertilizer Formulation on Wheat Grain Yield.

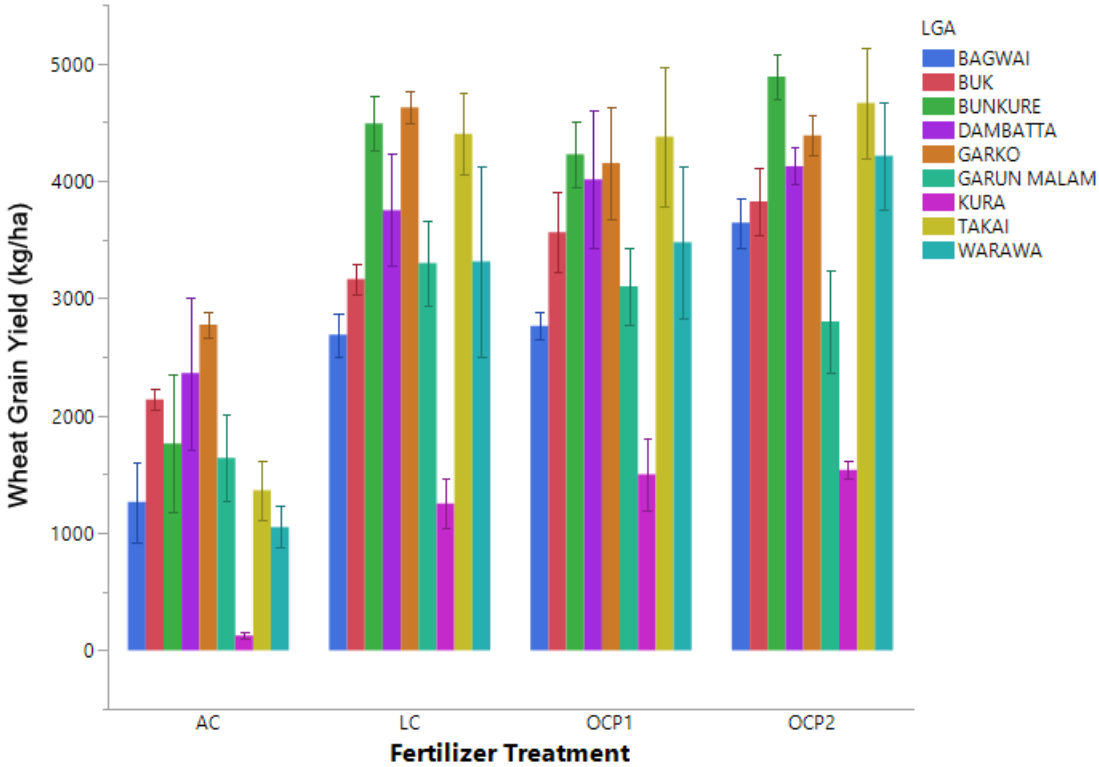

Fig. 3. Effect of Different Fertilizer Formulation on Wheat Grain Yield Across the different Local Government Areas.

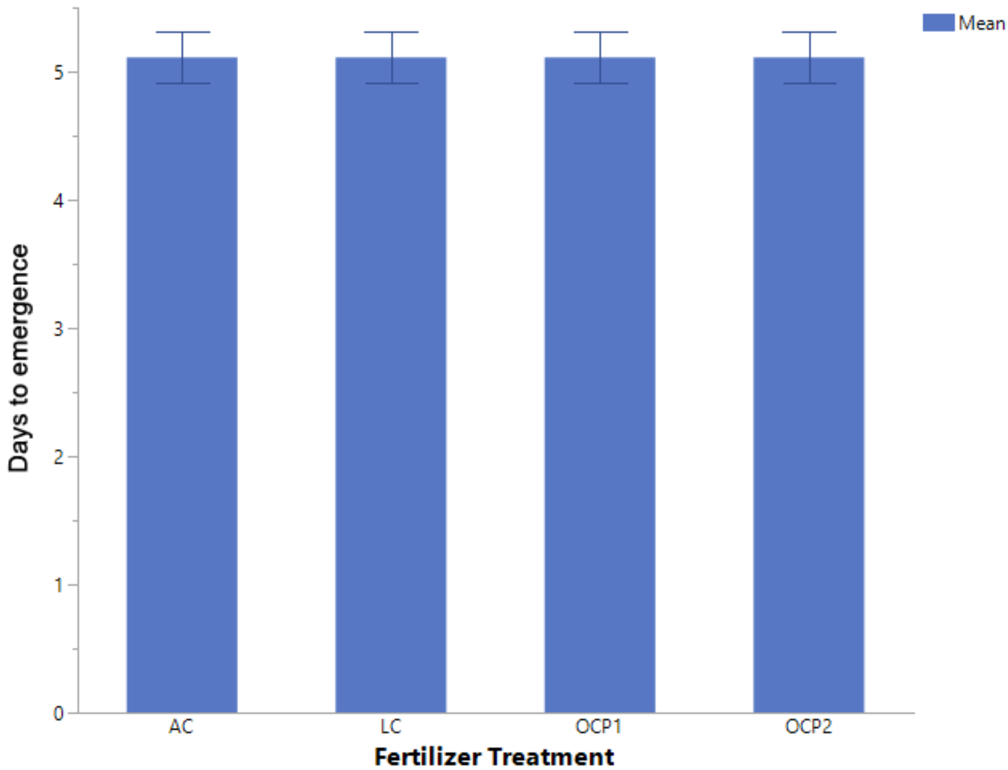

Fig. 4. Effect of Different Fertilizer Formulation on Number of Days to Emergence.

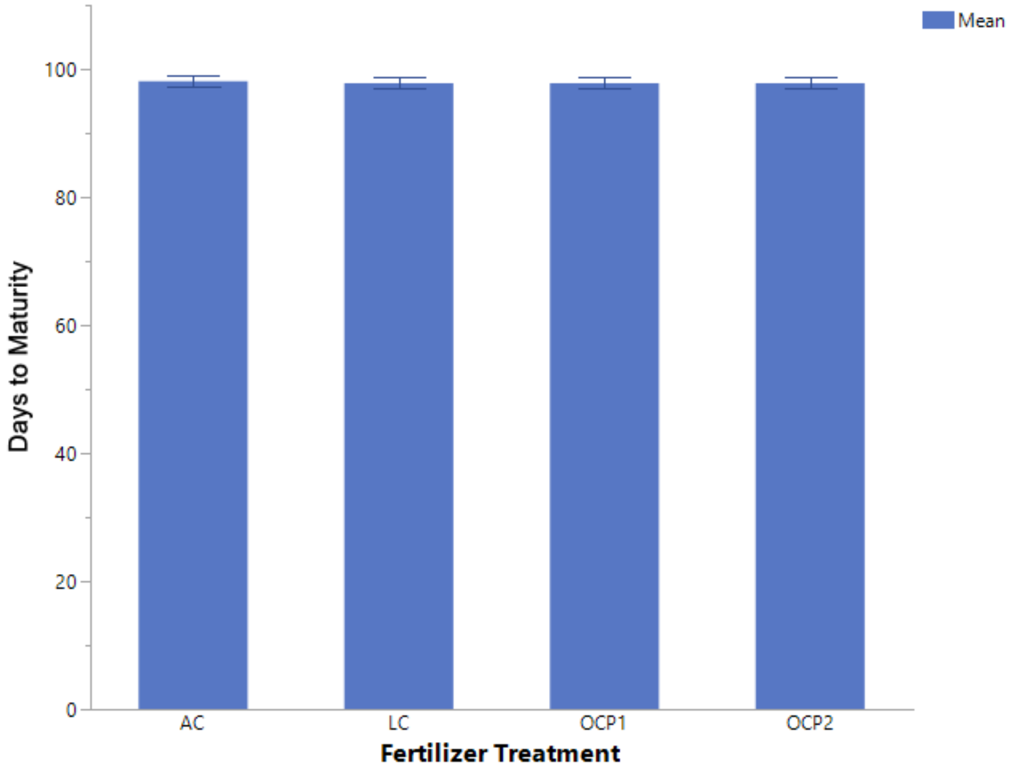

Fig. 5. Effect of Different Fertilizer Formulation on Number of days to maturity.

CONCLUSION AND RECOMMENDATIONS

The wheat grain yield due to indigenous nutrient supply (about 1600 kg/ha) is an indication of some amount of nutrients in soils of the Nigerian dry Savanna. However, balanced N, P K fertilizer application is likely to be highly profitable for wheat production in the Savanna soils of Nigeria if the crop yield is not much constrained by factors other than nutrient deficiency. If typical yields are about 1600 kg with no fertilizer applied and the yield doubles with addition of N, P and K alone (Fig. 2), a further addition of Mg and S and with another addition of micronutrients (Zn, B and Mo), the probability of profitable yield response to a more balance application of this nutrients is high. Application of N, P, K with other macro and micronutrients has good profit potential in Nigeria since a reduced amount of the N (100kg) less than the generic recommendation (120kg N) gives higher yield due to the introduction of other nutrients (Mg, S, Zn, B and Mo).

Additional information is needed to determine which deficiencies of Mg, S, Zn, B and Mo are most important. Wheat grain yield responses to applied nutrients tended to be greater in soils with medium to high clay content. Apart from soil nutrient deficiency, the synergistic effect of some macro and micronutrients with N, P and K will greatly influence yield of wheat.

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POST-HARVEST DIALOGUES ENGAGE FARMERS PARTICIPATING WITHIN THE ON-FARM EXPERIMENTATION PROCESS
#9687

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ABSTRACT

Initiated in 2021, APNI's on-farm experimentation project called NUTCAT, or the NUTtrient CATalyzed Agricultural Transformation project is uniquely poised to implement a change process anchored on scalable behavioral change that is supported by agronomic insights and validated by data. The experimental design adopted divided smallholder fields into an Optimized treatment (OT) initially defined by local cropping system experts and a Farmer practice (FP) treatment. A total of 268 sites were established in seven African countries. By design, a continuous cycle of open engagement with farmers is key component of this farmer-centric research due to its ability to generate a variety of co-leaning opportunities while encouraging participation amongst farmers and other stakeholders. The post-harvest dialogue settings adopted within NUTCAT prove to be an effective mechanism to ensure the viewpoint of participating farmers is fully considered as nutrient management strategies evolve and become co-generated amongst stakeholders to be locally appropriate.

INTRODUCTION

The NUTCAT project is APNI's flagship project for co-design, co-development, and delivery of relevant precision nutrient management (PNM) innovations for cereal-based cropping systems in Africa. The project's objectives include: 1) improvement of cereal system production using precision nutrient management (PNM), 2) evaluation of grain yield potential and spatial variation in smallholder agriculture using remote sensing, and 3) promotion of farmer-centric innovation and co-learning through **On-Farm Experimentation (OFE)**.

The OFE process for the NUTCAT project follows several steps or activities (**Fig. 1**). It starts with engagement, whereby cooperating farmers and experimental sites are identified. Acquisition of agronomic (yield, biomass), spectral (Sentinel 2 data) and socio-economic data are all important parts of this step.

To acquire agronomic data the project uses a simple experimental design wherein smallholder farm-scale plots (2 ha or less) are divided into an Optimized treatment (OT) and a Farmer practice (FP) treatment. The OT is defined by a team of local cropping system experts [i.e., the Cereal Improvement Team (CIT)], as the combination of practices and inputs required to produce an attainable yield target specific to the agro-ecological zone (AEZ) within the country. The FP treatment mirrors the practices and inputs the farmer was planning to apply that season. To date, about 268 trial sites have been established in seven countries across Africa (**Fig. 2**).

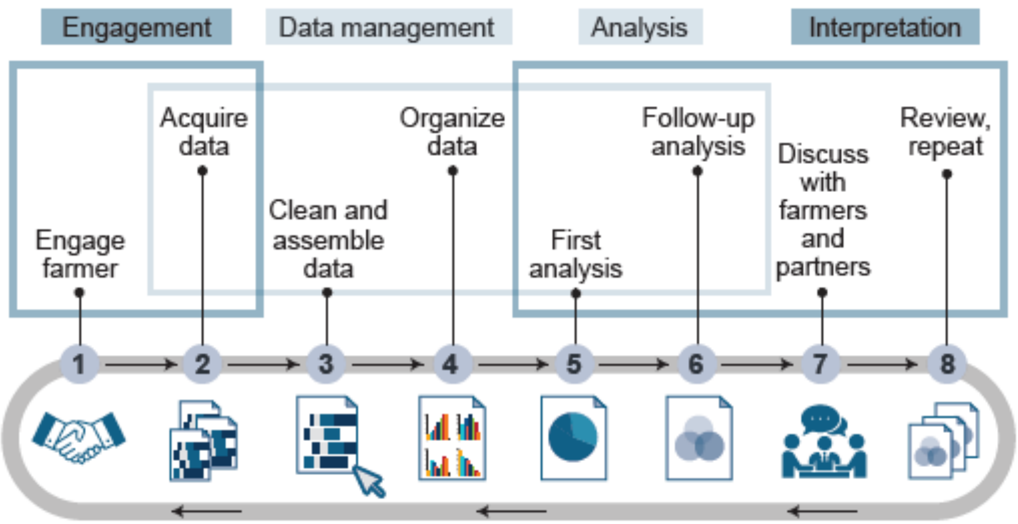


Fig. 1. The OFE process for NUTCAT (adapted from Lacoste et al., 2021).

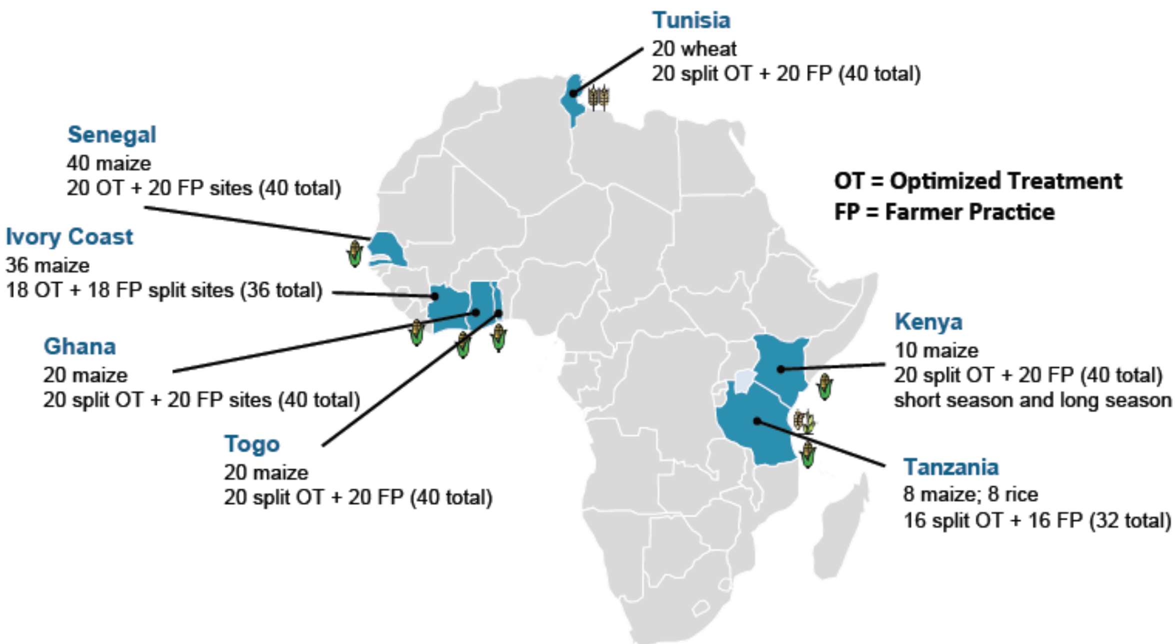


Fig. 2. NUTCAT field site locations (268) during the 2021/2022 experimental season.

Co-learning via post-harvest dialogue

Open engagement with farmers is, by design, a key plank of the OFE platform. It seeks a co-learning environment that encourages farmer participation in landscape-scale research while providing a means to better understand the learning, decision-making and management change processes of farmers themselves. Such engagement is the goal of the **post-harvest dialogue (PHD) workshop**, which after the steps of data collection and analysis, provides a setting to share inferences made from the results achieved. The open discussion sheds light on what worked best in farmers' fields. Supporting technical and scientific advice is also sought from other project stakeholders including regional extension staff, agronomists, and APNI scientists. NUTCAT trial sites in northern Côte d'Ivoire and Kenya provide examples from contrasting biophysical, cropping, and socio-cultural patterns. For instance, northern Côte d'Ivoire has a uni-modal rainfall pattern (one cropping season) representative of the cereal-root crop mixed farming system of West and Central

Africa. Kenya's bimodal pattern (two cropping seasons per year) is typical of the maize mixed farming systems found in East, Central and Southern Africa. However, maize is the main cereal crop for both regions, and it is grown in association with legumes, root crops and cotton in intercrop, rotation, or relay sequences.

PHD workshops for these regions gathered participating farmers as well as neighboring farmers who gained interest in the activities they observed throughout the season. Focus group discussions and in-depth interview approaches were supported by evidence drawn from agronomic and remote sensing data. Farmer engagement with extension specialists, agronomists and other agricultural stakeholders provided an opportunity to share observations and lessons learned, initiate plans for next season's plantings, and fine-tune the optimized treatment (OT) packages.

Innovation awareness and learning

The workshops uncovered a good level of awareness amongst NUTCAT farmers about cropping systems innovations such as planting in rows, recommended spacing, weed control, pest control, and fertilizer use according to the 4R Nutrient Stewardship framework.

Each workshop made it apparent that much peer-to-peer (social) learning is already taking place within the study areas. Non-NUTCAT farmers learned about good agronomic practices (GAP) from NUTCAT farmers and attained better yields after applying the acquired knowledge. There is also clear evidence of didactic learning through NUTCAT and other projects where APNI has been an original source of GAP and 4R Nutrient Stewardship practices. Tracking how these two types of learning (social vs. didactic) are evolving is important. The PHDs provided a participatory platform to explore the role of data (digital and spatial) in accelerating such learning and making it scalable.

Management change

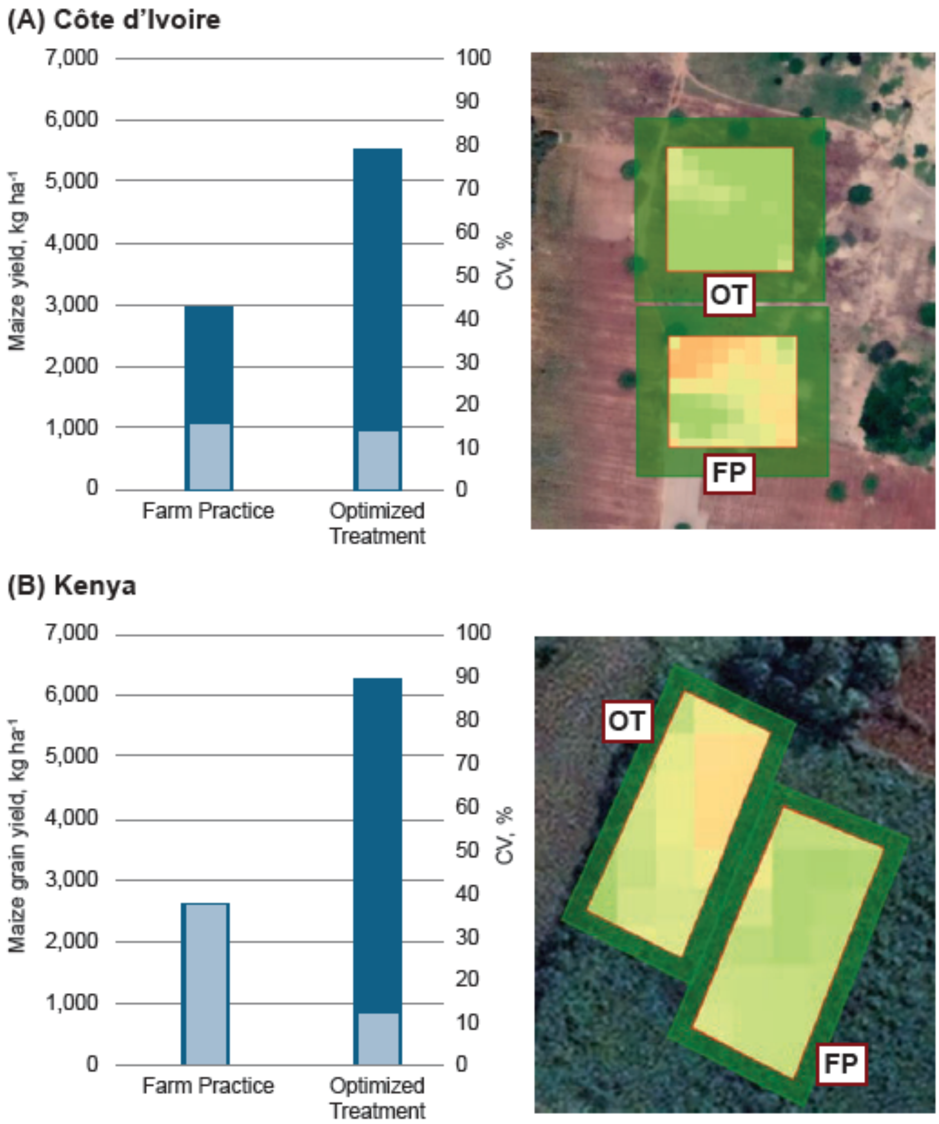
Dialogues helped unravel the different perspectives farmers have about variability within their fields (FP) and between fields (OT vs FP). They were also critical in deciphering some of the confounding issues arising from the data analysis including:

Why in some cases were yields so similar for the FP and OT?

As an example, Mr. Ouattara Adama, a farmer in Côte d'Ivoire, harvested three-fold the amount he usually gets on larger farm sizes from his 1 ha FP field after applying the full technological package he had observed in the adjacent OT field. This points to a move towards gradual agricultural intensification, which apart from being an effective risk-reduction strategy is highly relevant in the context of rising input costs (Bonilla-Cedrez et al. 2021; Hassen and El Bilali 2022).

Why did OT yields fail to meet the set targets?

Two cases were apparent in eastern Kenya where OT and FP yields were similar, most probably due to the combined use of inorganic and organic fertilizer in the FPs. Under the conditions of an erratic rainfall regime during the short-rain season of 2021/2022, poor grain yield performance was avoided through the synergistic effects of combining mineral fertilizers and organic manures rather than reliance on mineral fertilizers alone (Mucheru-Muna et al. 2014; Mugwe et al. 2009). Given that the yield target of 7.5 t ha^{-1} was not met for the Kenyan OT treatments this was an important insight for the Kenyan CIT, which now proposes the additional application of manure at 5 t ha^{-1} in all OT plots.



Agronomic and remotely sensed results from one site in Côte d'Ivoire (A) and Kenya (B).

Why was there very little divergence between FP and OT spectral data for the entire season?

Strong spectral signatures (NDVI, NIR, SWIR) were observed from both OT and FP fields, but there was little correlation between these signatures and yield. The confoundingly strong NDVI signatures of FP plots could have been due to weed pressure as the signatures do not distinguish between different plant species. Based on remotely-sensed imageries and their own observation, farmers recognized within-field variability of their fields, which according to them is driven by several factors. In Kenya, intercropping or mixed cropping, weed infestation (Striga), shading effects of trees, and type of germplasm used were mentioned as drivers of variability. For both countries, management aspects (e.g., manure application, herbicide use) and edaphic factors were critical.

All NUTCAT farmers expressed an intention to change their current practices in the coming season. This shift in attitude was based on the learning received from different channels and better yield performance of the OT. Most aim to adopt key elements of the 4Rs such as improved fertilizer placement and split application. Increased emphasis on recommended plant spacings, herbicide use, armyworm control, use of hybrid maize seed was noted. In Kenya, some farmers will employ practices that were not previously part of the OT package such as manure or compost application.

The next steps

Going forward, a critical step involves monitoring of how farmers implement change within their fields. In addition, a pattern of both peer-to-peer and didactic learning is emerging, which suggests the potential for enhanced social learning among farmers or farmer associations through the agency of the CIT. Therefore, the project has developed a management change and learning tracking tool, which is modelled on the Social Behavior Approach (SBA) adopted by the Catholic Relief Services (CRS, 2021). This tool is further fine-tuned using a Competency Model Approach to help us unravel learning through a skills competence assessment (CRS, 2021). Hence, the tool instils skills competency within a continuous learning and innovation cycle. This tool will be deployed to farmers at three to four key stages in the next cropping season. Similarly, a scouting protocol is in place to monitor weed and pest pressure, crop establishment, and other observations as a complement to existing data to help in explaining confounding issues.

The next steps in the OFE process entail the tracking and documentation of farmer learning and experimentation as they engage in the change process. This will be a basis for further interactions with relevant partners to capitalize the OFE process through identification of value, development of scalable business models that show how partners can invest, measuring outcomes (expected and unanticipated) and the sustained building of the process.

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PRECISION AGRICULTURE FOR SMALLHOLDERS

4RS AS AN ENTRY POINT FOR PRECISION AGRICULTURE IN SMALLHOLDER FARMING SYSTEMS OF AFRICA
#9618

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ABSTRACT

The implementation of precision agriculture (PA) in Africa at scale may be thought to be more of challenge compared to other areas of the world due to the complexity of its smallholder landscape. However, experiences gained from practical application of the principles of 4R Nutrient Stewardship provide one roadmap to establishing transferable, field-scale nutrient management interventions well aligned with PA's goal of optimal crop productivity and profitability across a variable landscape.

Keywords: 4R Nutrient Stewardship, Nutrient Management

A major aim of precision agriculture (PA) is to observe, measure and respond to between and within field variability in crop growth and yield. Through this, PA seeks to ensure optimal distribution of inputs such as fertilizers based on the documented variability, resulting in increased input efficiency, and reduced variability in crop growth and yield. Crop production in Africa is primarily carried out in smallholder farming systems that are often characterized by low and highly variable yields at various spatial and temporal scales. At lower spatial scales, strong variability in yields at low and optimum nutrient application rates has been documented both between and within farms (Kihara et al., 2016; Vanlauwe et al., 2006), presenting a scope for the use of PA to manage variability and enhance crop productivity in smallholder farming systems of Africa. However, while PA has found success in farming systems generally characterized by large land holdings, monocropping, and highly mechanized systems, smallholder farming systems in Africa are frequently characterized by highly fragmented small land holdings with diverse cropping systems and minimal mechanization. Such conditions pose a challenge to the implementation of PA in Africa based on the tools and techniques that have largely underpinned the success of PA in farming systems such as those of North America, where the use of sensors mounted on farm machinery such as tractors, or on unmanned aerial vehicles (UAVs) is a common practice in observing, measuring, and responding to farm level variability.

In the absence of tools and techniques primarily used to assess, quantify, and account for variability in crop yields in PA, locally relevant proxies that have been shown to sufficiently capture the observed variability within and between fields can be used as a means of accounting for variability in yields in smallholder farming systems of Africa. For instance, at local scales, variability between and within farms is mainly driven by management (Njoroge et al., 2019; Vanlauwe et al., 2006). For example, higher fertility fields that respond strongly to fertilizer applications have associated with prior regular applications of organic resources (Njoroge et al., 2019; Vanlauwe et al., 2006; Zingore et al., 2007).

4R Nutrient Stewardship (Fig. 1) is an approach developed to communicate the right ways to manage applied nutrients based on four principles namely: applying the Right Source of nutrients, at the Right Rate, at the Right Time in the growing season, and in the Right Place. 4R Nutrient Stewardship therefore provides a basis for effective use of nutrients which is important for developing sustainable cropping systems that support improved food production, increased incomes for farmers, and enhancement and maintenance of soil fertility.

The application of 4R principles offers an opportunity for the adoption of locally practical applications that can help mainstream specific objectives of PA (Table 1), once locally relevant proxies have been used to identify and quantify variability at local scales. For example, by providing for the adjustment of local recommendations on fertilizer application rates based on observed variability between or within fields using locally relevant proxies, the 4R principle on Right Rate supports the variable rate recommendation in PA, and ensures the optimal distribution of inputs based on documented variability as envisioned by PA. Similarly, through practical applications that aim at ensuring nutrients are applied at the Right Time in line with crop nutrient uptake requirements, and those that aim at ensuring nutrients are applied where plants can easily access them based on differences in root architecture as provided for by the principle on Right Place, 4Rs related applications ensure the optimization of available nutrient sources in line with the goals of PA.

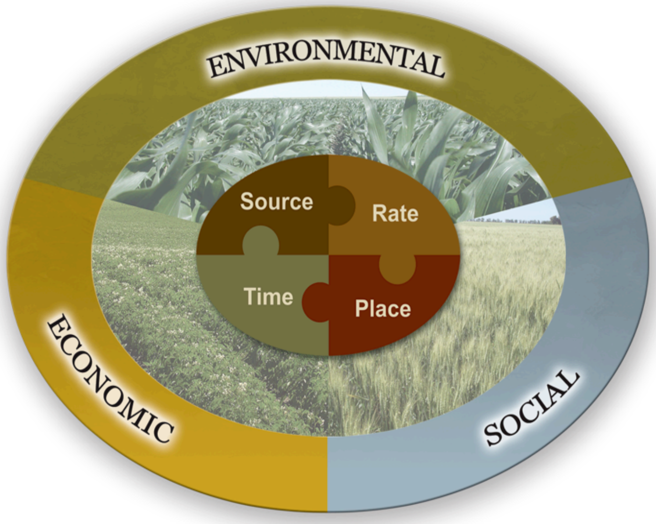

Fig. 1. The 4R Nutrient Stewardship concept.

The ability to implement 4R principles using simple locally available tools such as bottle tops and planting strings that support precise and uniform nutrient applications and guide precise planting respectively, presents an opportunity to override challenges such as limited mechanization and small fragmented farm holdings that limit the implementation of PA in smallholder farming systems of Africa. In addition, implementation of 4Rs alongside improved agronomic practices also helps to deliver multiple sustainability outcomes such as: increased crop productivity, improved profitability for farmers, enhanced nutrient use efficiency, reduced losses to the environment, and improvements in soil health. These outcomes are well in line with the outcomes that result from the implementation of PA, further demonstrating the scope for applying 4Rs as an effective entry point for PA in smallholder farming systems of Africa.

Table 1. Practical applications based on 4Rs that align with key objectives of precision agriculture (PA).

4R Principle	Aim	Practical applications	Link with PA
Right Source	Applying the correct fertilizer and organic resources that provide growing crops with all nutrients required for good growth and maturity.	Ensure balanced supply of nutrients based on e.g. - Plant requirements - Deficient nutrients	Provides basis for optimizing available nutrient sources.
Right Rate	Supplying growing plants with the right amount of nutrients for healthy growth and development.	Adjust rates for differences in field quality based on key proxies.	Supports variable rate applications that account for spatial variability.
Right Time	Matching nutrient application with the timing of plant nutrient uptake.	Match nutrient applications to key crop growth stages.	Ensures optimal uptake of applied nutrients through synchrony with peak nutrient uptake time.
Right Place	Adding nutrients to the soil at a place where the crops can easily access them.	Match nutrient applications to root architecture, tillage system, spatial variability.	Supports optimal distribution of required nutrients.

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DRIVERS OF POST-HARVEST AFLATOXIN CONTAMINATION: EVIDENCE GATHERED FROM KNOWLEDGE DISPARITIES AND FIELD SURVEYS OF MAIZE FARMERS IN THE RIFT-VALLEY REGION OF KENYA #9319

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ABSTRACT

Maize-dependent populations in sub-Saharan Africa are continually exposed to aflatoxin poisoning owing to their regular consumption of this dietetic cereal. Being a staple in Kenyan households, consumption of maize-based meals is done almost daily, thereby exposing consumers to aflatoxicoses. This study assessed awareness levels, knowledge disparities and perceptions regarding aflatoxin contamination at the post-harvest phase among farmers in the Rift-valley region of Kenya. Households were randomly selected using a Geographical Positioning System (GPS) overlay of the agro-ecological zones within Uasin Gishu and Elgeyo Marakwet counties. Face-to-face interviews were conducted in 212 smallholder and large-scale farms. The study documented the demographic profiles of farmers, knowledge, awareness, and perceptions of aflatoxin contamination using a pre-designed structured questionnaire. Most farmers were familiar with aflatoxins and the adverse effects they present to health (61.32%). Almost all the farmers (94.37%) were aware of storage molds and food spoilage fungi. However, few farmers adopted good post-harvest practices (PHPs) such as avoiding premature harvests (49.8%), using well-ventilated storage spaces (44.6%), grain sorting (30.5%), proper drying of maize (17.8%) and using hermetic bags for storage (30.5%). Conclusively, intensified farmer education is required to train farmers on good PHPs to protect their maize from aflatoxigenic fungi and aflatoxin accumulation.

INTRODUCTION

Tropical food systems increasingly remain predisposed to frequent mycotoxin outbreaks thatcripple all possibilities of them being self-sustaining. In Kenya, massive attention is aways diverted towards the localities where fatal mycotoxicoses tend to occur, while other regions, though being equally at risk, tend to be neglected. A classic example are the lethal aflatoxicosis outbreaks that have transpired in Eastern Kenya spanning over several years. All of them have received overwhelming attention (Lanyasunya et al. 2005; Azziz-Baumgartner et al. 2005; Daniel et al. 2011; Okoth et al. 2012; Kang'ethe et al. 2017), whilst agricultural zones in the western regions remain unexplored. The Rift Valley region of Kenya is one such location where little research on mycotoxin and aflatoxin contamination has been conducted although it is the country's food basket, particularly when it comes to maize cultivation and production. The aforementioned geographical location produces approximately 80% of maize countrywide (Reynolds et al. 2015).

Consumers across Kenya rely on this maize for their self-reliance, a factor that denotes the importance of assessing the aflatoxin situation in this region. Zero aflatoxin or mycotoxin outbreaks have been reported in the Rift Valley, and the lack of surveillance programs could be solely responsible for this observation. In a singular study, Mutegi (2010) reported high prevalence of aflatoxin contamination in peanuts (*Arachis hypogaea* L.), but since its consumption is not as widely popular as maize, the revelation did not receive much attention. Being a tropical country, Kenya primarily cultivates its maize under agro-climatic conditions that are known to accelerate fungal colonization and subsequent mycotoxin multiplication (Mutiga et al. 2015; Okoth et al. 2018).

Most people practicing maize cultivation are resource-poor farmers whose pre- and post-harvest practices easily subject the cereal to increased mycotoxin contamination. The objectives of this study were to assess the magnitude of aflatoxin contamination in two major maize cultivation regions where minimal research on mycotoxin prevalence has been conducted, namely Uasin Gishu and Elgeyo Marakwet counties located in the Rift Valley Region of Kenya. The study further sought to investigate the main drivers of post-harvest aflatoxin contamination by assessing knowledge disparities by conducting field surveys among both large-scale and small-scale maize farmers.

MATERIALS AND METHODS

Study regions

Regional site surveys were conducted in Uasin Gishu (Fig. S1) and Elgeyo Marakwet (Fig. S2) counties between June and November 2021. Both counties fall within the Rift Valley, an administrative region popularly known for large-scale cereal cultivation and production, including maize, millet, sorghum, and wheat. By far, maize accounts for the widely cultivated cereal, with nearly most farmers growing the crop in either small or large scale. The corresponding agro-ecological zones (AEZ) for both counties were categorized into either of the following: (1) upper highlands (UH); (2) upper midlands (UM); (3) lower midlands (LM); (4) highlands; (5) lowlands; and (6) escarpment. Within each county, sub-counties or smaller administrative districts were selected as preferential field survey hubs. In each sub-county, villages were purposively selected and a total of 213 farmers interviewed subject to their consent to take part in the study.

Questionnaire design, development, administration, and data collection

Structured questionnaires designed using KoboCollect Toolkit open-source Software (KoBoCollect v2021 1.3.4, Harvard University, Cambridge, MA, USA) were administered to maize farmers for purposes of obtaining quantitative data on post-harvest practices.

The questionnaires were organized according to the following sub-sections: (1) sociodemographic information; (2) maize cultivation practices; (3) major post-harvest pests and diseases; and most importantly, (4) participant knowledge and awareness of mycotoxins.

RESULTS AND DISCUSSION

Farmers across Uasin Gishu and Elgeyo Marakwet practice both small- and large-scale farming depending on available land acreage. Maize varieties commonly grown in the Rift Region are the hybrid series, with Hybrid-614 (H614) being the most popular among farmers at 41.53%, followed closely by H6213 at 39.87%. Some farmers opted for indigenous maize varieties such as *Ndume, Pannar, and Duma* due to their large cob size, disease tolerance, high yielding abilities and kernel type. When the chi-square test was applied in testing the fit of association between knowledge of aflatoxin and the variables of gender and level of education, the former showed a significant difference ($p < 0.05$), indicating that gender plays a pivotal role in aflatoxin awareness and management in the study region. The variables of age, county of residence, income-generating activity, and level of education were not significantly associated with knowledge of aflatoxins, as their p-values were all greater than the level of significance ($p > 0.05$).

The present study sought to investigate the knowledge disparities, perceptions, and awareness levels of aflatoxin contamination among maize farmers residing in the Rift Valley Region of Kenya. Recurrent outbreaks of acute aflatoxin poisoning and fatal aflatoxicosis in Kenya associated with consumption of contaminated maize are often reported in the Eastern Region (Machakos, Makueni, and Kitui). Hardly do these reports highlight any outbreaks in the Western or Rift Valley Regions, which could equally be possible risk-alert areas. It remains unsubstantiated whether mycotoxins are a periodic, sporadic, or chronic problem in the aforementioned areas where these fatalities have not yet been reported. Deemed the breadbasket of Kenya, the Rift Valley produces the bulk of Kenyan maize and is primarily where the cultivation and production of this important cereal is done majorly in large scale. With agriculture generating revenue and income for more than half of the households residing in Uasin Gishu and Elgeyo Marakwet Counties, the importance of farming in this area cannot be overemphasized. In the current study, we endeavored to extend the understanding of the aflatoxin situation in the Rift Valley, Kenya's highest maize-producing region, through increased interviewing of farmers whilst undertaking farm assessments across multiple locations.

The regional survey specifically targeted the post-harvest level, particularly storage, while Mutegi (2010) compared the findings to pre-harvest parameters such as climatic patterns, cropping systems (mono-cropping versus mixed cropping), harvesting techniques, and other important farm-management practices. Approximately 78% of people residing in Uasin Gishu and Elgeyo Marakwet Counties earn their living primarily through engagement in crop farming and livestock husbandry (MoALF 2017). Nonetheless, despite these regions being the trailblazers in maize farming, scarce comprehensive mycotoxin surveys have been conducted in the region to ascertain whether there is any prevalence of aflatoxins. Our study revealed that even though a fraction of the farmers were well-versed with aflatoxin contamination at post-harvest, most of them still required intensive training to be taught about the importance of adhering to good post-harvest practices and how these would protect their maize from aflatoxin accumulation.

Aflatoxin surveillance and mycotoxin monitoring is evidently paramount not only in the known hot-spot regions but also in the breadbaskets of Kenya, where there is high maize production.

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PRODUCTIVITY AND PROFITABILITY OF MAIZE (*ZEA MAYS* L.) AS AFFECTED BY PLANTING AND FERTILIZATION SCHEMES ON THE FERRALSOLS OF SOUTHERN TOGO
#9453

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ABSTRACT

A sustainable improvement of crop productivity and profitability in the current context of climate change and land degradation is necessary to meet food and cash needs of a ceaselessly growing population. To help achieve this aim, we carried out a 2-year experiment (2020 and 2021) at the University of Lomé Agronomic Experiment Station. The experiment was set up in a split-plot design with three (03) replicates. Two planting schemes (SC_1= 80 cm x 40 cm and SC_2 = 80 cm x 25 cm,) and four fertilization schemes: control (F_0= 0 kgha^{-1}); 200 kgha^{-1} of $N_{15}P_{15}K_{15}$ + 100 kg ha^{-1} of urea 46% of N (F_1), 6 000 kg ha^{-1} of chicken dungs (F_2) and 6 000 kg ha^{-1} small ruminant dungs (F_3) were the studied factors. Maize grain yield and profitability under each treatment were determined. The results analysis showed that the planting schemes, fertilization treatments and rainfall were significantly influenced the maize grain yields and profitability of its production. On 2-year average basis, maize grain recorded under SC_2 (80 cm x 25 cm) planting scheme were 31% higher than those obtained under SC_1. Average yield recorded under F_2 was higher than those of F_0, F_1 and F_3 by 60; 2 and 28% respectively. On 2-year average basis, the highest maize grain yields were observed under the SC_2F_1 (3.43±0.24 t ha^{-1}) and SC_2F_2 (3.39±0.18 t ha^{-1}) treatments, which were statistically similar and were respectively 112% and 109% higher than the lowest yield gotten under SC_1F_0 (1.59±0.23 t ha^{-1}). The highest profit (343 000 FCFA ha^{-1} =US$ 512.46) was registered under SC_2F_1 treatment. The adoption of SC_1F_1; SC_2F_1 and SC_2F_2 gave value/cost ratio (VCR) greater than 2 and were profitable; but the use of SC_2F_1 and SC_2F_2 was the most profitable and could be easily adopted by the producers whatever the socio-political or environmental conditions were. The application of SC_2F_1 and SC_2F_2 under Ikenne 9449 SR variety could be recommended to farmers in the first two years of cultivation on soil left in fallow for three years.

Keywords: Maize grains, planting and fertilization schemes, yield, profit and value cost ratio.

INTRODUCTION

Maize is the staple food crop for most people in Sub-Saharan Africa (SSA). It is grown in diverse agro-ecological zones and farming systems and consumed by people with diverse preferences and socio-economic backgrounds in SSA (Macauley & Ramadjita, 2015). It is also used for animal feeding, in the textile and pharmaceutical industries, in the production of biodegradable plastics and biofuel (Macauley & Ramadjita, 2015). In Togo, maize is one of the main food crops. It comes in third position after yam and cassava, but in the lead of cereal crops from the point of view of production. Despite, the efforts made in agriculture by the various stakeholders to improve its production and the assets available in the country to succeed in its cultivation, yields were still low. Since 2010, average maize grain yields at national level have never exceeded 1.50 t ha^{-1} (DSID, 2022). Low crop yields were mainly explained by climate variability, lack of water control, to low adoption of improved varieties and especially soil fertility decline. The need to improve crop yields on existing farmland became then an overriding and obvious objective.

To overcome the problem of yield decline, several studies have been carried out on mineral and organic fertilization (Bationo et al., 2004; Khalid et al., 2014; Mazinagou et al., 2022), farming practices and on adaptation to climate change (Amouzou et al., 2013; Sogbedji et al., 2017). Many of these studies had shown that the use of fertilizers is a key factor in modernizing agriculture in developing countries. According to FAO (2005), maintaining soil fertility would be the keystone in this context of food crops. However, studies on the effect of planting schemes or their interactions with different manures on crop yields are underdeveloped in Togo. With the problems of climate change that have been rife in recent years, some of these studies should be resumed by simultaneously considering key elements including the land degradation, climatic change, plant material and farming practices which have a great influence on crop production. Furthermore, the various proposals made in previous studies have a financial impact that the farmer who practices subsistence agriculture cannot support (Galla et al. 2011; Kasongo et al., 2013).

In a context of food insecurity and soil dégradation, it is essential to determine agricultural production techniques that should allow producers to sustainably increase, not only crop yields, but also to increase their incomes to improve their living conditions. Thus, the search for information concerning the response of maize to fertilizers according to the planting scheme seems essential. The objectives of this study were to: (i) evaluate the effect of planting and fertilization schemes on maize grain yield and (ii) determine the most profitable production technique.

MATERIAL AND METHODS

Experimental site

The study was carried out at the Lomé Agronomic Experiment Station (SEAL), located at the University of Lomé -Togo (6°22' N, 1°13'E; altitude = 50 m, slope less than 1 %). The soil type was a rhodic Ferralsol locally called “Terres de barre”, developped from the continental deposit (Saragoni *et al.,* 1992) and covered part of the arable land in the Ivory Coast, Ghana, Togo, Benin, and Nigeria (Louette, 1988). The climate of the experimental site is the guinean type, bimodal and allows for two maize cropping seasons, one from April to July and another from September to December. Annual rainfall at the site is between 800 and 1100 mm. The annual average temperature is between 24 and 27 °C (Worou, 2000; Somana *et al.*, 2001). At the onset of this experiment, the site has been under fallow for three years.

Soil and crop management

The experiment was set up during the first growing seasons (April to August) of two consecutive years (2020 and 2021). A split-plot design with three replications was used. Two planting schemes were in main plots and four fertilization treatments in the subplots. The two planting schemes used were: (i) 80 cm x 40 cm (SC_1) and (ii) 80 cm x 25 cm (SC_2). The four four fertilization treatments applied were: (i) control (F_0=0 $kgha^{-1}$); (ii) 200 $kgha^{-1}$ of NPK: 15-15-15 + 100 $kgha^{-1}$ of urea 46% N (F_1); (iii) 6 000 $kgha^{-1}$ of chicken dungs (F_2) and (iv) 6 000 $kgha^{-1}$ of small ruminant dungs (F_3). Fertilization treatment F_1 is a recommendation by the national agricultural extension services in Togo (Sogbedji *et al.*, 2017), and F_3 is a recommended FYM-based organic amendment by IFDC (2013). The maize varietie used for experiment was Ikenne 9449 SR (Ikenne). At the beginning of each cropping year, the experimental site was prepared through the following successive operations: clearing, blocks and plots demarcation and manually deep plowing. The maize was sown at four seeds per pocket, follow-up of thinning at two plants per pocket for SC_1 (giving a density of 62 500 plants ha^{-1}) and at one plant per pocket for SC_2 (with a density of 50 000 plants ha^{-1}) were carried out ten days after sowing. NPK: 15-15-15 fertilizer, chicken and small ruminant dungs were applied two weeks after sowing, while urea 46% N was applied at the beginning of flowering. Animal dungs were subjected to composting for three months before their application.

Data collection and analysis

Maize grain yields were determined from the three center rows of each experimental plot. The harvested cobs were dried and then shelled. The maize grain weights were taken when the moisture content of the grains was around 12%. The analysis of variance (ANOVA) of the data obtained was done by using the GenSTAT discovery edition 12 software at the 5% threshold and Duncan's test was used to discriminate the means at this threshold.

Economic analysis method

2-year average (2020 and 2021) profitability of maize production under each treatment (combination of planting schemes and fertilizers), was determined through a partial budget analysis. The profitability is the difference between outputs and inputs. Output consisted of the amount of cash values corresponding to the averge maize grain produced in the two years, which was assumed to be sold at 200 F CFA (US$ 0.30) kg^{-1}, the 2-year average sale price of maize grain at harvest (august) on the local market. The inputs consisted of the production costs under each treatment, including those for soil preparation, seeds, crop planting and related tasks, fertilizers and insecticid (Emacot 050 WG) purchase and their application, crop weeding. and crop harvesting and associated tasks. Labor costs were estimated at 2 000 F CFA (US$ 2.99 per person day (Detchinli and Sogbedji, 2015) and fertilizer costs were based on current prices which were determined to be 250 F CFA (US$ 0.37) kg^{-1}. Chicken dungs or small ruminant dungs was estimated at 20 000 F CFA (US$ 29.88) $Mgha^{-1}$ (Detchinli and Sogbedji, 2015).

The value/cost ratio (VCR) is also determinated under each treatment in order to identify the most profitable one. VCR is the ratio of the value of the yield increase over the control to the cost of the fertilizer used. According to the CDI and IFDC (2014), the VCR must be at least equal to 2 to allow farmers to cover the direct costs related to the use of fertilizers on the farm.

RESULTS AND DISCUSSIONS

Effect of planting and fertilization schemes on maize grain yield

Table 1 shows the maize grain yields from the 2-year experiment. On 2-year average basis, the application of 200 kgha-1 of NPK:15-15-15 + 100 $kgha^{-1}$ of urea 46% N (F1) and 6 000 $kgha^{-1}$ of chicken dungs (F_2) with the adoption of the SC_2 gave the highest maize grain yields. These yields under SC_2F_1 (3.43±0.24 t ha^{-1}) and SC_2F_2 (3.39±0.18 t ha^{-1}) are statistically identical and are respectively 112% and 109% higher than the lowest yield (1.59±0.23 t ha^{-1}) obtained under control (F_0) with the adoption of the 80 cm x 40 cm planting scheme (SC_1). The planting scheme 80 cm x 25 cm (SC_2) gave the highest maize grain yields in 2-yr experiment.

The highest maize grain yields obtained under SC_2F_1 and SC_2F_2, on the 2-year average basis could be explained by the effect of cropping precedents; the rapid mineralization of these fertilizers and the nutrient richness of chicken dungs than those for small ruminants dungs and to their rear-effect. According to Useni *et al.* (2012), the exclusive application of mineral fertilizers is generally effective only during the first years of continuous inputs; there is often a decline in yield after a few years of application due to the degradation of soil properties. In contrast, the use of organic manure, especially poultry manure improves not only the yield but also soil chemical parameters (Gomgnimbou *et al.*, 2019). It was shown that chicken dungs were of great potential for improving soil nutrient availability and were able to provide the amount of nutrients needed for crops compared to the control (Kimuni *et al.*, 2014). The application of compost increased then crop yields and thus contributes to improving food availability (Ouedraogo *et al.*, 2000).

The adoption of SC_2 gave the highest maize grain yields under all the fertilization treatments. This planting scheme helped the maize plants to use sufficiently the nutrients released during the decomposition of fertlizers to express their performance. Despite the reduced gap between plants on the line with SC_2, this planting scheme would promote good aeration between the plants and would therefore allow a better use of the nutrients provided to them for their growth and development. the results of this study are like those of Hasan *et al* (2018) and Zarea *et al.* (2005) who showed that reducing the planting scheme increases crop yields.

Table 1. Maize grain yields from 2-year average under different treatments.

Planting schemes	Fertilization treatments				Means	F.pr	CV (%)
	F_0	F_1	F_2	F_3			
Maize grain yields in t ha^{-1}							
SC_1 (80 cm x 40 cm)	1.59±0.23c	2.61±0.17a	2.77±0.27a	2.08±0.14b	2.26±0.51b	0.012	17.80
SC_2 (80 cm x 25 cm)	2.25±0.19c	3.43±0.24a	3.39±0.18a	2.74±0.17b	2.95±0.53a	<.001	15.60
Means	1.92±0.41c	3.02±0.45a	3.08±0.48a	2.41±0.42b	2.61±0.62	<.001	16.30

F_0 = 0 kgha^{-1}; F_1= 200 kgha^{-1} of NPK: 15-15-15 + 100 kgha^{-1} of urea 46% N; F_2= 6 000 kgha^{-1} of chicken dungs and F_3= 6 000 kgha^{-1} of small ruminant dungs. CV= Coefficient of variation. The data were discriminated in the horizontal direction; except the average values of the planting schemes, which were discriminated in the vertical direction (P=0.05). Values that are followed by the same letters are statistically identical.

Economic analysis of maize grain production techniques

Results of the partial balance (difference between outputs and inputs) and the value/cost ratios were presented in Table 2. On 2-year average basis, the profits were positive under all the treatments and the highest profit (343 000 FCFA=US$512.46) were got under the adoption of the 80 cm x 25 cm (SC_2) with application of 200 kgha^{-1} of NPK: 15-15-15 + 100 kgha^{-1} of urea 46% N (F_1). As for the value/cost ratios (VCR), the application of SC_1F_1; SC_2F_1 and SC_2F_2 200 gave VCR greater than 2; while the application of SC_1F_2 ; SC_2F_3 to maize plants gave VCRs located between 1.5 and 2. The application of SC_1F_3 to maize plants gave the lowest VCR which was less than 1. The highest VCR (4.91) was got under SC_2F_1.

The positives balances got under all treatements showed that their use in the first two years of cultivation on land left fallow for three years was profitable. This highest profit registraded under SC_2F_1 could be explained, not only by the better yields obtained under this treatment; but also, by the low production costs linked to the use of this mineral manure compared to the production costs linked to the use of organic manures. The value cost ratios greater than 2 under SC_1F_1; SC_2F_1 and SC_2F_2 showed that these treatments were profitable and could be easily adopted by producers (CDI and IFDC, 2014; Mankoussou *et al.*, 2017). But in an unstable political and socioeconomic environment or in regions more sensitive to drought (where the risk is much higher) at least a VCR of 3 is needed before producers could dare to take the risk of investing in the use of the fertilizers (FAO and IFA, 2000; CDI and IFDC, 2014). In these conditions, only SC_2F_1 and SC_2F_2 treatment could be used by the farmers. The adoption is reluctant for SC_1F_2 and SC_2F_3 which had their VCR between 1.5 and 2; but SC_1F_3 treatment must be rejected because his VCR was below 1.5 (Mankoussou *et al.*, 2017).

Table 2. Partial balance and value/cost ratios of each treatment.

Parameter	SC_1F_0	SC_2F_0	SC_1F_1	SC_2F_1	SC_1F_2	SC_2F_2	SC_1F_3	SC_2F_3
	F CFA ha^{-1}							
Output	+318 000	450 000	522 000	686 000	554 000	678 000	416 000	548 000
Input	-248 000	248 000	343 000	343 000	378 000	378 000	378 000	378 000
Labor	218 000	218 000	238 000	238 000	228 000	228 000	228 000	228 000
Seeds	10 000	10 000	10 000	10 000	10 000	10 000	10 000	10 000
Fertilizer	0	0	75 000	75 000	120 000	120 000	120 000	120 000
Pesticide	20,000	20 000	20 000	20 000	20 000	20 000	20 000	20 000
Balance	**70 000 US$104.58**	**202 000 US$301.80**	**179 000 US$267.43**	**343 000 US$512.46**	**176 000 US$262.95**	**300 000 US$448.21**	**38 000 US$56.77**	**170 000 US$253.99**
VCR	**0**	**0**	**2,72**	**4,91**	**1,97**	**3,00**	**0,82**	**1,92**

1 USD = 669,325 of West Africa franc F CFA, 29/09/2022 at 20h 02. VCR=Value cost ratio. SC_1 = Cropping scheme 80 cm x 40 cm SC_2 = Cropping scheme 80 cm x 25 cm. F_0 = 0 $kgha^{-1}$; F_1= 200 $kgha^{-1}$ of NPK: 15-15-15 + 100 $kgha^{-1}$ of urea 46% N; F_2= 6 000 $kgha^{-1}$ of chicken dungs and F_3= 6 000 $kgha^{-1}$ of small ruminant dungs.

CONCLUSION

At the end of this study, whose aim is to sustainably improve the productivity and profitability of maize production, it appears that the application of 200 $kgha^{-1}$ of NPK:15-15-15 + 100 kg ha^{-1} urea 46% N (F_1) and 6 000 kg ha^{-1} of chicken dungs (F_2) with the adoption of the 80 cm x 25 cm (SC_2) planting scheme improved significantly maize grain yield in the first two years of cultivation. But the use of SC_2F_1 treatment gave the highest profit and the highest value/cost ratio. SC_1F_1; SC_2F_1 and SC_2F_2 treatments were profitable; but SC_2F_1 and SC_2F_2 were the most profitable and could be easily adopted by the producers in any political or environmental conditions. The application of these treatments under Ikenne 9449 SR variety could be recommended to the farmers in the first two years of cultivation on soil left fallow for three years.

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PRECISION AGRICULTURE, THE KEY TO INCREASED PRODUCTIVITY FOR SMALLHOLDER FARMERS; A CASE OF SOUTH-EAST NIGERIA #9480

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ABSTRACT

The aim of this study was to analyze the impact of precision agriculture on the farming operations of smallholder farmers in South-East Nigeria. In general, the system of farming in Nigeria lacks precision especially since it is being practised primarily by smallholder farmers and is mainly determined and analyzed using mundane, redundant, and time-consuming technology. This has resulted in uneven food production potential across the value chains. Agricultural Input waste despite its growing scarcity is already becoming a pandemic on its own as many of these referenced smallholder farmers don't apply Precision in their input application. Through my research, while working with farmers in South-East Nigeria I discovered that most of these smallholder farmers don't use precise input application technology and they still rely on old farm management systems which reduces their productivity and general farming capacities. Our introduction of Precision agriculture to them was a great opportunity for them to witness first-hand the accuracy of drones in farm data collection, farm mapping, terrain analysis, crop count and fertility distribution mapping. These amongst others are some of the key variables impacting their farming productivity. These drones reduce farming redundancies and increase speed by up to 10x when compared to the traditional method of farm management presently being utilized by smallholder farmers. They further reduce agricultural input waste by up to 60% thus saving the smallholder farmer 60% of his original capital intended for the purchase of agricultural inputs. This saving can either be utilized for more input or simply used to sort out other needs of the smallholder farmer. Precision agriculture does not only guarantee speed, but it also ensures increased productivity and profitability. Smallholder farmers make up the largest population of food producers in the African agricultural sphere and the key to increasing their productivity lies in precision, from the application of inputs to ensure an increase in yield, to the general management of the farms. Precision agriculture will help smallholder farmers increase their farm sizes because of the guaranteed reduction in wastage of inputs and increased saving of time and resources. This simple tactic will turn these seemingly underserved populations into formidable food producers.

INTRODUCTION

Nigeria relies on about $10 billion worth of imports to meet its food and agricultural production shortfalls with food inflation rising to 22.95% in the first quarter of 2021. Causes of food inflation include conflict, insurgency, kidnapping, and wastage of agricultural input and produce. Nigeria has seen the prices of locally grown food spike to new highs in 2022 further weakening consumers' purchasing power. Using Rice as a case study, in 2021 the total available market size for Rice according to the international trade administration is $3,530million and the total estimated local production was $2,300million leaving about $1,230million for importation. Despite these numbers, Nigeria is Africa's largest producer of Rice and is among the top 15 producers globally, yet imports continue to meet about half of the country's demand for Rice with Thailand and India as two of the leading import destinations.

Precision agriculture is the future of farming and is necessary for increased productivity in the Nigerian agricultural system. With precision agriculture in Nigeria, Nigerian farmers will efficiently manage their farms especially by reducing waste of input and land both of which are major factors that reduce productivity and food availability in the Nigerian agricultural system. While increasing speed and productivity, precision agriculture will also combat the issue of food insecurity as the nation's population increases daily. Agritech has made farming operations like crop monitoring, survey, farm mapping, soil water analysis, plant stress determination, and input application to mention a few, easy and stressless with increased precision.

MATERIALS AND METHODS

An impactful correlational survey was used to examine smallholder Rice farmers in the South-Eastern Region of Nigeria and their farming methods.

Drone data capture of farmlands and precise surveys were used to show these smallholder farmers the difference between the conventional farm survey method, routine round the farm crop checks and the speed of high-end machines capturing farm data in minutes and producing more precise results on farm variables.

Precision application of Agrochemicals on farmers' farms using input spray drones highlighted the reason precision agriculture is the next big thing. Especially with its speed and variable rate technology, spray drones can control the amount of input required per field and this helps reduce input waste by at least 60%. These drones also spray as programmed in locations they are needed, and this ensures 100% precision.

Interactive DIY sessions and basic training using audio and visual learning materials also aided the acceptance process for these rural farmers.

RESULTS AND DISCUSSION

Effectiveness of Precision Agriculture on the Smallholder farmers.

Impactful surveys showed the level of redundancies that existed in smallholder farmers' farming activities. Most of these smallholder farmers even lack basic input and implements to effectively produce. Also, despite the gross lack of capital to secure input noticed among these farmers, wastage of land and already scarce input was another noticeable factor among these groups of smallholder farmers.

The results of our farm demonstrations and interactive sessions are so far assisting more than 400 individual smallholder farmers to increase their farming productivity. With more precise farm data, they now know exactly how and where to plant, they also benefit from the precise application of input like agrochemicals and effective field monitoring with improved efficiency. Moreover, this farm management model has encouraged them to increase their farm sizes, and this will in turn increase their output.

Subscribed farmers are already seeing the difference in the resulting yield from the adoption of precision agriculture, and upon harvest, they are sure to gain more than 50% more produce than in previous planting seasons. This no doubt proves that with precision agriculture Africa will be a formidable continent when matters of food production are discussed.

As early adopters of Agritech and precision climate-smart agriculture in Nigeria, I and my team intend to duplicate this success in more locations to further increase the food productivity of smallholder farmers in Nigeria because these seemingly vulnerable farmers hold the key to the nation's food security.

FURTHER READING

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DETERMINATION OF MAJOR LIMITING NUTRIENTS AND SITE-SPECIFIC FERTILIZER RECOMMENDATION TOWARDS OPTIMIZING RICE PRODUCTION IN THE IRRIGATED PERIMETER OF THE ZIO VALLEY (TOGO) #9481

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ABSTRACT

Adoption of appropriate inorganic fertilization schemes is essential to improving fertilizer use efficiency and crop performance for precision agriculture. This study aims to contribute to the improvement of rice yields in the irrigated perimeter of the Zio Valley in Togo through appropriate inorganic fertilization. Nutrient omission trials were set up during November 2020 to March 2021 and May to September 2021, with farmers identified in the four (04) villages (Mission Tove, Ziowonou, Kovie and Assome) located in the Zio valley. Three (03) producers per village were selected on the rice-growing perimeter of the Zio valley. A complete randomized block design with five treatments was installed at each site. The treatments consist of diagnostic plots: T1(N81P110K88), T2(N0P110K88), T3(N81P0K88), T4(N81P110K0) and T5(N0P0K0). Each treatment was carried out in three repetitions. The data collected related to the yield of paddy grains and straw. Analyses were also carried out to determine the export rate of N, P and K in the grains and in the straw. The subtractive trials showed a significant difference between the plots having been fertilized and the non-fertilized plots on the yield of paddy rice. On average, the full NPK treatment gave the highest yield (4 557.82 kg/ha). It is followed by T4 (3 873.67 kg/ha) and T3 (3 493,04 kg/ha) treatments, then T2 (2 808.78 kg/ha). The lack of Nitrogen, Phosphorus and Potassium led to respective yield reductions of 60%, 29% and 17% compared to the T1 (NPK) plots. The order of nutrient limitation in the perimeter is N>P>K. Kovie and Mission Tove producers should use the N130P34K77 formula for a target yield of 4.25 t/ha. The recommended formulas for the Ziowonou and Assomé villages are respectively N96P21K82 and N81P11K26 with respective target yields of 5.7 t/ha and 4.1 t/ha.

Keywords: Irrigation, rice, nutrient, yield, fertilization formula

INTRODUCTION

In irrigated rice cultivation in West Africa, nitrogen (N) and phosphorus (P) fertilizers account for about 20% of total production costs. More generally, it is noted that the cost of fertilizers represents more than 30% of operating expenses (Donovan et al., 1999). Because of this importance, it is necessary to ensure the efficiency of the fertilizers used through a permanent adaptation of the fertilization formulas to production areas and crops. However, a single pan-territorial formula ($N_{76}P_{30}K_{30}$) has been recommended for several decades for all cereal crops in Togo. It emerged from the work of Ngbendema et al. (2017), that the application of this formula in irrigated rice cultivation only makes it possible to obtain yields of 3.5 t/ha on average with an operating account deficit of 32 000 FCFA. In this situation, rice farmers increase the amounts of fertilizers without any scientific basis in the hope of improving their yields and the profitability of their farms. This inappropriate practice results in loss of nutrients and wastage of foreign exchange and can even lead to environmental pollution (Ezui, 2010). Thus, all actions to improve production should consider the new challenges and objectives of agricultural production, including the reduction of the environmental impacts of crops, the control of production costs and the balanced use of fertilizers (Yousaf et al., 2016), especially for crops of major importance for food security such as rice.

The production of rice in the irrigated perimeters makes it possible to improve yields thanks to the favourable growing conditions they offer and especially with the possibility of conducting at least two cycles of rice cultivation per year. This study aims to contribute to the improvement of paddy rice yields in the irrigated perimeter of the Zio valley through appropriate mineral fertilization. Specifically, the study aims to (i) identify and prioritize the major nutrients limiting rice production and (ii) propose suitable and economically viable fertilization formulas.

MATERIALS AND METHODS

For the identification of the major limiting nutrients and the recommendation of fertilization formulas, Nutrient omission trials were set up during November 2020 to March 2021 and May to September 2021, with producers identified in the four (04) villages (Mission Tove, Ziowonou, Kovie and Assome) located in the Zio valley. Three (03) producers per village were selected on the rice-growing perimeter of the Zio valley. A complete randomized block design with five treatments was installed at each site. The treatments consist of diagnostic plots: T1($N_{81}P_{110}K_{88}$), T2($N_0P_{110}K_{88}$), T3($N_{81}P_0K_{88}$), T4($N_{81}P_{110}K_0$) and T5($N_0P_0K_0$). Each treatment was carried out in three repetitions. The data collected related to the yield of paddy grains and straw. Analyses were also carried out to determine the export rate of N, P and K in the grains and in the straw. The application of urea is conducted in three stages, i.e., 50% at 15 days after transplanting (DAR), 25% at 30 DAR and 25% at 45 DAR. As for the TSP and KCl the whole quantity is brought 7 DAR. The paddy rice harvest has been done at 118 DAR for the first season and 122 for the second season.

The order of limiting the needs of rice plants in N, P and K nutrients is determined according to the methodology of Mawussi et al. (2015). Statistical analysis of the grain and straw yield data for the different treatments was conducted using the SPPS V26 software through an analysis of the variance of the data and discrimination of the means according to the Student Newman Keuls test at the threshold of 5 %. Major nutrient requirements were estimated based on three factors: yield gap, nutrient internal efficiency (IE) and recovery rate (TR) following the formula (a) below (Dogbe et al., 2015). The yield gap was calculated as the difference between the target yield (NPK) and the yield from the zero N, zero P, or zero K omission plots. For EI and TR, reference values were used. Thus, in this paper, we have adopted EI of 53 kg grain produced for any kg N absorbed, 34.8 kg grain produced/kg of K absorbed, and 294 kg grain produced/kg of P absorbed (Sahrawat, 2000). Regarding the recovery rate, we adopted the average recovery fractions of N, P and K of 30%, 15%, and 30% respectively (Dobermann and Fairhust, 2000; Dogbe et al., 2015). Two economic parameters were used to assess the profitability of the different recommended options: the value cost ratio (VCR) and the marginal revenue rate (MRT).

RESULTS AND DISCUSSION

Determination of the order of limitation of nutrients N, P and K

The average yields of paddy rice and straw obtained in each village of the irrigated perimeter over the two cropping cycles are given in Table 1.

Table 1. Effect of mineral fertilizers on paddy rice and straw yield in the four villages.

		Ziowonou	Kovié	Mission Tové	Assomé	Moyenne
Paddy grain yield (t/ha)	T1	5.76±0.2 a	4.27±0.9 a	4.10±0.8 a	4.15±0.1 a	4.56 ±0.9 a
	T2	4.18±0.6 c	2.19±0.7 cd	1.99±0.9 c	2.86±0.2 b	2.81±1.1 c
	T3	4.78±0.3 b	2.78±0.9 bc	2.72±0.3 bc	3.67±0.1 a	3.49±1.1 bc
	T4	4.84±0.4 b	3.46±0.8 ab	3.30±0.7 ab	3.87±0.1 a	3.87±0.8 b
	T5	2.88±0.7 d	1.26±0.4 d	1.59 ±0.3 c	1.79±0.2 c	1.88±0.8 d
Straw yield (t/ha)	T1	5.70±0.4 a	4.35±0.3 a	4.07±1.1 a	4.21±0.2 a	4.62±0.8 a
	T2	2.98±0.1 b	2.66±0.1 b	2.18±0.8 c	2.48±0.1 d	2.58±0.4 c
	T3	3.01±0.4 b	3.98±0.7 a	3.57±0.4 b	3.15±0.8 c	3.45±0.2 b
	T4	3.13±0.2 b	4.29±0.4 a	4.09±0.6 a	3.82±0.5 b	3.83±0.4 b
	T5	1.08±1.0 c	1.84±0.8 c	1.61±0.3 d	1.27±0.7 e	1.47±0.6 d

The results of the subtractive tests showed that the absence of one of the three major nutrients leads to a significant drop in rice yield in the four villages of the irrigated perimeter of the Zio valley. On average, T1($N_{81}P_{110}K_{88}$) gave the best output as well for the paddy rice as for the straw is respectively 4,56 t/ha and 4,62 t/ha. The lack of nitrogen in T2 led to a strong decrease in yield. Thus, over the two seasons, the average yield of paddy rice recorded on the plots having received T1($N_{81}P_{110}K_{88}$) was higher than those obtained under T2 ($N_0P_{110}K_{88}$), T3 ($N_{81}P_0K_{88}$) and T4 ($N_{81}P_{110}K_0$) respectively by 60, 29 and 17%. As for rice straw yield, the yield increase rates of T1 compared to T2, T3 and T4 were 79%, 34% and 20% respectively. Thus, the yield of paddy rice in the irrigated perimeter of Zio is more limited by nitrogen. The order of nutrient limitation is therefore: N>P>K. Nitrogen is found to be the most limiting for yield, while yield reductions caused by the absence of phosphorus or potassium seem statistically similar. Nitrogen indeed plays a vital role in grain production (Wanyama et al., 2015). Several other studies have also shown that Nitrogen and Phosphorus are the two main nutrients limiting the yield of rice production in West Africa due to poor soil organic matter (Dogbe et al., 2015).

Nutrient recommendations

Additional export needs and specific fertilization recommendations for producers in villages located in the Zio Valley irrigated perimeter are presented in Table 5. Nutrient needs varied from one village to another. For nitrogen, the need is higher in Mission Tové (21.01 kg/ha) and Kovié (21.43 kg/ha) than in Ziowonou (15.44 kg/ha) and Assomé (13.03 kg/ha). The P requirement per village follows the same hierarchy as that of nitrogen with a higher requirement in Mission Tové (7.37 kg/ha) and a lower requirement in Assomé (2.36 kg/ha). As regards the K requirement, it is almost identical in Ziowonou, Mission Tové and Kovié at around 1.4 kg/ha whereas it is 0.4 kg/ha in Assomé. The soils of Assome therefore appear to be the least poor.

The amounts of nutrients in the recommended formulas are economically sustainable and will significantly improve rice yields. IFDC, (2014) found that farmers began to opt for fertilizer use when the RVC is two (2) or more. Compared to the current recommendation, the quantities will increase from 76 to 110 fertilizer units per ha for nitrogen and from 30 to 66 units per ha for potassium. For phosphorus, there is a slight decrease from 30 to 24 fertilizing units.

Table 2. Yield gap and village-specific recommendation.

	Treatment	Yield gap (kg/ha)	Nutrient recommendation (kg/ha)			RVC	MRT (%)
			N	P_2O_5	K_2O		
Ziowonou	T4($N_{81}P_{110}K_0$)	858.93			82.27		
	T3 ($N_{81}P_0K_{88}$)	917.27		20.80		2.98	165
	T2($N_0P_{110}K_{88}$)	1523.22	95.8				
	T5 ($N_0P_0K_0$)	2818.46					
Kovié	T4($N_{81}P_{110}K_0$)	805.4			77.15		
	T3 ($N_{81}P_0K_{88}$)	1487.3		33.73		2.52	1 25
	T2($N_0P_{110}K_{88}$)	2073.01	130.38				
	T5 ($N_0P_0K_0$)	3012.7					
Mission Tové	T4($N_{81}P_{110}K_0$)	797.73			76.41		
	T3 ($N_{81}P_0K_{88}$)	1379.11		31.27		2.12	108
	T2($N_0P_{110}K_{88}$)	2114.09	132.96				
	T5 ($N_0P_0K_0$)	2508.7					
Assome	T4($N_{81}P_{110}K_0$)	274.55			26.30		
	T3 ($N_{81}P_0K_{88}$)	475.48		10.78		4.19	263
	T2($N_0P_{110}K_{88}$)	1285.87	80.87				
	T5 ($N_0P_0K_0$)	2352.48					

CONCLUSION

This study has made it possible to highlight the importance of the major nutrients N, P and K in improving the yield of paddy rice in the irrigated perimeter of the Zio valley. It also made it possible to identify the edaphic diversity and the nutritional needs of the rice plots on the perimeter of Zio and to confirm the need to adapt the fertilization formulas for each production zone. Nitrogen is revealed as the major nutritive element limiting rice production in the irrigated perimeter of the Zio valley. However, due to the poor soils of the perimeter, phosphorus and potassium also proved to be limiting.

The results of the soil studies, combined with those of the subtractive tests conducted during two cropping cycles between 2020 and 2022, make it possible to propose three economically viable fertilization formulas with realistic target yields. Thus, the producers of Kovié and Mission Tové will use the $N_{130}P_{34}K_{77}$. The formulas recommended for Ziowonou and Assomé villages are respectively $N_{96}P_{21}K_{82}$ and $N_{81}P_{11}K_{26}$.

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EFFECT OF REDUCED TILLAGE, RESIDUE RETENTION AND CROPPING SYSTEM ON GROWTH AND YIELD OF GREEN GRAM IN ARID AND SEMI ARID ENVIRONMENTS OF KENYA
#9501

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ABSTRACT

Green gram yield has remained significantly low despite the development of improved varieties. This could be attributed to low soil fertility, unreliable rainfall as well as inappropriate cropping practices. Nonetheless, implementation of precision agriculture (PA) within the context of reduced tillage incorporated with residue retention and intercropping has the potential to increase green gram yield in arid and semi-arid environments. The objective of this study was to determine the effect of reduced tillage, residue retention and cropping system on green gram growth and yield. Results showed that green gram grown under tied ridges performed better than those under conventional tillage and no till. Residue retention of 3 t/ha significantly increased green gram yield. The result showed that tied ridges × residue retention 3 t/ha × sole crop interaction increased green gram yield. Farming practices incorporating tied ridges, residue retention and sole crop system can be applied as an aspect of PA to increase agricultural productivity and sustainability.

Keywords: tied ridges, interactions, sole crop, seed yield

INTRODUCTION

Green gram production is below the yield potential due to continuous exploitation of natural resources to meet the increased food demand to feed the steadily growing population. Precision agriculture is a considered as a solution for improved crop yield and sustainable green gram production. Green gram (*Vigna radiata*) is a significant leguminous crop which does well in arid and semi-arid environments and improving its productivity will could improve livelihood of people living in such hardship environments. Unfortunately, green gram yield has remained significantly low despite continuous development of improved varieties, this could be attributed to low soil fertility as well as inappropriate tillage and cropping practices among others. Hence, implementation of precision agriculture in green gram production coupled with reduced tillage, residue retention and cropping system could improve green gram yield (Friedrich et al., 2009).

There has been significant amount of research done to evaluate residue retention, reduced tillage as well as intercropping with emphasis on cereals but little emphasis on green gram crop (Kitonyo et al., 2018). Little is known on how mulch contribute to increased green gram growth and yield (Giller et al., 2009). This research attempted to fill the above identified gaps in the effect of reduced tillage, residue retention and cropping system on green gram growth and yield. Thus, the objective of this research was to evaluate the effect of reduced tillage, residue retention and cropping system on green gram growth and yield. It was hypothesized that reduce tillage, residue retention and intercropping positively influence growth and yield of green gram.

MATERIALS AND METHODS

Field experiments were concurrently conducted under rain fed conditions both on-station at Kenya Agricultural and Livestock Research Organization (KALRO) in Katumani and on-farm Kyua, Katangi both in Machakos County Kenya during 2020 short rains and 2021 long rains. The experiments were laid out in randomized complete block design with split-split plot arrangements. The treatments comprised of three tillage practices (conventional tillage, tied-ridges and no-till), two crop residue amount (0 and 3 t/ha) and two cropping systems (sole crop and intercrop). Main plot comprised tillage systems, residue amount sub plot and cropping system sub-sub plot. The test crop was green gram KS20 variety with sorghum Gadam variety as intercrop.

Green gram yield components collected were seed yield, number of pods per plant, number of seeds per pod and 1000 seed weight. The data was subjected to analysis of variance by use of GenStat Version. 12 statistical software. Treatment means were compared and separated using Fisher’s least significant difference test at 5% probability level.

RESULTS AND DISCUSSION

Green gram seed yield was significantly ($P \leq 0.001$) affected by tillage practices, residue amount and cropping system. Green gram yield was significantly ($P \leq 0.004$) affected by interactions between tillage practices * residue amount, tillage practices * cropping system and residue amount * cropping system ($P \leq 0.003$). Interactions of tillage practices * residue amount * cropping residue had no significant effect on green gram yield. Green gram yield increased under tied ridges by 1.58 t/ha this could be due to higher moisture conservation because of tied ridges. Green gram yield under residue retention out yielded those under bare land by 1.4 t/ha. Increase in yield under residue retention could be attributed to prevention of soil moisture evaporation available for crop use. Sole green gram crops out-yielded intercrop by 1.305 t/ha. Increase in yield under sole crop could be attributed to lack of competition of resources from other crops (Masaku, M. K., 2019).

Reduction of yield under intercrop could be due to presence of interspecies competition. Green gram yield increased under interaction between tied ridges * residue retention by 1.58 t/ha which could be attributed to rainwater capture and retentions and soil moisture conservation due to mulch and tied ridges. Yield increased because of tied ridges * sole crop interaction by 1.728 t/ha due absence of competition and presence of soil moisture conservation.

Number of seeds per pod increased under tied ridges by (13.9), residue retention by (13.1) and sole crop by (13.2). Number of seeds per pod increased under interaction between tied ridges * sole crop by 12.3 and residue retention * sole crop by (13.6). Number of seeds per pod increased under interaction between tied ridges * residue retention * sole crop (14.9).

Number of pods per plant increased under tied ridges by (13.3), residue retention by (11.9) and sole crop by (11.1). Interaction between tied ridges * sole crop significantly affected number of pods per plant.

CONCLUSION AND RECOMMENDATION

The general findings suggest that tied ridges * residue retention * sole crop interaction was effective in increasing green gram growth and yield in comparison to conventional tillage, bare land and intercropping. Small scale farmers be encouraged to construct tied ridges for rainwater harvesting and utilization by crops. Crop residue retention in the farms need to be promoted for improved yield. More Research need to be done on the effect of tillage, residue retention on various green gram varieties**.** More research needed on the critical residue amount for increased yield.

Table 1. Green gram yield under tillage, residue amount and cropping system during 2020 short rain and 2021 long rain seasons at Katangi.

Treatments	No. of pods/plant		No. of Seeds/pod		1000 Seed weight (g)		Seed yield t/ha	
	2020	2021	2020	2021	2020	2021	2020	2021
Tillage (T)								
CT	8.5	10.2	11.1	12.7	61.74	57.67	0.726	1.1327
No-till	7.9	6.1	11.1	12	59.13	57.28	0.388	0.7009
TR	10.2	13.3	12.4	13.9	64.51	66.32	0.599	1.3594
P Tillage	0.081	<.001	0.475	0.012	0.039	<.001	0.003	<.001
(P≤0.05)	2.106	0.366	3.0686	0.9378	3.696	1.711	0.10005	0.04761
Residue amount (Res)								
0 t/ha	8.1	8.5	10.8	12.6	60.29	58.52	0.9267	0.8709
3 t/ha	9.6	11.2	12.3	13.1	63.29	62.32	1.4033	1.2578
P Residue	0.139	<.001	0.001	0.019	0.014	0.001	<.001	<.001
(P≤0.05)	2.193	0.892	0.6219	0.3557	2.129	1.665	0.05961	0.01071
Cropping system (CS)								
Sole	9.1	10.5	11.4	13.2	62.5	61.76	1.305	1.305
Intercrop	8.6	9.2	11.7	12.5	61.09	59.08	1.025	1.025
P Cropping	0.664	0.004	0.092	0.001	0.252	<.001	<.001	<.001
(P≤0.05)	2.396	0.759	0.3926	0.3228	2.553	0.7	0.03126	0.02835
Significant levels								
Till * Res	0.7	0.033	0.255	0.178	0.985	0.178	0.004	0.205
Till * CS	0.382	0.0696	<.001	0.747	0.032	0.051	0.004	<.001
Res * CS	0.666	0.652	0.527	0.017	0.78	0.376	0.371	0.003
T * Res * CS	0.148	0.032	<.001	0.014	0.525	0.139	0.293	0.588

Table 2. Green gram yield under tillage, residue amount and cropping system during 2020 short rain and 2021 long rain seasons at Katumani.

Treatments	No. of pods/plant		No. of Seeds/pod		1000 Seed weight (g)		Seed yield t/ha	
	2020	2021	2020	2021	2020	2021	2020	2021
Tillage (T)								
CT	12.4	5.6	12.3	11.5	65.7	65.46	0.726	0.2058
No-till	8.6	5	11.9	11.4	62.3	59.8	0.388	0.145
TR	11.8	6.8	11.7	12	82.9	66.96	0.599	0.4035
P value	0.014	0.262	0.932	0.559	0.36	0.172	0.014	0.047
LSD (P≤0.05)	2.076	2.528	4.258	1.598	37.56	8.829	0.1127	0.19697
Residue amount (Res)								
0 t/ha	11.9	11.8	11.7	11.8	65	62.87	0.2228	0.2228
3 t/ha	9.9	11.5	12.3	11.5	75.7	65.27	0.2801	0.2801
P Residue	0.044	0.497	0.367	0.497	0.346	0.27	0.017	0.017
LSD (P≤0.05)	1.904	1.034	1.443	1.034	25.62	4.825	0.1146	0.04266
Cropping system (CS)								
Sole	11.1	6	11.7	11.9	75.4	64.8	0.2681	0.2681
Intercrop	10.8	5.6	12.2	11.4	65.2	63.35	0.2347	0.2347
P Cropping	0.694	0.561	0.404	0.141	0.358	0.053	0.076	0.076
LSD (P≤0.05)	1.831	1.538	1.23	0.76	23.23	1.469	0.1092	0.03762
Significant levels								
Till * Res	0.393	0.7	0.597	0.617	0.433	0.62	0.251	0.251
Till * CS	0.066	0.382	0.197	0.551	0.325	0.101	0.603	0.603
Res * CS	0.119	0.666	0.063	0.148	0.363	0.324	0.132	0.132
Till * Res * CS	0.293	0.237	0.12	0.546	0.416	0.039	0.393	0.393

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PRECISION AGRICULTURE FOR TREECROPS

WATER AND NUTRIENT REQUIREMENTS OF HASS AVOCADO: A GUIDE FOR PRACTITIONERS IN UGANDA, SUB-SAHARAN AFRICA AND BEYOND #9538

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ABSTRACT

Hass avocado production is increasing in Uganda and sub-Saharan Africa (SSA) to tap into the lucrative market especially in Western Europe, China, Japan, and Russia. However, there is limited information about its water and nutrient requirements in end-user-friendly formats especially in Uganda and SSA. We consolidated the scanty information about water and nutrient requirements of Hass avocado and made necessary recalculations and unit conversions to aid meaningful uptake of the information by practitioners without the necessary basic scientific background. This end-user-friendly format of reporting could increase uptake and correct use of information about climate smart water and nutrient requirements for increased Hass avocado yields, fruit quality and incomes.

Keywords: Climate smart water and nutrient conservation practices, Hass avocado, nutrient requirements, supplemental irrigation, water requirements

INTRODUCTION

Avocado *(Persea americana* Mill., family *Lauraceae*) is a tropical/subtropical fruit tree with the most nutritious benefits in the world (15-30% oil and 123-387 cal 100 g^{-1}). About 68 g Hass avocado fruit can supply 345 mg K, 114 kcal of energy, 43 lg vitamin A, 14 lg vitamin K, 185 lg lutein/zeaxanthin, and 57 mg phytosterols (Dreher and Davenport, 2013). Avocado oil consists of monounsaturated fatty acids (71%), polyunsaturated fatty acids (13%), and saturated fatty acids (16%) which help promote healthy blood lipid profiles (Selladurai & Awachare, 2020). Some phytochemicals in the oil have anti-cancer properties, anti-aging-related muscular degeneration, and can suppress cardiovascular diseases (Cervantes-Paz & Yahia, 2021). Avocado fruit is also widely used in the cosmetics industry because if its marked softening and soothing effect and the highest skin-penetration rate (Swisher, 1988).

Avocado is grown by more than 50 countries across the world with Mexico (31.5%), Dominican Republic (9.1%), Peru and Colombia (7.3% each), Indonesia (6.3%), Kenya (5%), and Brazil (3.3%) dominating total fruit production worldwide estimated at 7.31 million tons in 2019 (FAO, 2021). Sub-Saharan Africa (SSA)'s share of this production was very dismal, with Kenya and Ethiopia dominating the scene (FAO, 2021). Poor agronomic practices and in particular, limited use of fertilisers and supplemental irrigation to complement rainfall are among the major constraints to Hass avocado production in SSA. Even elsewhere where fertiliser application and irrigation are done the information is not readily available in end-user-friendly formats for use by avocado typical farmers in SSA. For example, evaporative demands of Hass avocado were reported in depth of water in millimetres Planningor inches per day (Carr et al. 2013; Lahav et al. 2013). Similarly for irrigation water requirements, units ranged from inches and gallons (Guides 2018) to m^3 $acre^{-1}$ or ha^{-1} (Hoffmann and Du Plessis 1999). This diversity in reporting was also observed for nutrient requirements (Lovatt et al. 2015; Selladurai and Awachare 2020). We, therefore, consolidated this information, made the necessary recalculations and unit conversions, and adopted a unified simplified reporting format for easier uptake by practitioners in Uganda, SSA and beyond.

MATERIALS AND METHODS

We accessed peer-reviewed journal articles from common search engines including Web of Science, Web of Knowledge, Research Gate, Google, Encyclopaedia, AGORA, and Google scholar using the keywords of the study. We also accessed textbooks, edited books, and book chapters of interest to the study from websites such as Google scholar, Be-ok Africa, College Library and Makerere University e-library. Technical reports were also accessed from authoritative repositories including the FAO and USDA databases.

The information collected was synthesized and where necessary, recalculations and unit conversions were made to generate a unified end-user-friendly package for Hass avocado practitioners. For example, for Hass avocado evapotranspiration requirements the millimetres (mm), inches and gallons (Guides 2018) were converted into litres or m^3 ha^{-1} day^{-1} or yr^{-1} as the standard unit of reporting. For irrigation water requirements reported in Western Australia (McCarthy 2001), we converted kilolitres (kL) into litres (L) and m^3 day^{-1} or yr^{-1}. The water requirements in mm ha^{-1} or $acre^{-1}$ day^{-1} reported for temperate, tropical, and Mediterranean climates (Lahave et al. 2013) were converted to SI units of m^3 ha^{-1} day^{-1}.

For nutrient requirements, much of the literature reported SI unit of kg but variation in unit area including acres, ha, with the exception of a few where weights were reported in pounds, ounces, etc., which we recalculated and reported as kg ha^{-1}. We also homogenised the grade analyses to aid computation of nutrient requirements from mineral fertilisers. What we found interesting and should be promoted is the reporting of nutrient requirements per unit diameter of each tree and nutrient replenishment based on quantity removed per ton of fruit yield (see Table 1 for the conversions made).

Table 1. Conversions made to standardise units of reporting water and nutrient requirements of Hass avocado.

Unit conversions for water requirements	Nutrient values in different fertilizers
1 ounce = 28.35g 1 pound (lb) = 1 inch = 2.5 cm 1MPa = 1000 kPa 1 gallon = 3.785 liters 1 Hectare = 2.45 acres 1 Hectare = 10,000 square meters 1mm depth of water ha^{-1} = 10 m^3 = 1000L	TSP = 40% P_2O_5 = 17% P (i.e., % P = % P_2O_5 / 2.29) CAN = 26.6% N MOP = 60% K_2O = 50% K (i.e., % K = %K_2O / 1.2) SSP = 20% P_2O_5 = 8.7 %P

RESULTS AND DISCUSSION

Average rainfall for leading Hass avocado-producing regions of the world ranges from 899 – 1312 mm yr^{-1}, implying that the crop can grow in much of Uganda and indeed, SSA. Daily irrigation requirements to meet the evapotranspiration needs of Hass avocado (Table 2) range from 1.5 mm (15 m^3 ha^{-1}) in winter (in South Africa) to 6 mm (60 m^3 ha^{-1}) during summer in California. Yields increase with supplemental irrigation (Erazo-mesa 2021) hence, a high potential to more than triple fruit yields under predominantly rain-fed Hass avocado producing areas (Fig. 1). Novel climate smart technologies for increased residence time of water within the plant root zones (Smucker et al. 2018; Olupot et al., 2021) can cut supplemental irrigation requirements by 40 to 60% (Smucker et al. 2018).

Table 2. Daily irrigation water requirements of Hass avocado (mm ha^{-1} day^{-1} vs m^3 ha^{-1} day^{-1}).

Country/Region	**Season**	Transpiration water requirements		**Author(s)**
		(mm ha^{-1} day^{-1})	(m^3 $ha^{-1}day^{-1}$)	
California (USA)	Summer	6	60	Lahav et al. (20130
Tropics	-	4	40	Lahav et al. (2013)
Mediterranean	-	3 – 5	30 – 50	Lahav et al. (2013)
South Africa	Summer	-	40	Hoffman & Duplessis (1999)
South Africa	Winter	1.5	15	Hoffman & Duplessis (1999)
Kenya	Dry season	3.57	35.7	Oxfarm (2022)

Note: We recalculated transpiration water requirements (m^3 ha^{-1} day^{-1}) from the mm ha^{-1} day^{-1} data published by the cited author(s).

Generally, nutrient requirements of Hass avocado increase with phenological growth stage and are critical at flowering and after a heavy fruit yield, implying that old trees need more fertilisation than young trees to sustain high yields especially after a ‘heavy’ season.

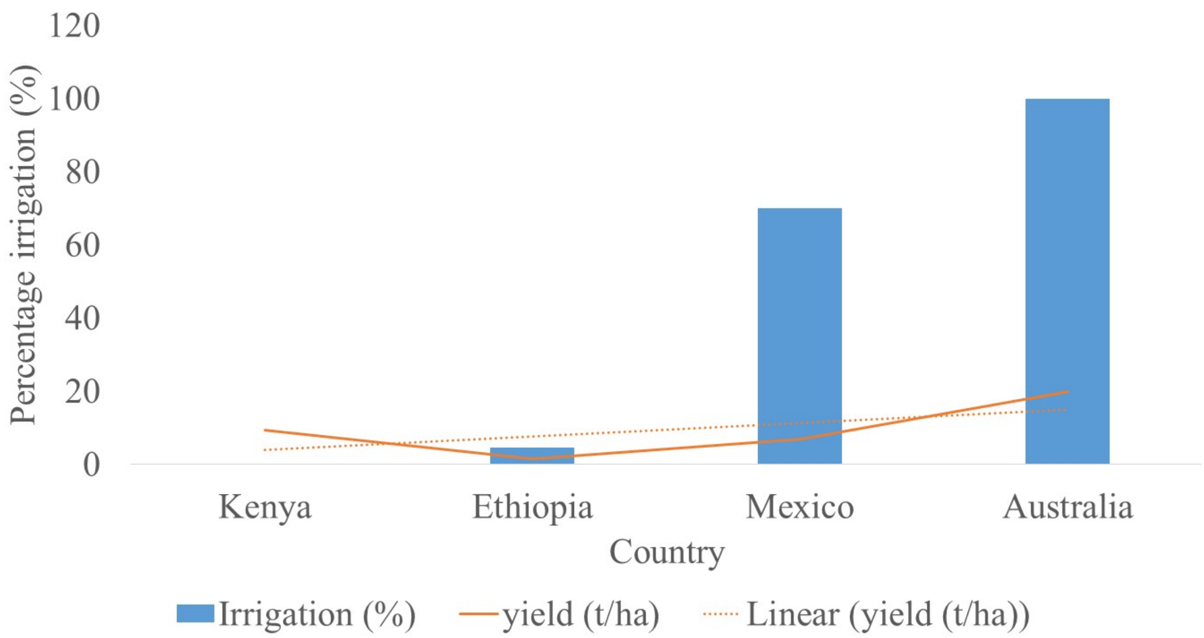

Fig. 1. Relationship between intensity of supplemental irrigation and average yields of Hass avocado orchards in selected countries.

For example, nutrient requirements increase from 5.2 kg N ha^{-1} (for one-year old trees) to 53.9 kg N ha^{-1} at ≥15 years; phosphorous increases from 6.0 kg P ha^{-1} to 31.8 kg P ha^{-1} and potassium from 17.6 kg K ha^{-1} in the 6th year to 50.7 kg K ha^{-1} at ≥15 years to supplement organic inputs such as farmyard manure (FYM) applied at 2,340 kg ha^{-1} (for one-year) or 4,680 kg ha^{-1} for seven-year old trees (Gentile et al. 2016). Best results are obtained when nutrients are applied per unit circumference of each tree (Table 3).

Table 3. Guidelines for Hass avocado nutrient requirements (g cm^{-1} tree trunk—Snijder & Stassen, 2000).

	Nutrient requirements of Hass avocado g cm^{-1} tree trunk circumference				
Soil type	N	P	K	Ca	Mg
Sandy soils (0 – 12% clay)	5.3	0.9	7.6	2.5	1.7
Medium potential soils (13 – 24% clay)	4.2	0.7	6.1	2.0	1.4
High potential soils (> 24% clay)	3.4	0.6	4.9	1.6	1.1

CONCLUSION

There is a potential to more than triple Hass avocado yields under predominantly rain-fed production systems in sub-Saharan Africa. This is possible with supplemental irrigation and novel climate smart technologies for coupling water and nutrient retention within plant root zones (Olupot et al. 2021). The simplified format of reporting information in this review should aid accurate targeting of water and nutrients as recommended to increase yields and production of high-quality Hass avocado fruit by practitioners.

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PRECISION NUTRIENT MANAGEMENT

EFFECT OF USING DIFFERENT FORMULATIONS OF FERTILIZERS ON STOMATAL CONDUCTANCE, LEAF CHLOROPHYLL FLUORESCENCE, GROWTH AND YIELD OF TABLE GRAPES CROPS GROWN IN THE NORTHEAST OF MOROCCO
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ABSTRACT

The aim of this research study was to investigate the impact of using fertilizers based on organic matter and amino acid on leaf stomatal conductance, chlorophyll a fluorescence, leaf relative content and stress index and growth and yield of the table grapes. Experiments were conducted on a commercial production scale of 35 ha located in the region of "El GARET", northeast of Morocco. Variety of Regal was used with plant density of 2000 plants/ha. Three commercial liquid fertilizer formulations were used: Fertilizer-1 (Total Nitrogen: 6,77%, Total Organic Nitrogen: 6,41%, Organic Carbon: 27,6%, Total Amino Acid: 36,01%, Free Amino Acid: 7,06%, Organic Matter: 47,5%), Fertilizer-2 (Total Nitrogen: 4%, Ureic Nitrogen: 4%, Oxide of potassium: 15%, Organic Matter: 30%, Boron: 0,5% and Molybdenum: 0,2%) and Fertilizer-3 (Total Nitrogen: 3,42%, Organic Nitrogen, 3,38%, Calcium: 0,20%, Iron: 78ppm). Three treatments were applied in this experiment: T1 (control), T2 (Fertilizer-1 and Fertilizer-2) and T3 (Fertilizers-3). An amount of 3L, 4L and 4L of irrigation water was injected above the root system and under the dripper for each tree. A conventional fertilization program was used by the grower in T1, T2 and T3 plots; except for the prototype T2 and T3 treatments plots where the fertilizers 1, 2 and 3 were applied. Fertilizers were applied 4 times and every 15-20 days. Results showed a significant increase in plant yield and stem growth for T2. Stomatal conductance was decreased for T2. The relative water content (RWC) was significantly increased with T3 and no differences between treatments were recorded for the stress index; F_v/F_m, DI_0/RC and ET_0/RC.

INTRODUCTION

Table grapes (*Vitis vinefera*) present an important crop production in Morocco. The surface area of the plantations is 49 000 ha, where 38 000 ha is for table grapes and 11 000 ha for wine production (Agrimaroc, 2021). The main varieties produced are: Doukkala, Muscat of Italy, Valency, Abbou, Boukhanzir and Muscat of Alexandria, which present about 77% of the total area of table grapes production. The practice of tree fertilization is based on nitrogen, phosphorus, potassium, calcium, magnesium, and micronutrients. Previous research demonstrated that using mixed fertilizers with microelements, organic matter, and amino acid 4-5 times during the phonological stage improved growth and yield of different crops (Martinez et al, 2018). Organic matter enhances plant growth and development, and it plays a vital role for improving photosynthesis (Ye et al., 2022). Amino acid is considered also as an element that increases production and improves plant stress status; It involves respiration; assimilation of chlorophyll transport and storage of carbohydrates (Popko et al., 2018).

Chlorophyll a fluorescence measurement presents a suitable way to evaluate photosynthesis efficiency and stress index of the crops (Schreiber, 2004). This method can provide data on the ability of plants to respond and tolerate environmental stresses (Maxwell and Johnson, 2000). The relationship between chlorophyll a fluorescence and nutrient status was evaluated in several studies on different species (Strand and Lundmark, 1995). Chlorophyll fluorescence usually indicates the transfer of electrons during the light phase of photosynthesis from the excitation of chlorophyll by light energy to the transfer of electrons for the dark phase (Tsimilli-Michael and Strasser, 2001). The ratio F_v/F_m varies between 0.75 and 0.85 in non-stressed plants and it is a good indicator for stress level status. Moreover, the parameter ET_0 indicates the number of electrons transferred for the dark reaction of photosynthesis to fix the CO_2 during the Calvin cycle (Cahize et al., 2018). The more plants are stressed, the electrons chain is getting interrupted, and the number of electrons transferred to the Calvin cycle decrease (Murata et al., 2007). The DI_0 is also a good indicator of plant stress and indicates the dissipation of energy as heat; the more plants are stressed the more the value of DI_0 increases (Waraiach et al., 2012).

The objective of this work is to evaluate the effect of different formulations of mixed fertilizer based on organic matter and amino acid on leaf stomatal conductance, chlorophyll a fluorescence and stress index, leaves relative content and plant growth and yield of table grapes grown under Mediterranean climate conditions of the northeast of Morocco.

MATERIALS AND METHODS

Experimental site

This study was carried out in the region of “El GARET” (34°59'51.0"N 3°03'50.9"W), northeast of Morocco, on a production of 8-year-old table grapes (Fig. 1a). This region is characterized by Mediterranean climate, with an average precipitation rate of 250-300 mm/ year. The planting density was 2000 plants/ha. Each row was spaced at 3m and the distance between two plants of the same row was 1,5 m. Variety of “Regal” was used during this experiment. A dripper of 4 L/h was used for irrigation. The crops have been managed according to the good practices of the commercial production of table grapes in Morocco.

Treatments

Three commercial liquid fertilizer formulations were used: Fertilizer-1 (Total Nitrogen: 6,77%, Total Organic Nitrogen: 6,41%, Organic Carbon: 27,6%, Total Amino Acid: 36,01%, Free Amino Acid: 7,06%, Organic Matter: 47,5%), Fertilizer-2 (Total Nitrogen: 4%, Ureic Nitrogen: 4%, Oxide of potassium: 15%, Organic Matter: 30%, Boron: 0,5% and Molybdenum: 0,2%) and Fertilizer-3 (Total Nitrogen: 3,42%, Organic Nitrogen, 3,38%, Calcium: 0,20%, Iron: 78ppm and). Three treatments were applied in this experiment: T1 (control), T2 (Fertilizer-1 and Fertilizer-2) and T3 (Fertilizers-3). A conventional fertilization program was used by the grower in T1, T2 and T3 plots; except for the prototype T2 and T3 treatments plots where the fertilizers 1, 2 and 3 were applied. For T2, the Fertilizer-1 was applied on April 11th, May 11th, June 9th and July 7th, 2022, and the Fertilizer-2 was applied on April 29th, May 25th, June 23rd, and July 21st, 2022, respectively. For T3, the Fertilizer-3 was applied only, on April 11th, May 11th, June 9th, and July 7th, respectively. According to the commercial recommendation of three products, an amount of 3L, 4L and 4L of irrigation water was injected above the root system and under the dripper for each tree with 1ml (or 2 L/ha), 5ml (10 L/ha) and 5ml (10 L/ha) of the concentrate solution for fertilizers 1, 2 and 3, respectively. Twenty-four trees were selected for each treatment to quantify the physiological and productivity measurements.

Measurements

Plant growth: parameters were measured every 2 weeks from April until July. Measurements were recorded on 12 plants for each treatment. Plant height and number of sticks were recorded. One stick was selected for each tree to measure it length, number of nodes. Then, the fifth shoot from the apex of the stick was selected to measures its length.

Relative water content (RWC): twelve samples were taken twice (July 17th), early in the morning, from each treatment. Top-most fully expanded leaves were sampled; the fifth leaf from the apex of the fifth selected shoot of the selected stick. Fresh samples were weighted (FW) and then were immediately hydrated in distilled water to full turgidity and then moved to the laboratory for 48 h under normal room light and temperature conditions. After hydration, samples were weighted (TW) and then moved to steaming room at 80°C for 48h and weighed to determine dry weight (DW). The formulate of the calculation of RWC is presented as following (Equation 1):

$$\text{RWC (\%)} = [(\text{FW-DW}) / (\text{TW-DW})] \times 100 \quad \text{(Equation 1)}$$

Stomatal conductance (gs) was measured by & Porometer (SC-1 Porometer, Meter Group Inc., USA) and chlorophyll a fluorescence with Handey PEA (Hansatech, UK). Measurements were recorded on a hot and sunny day, (July 13th) from 11:00 until 13:00. Measurements were taken on the fifth leaf from the apex of the fifth selected shoot of the selected stick. For the stress fluorescence measurements, leaves were adapted to the dark for 30 min using a clip. Then, a light flash of 3000 µmol/m2/s (650 nm) was applied for 1 s (gain = x1) on the leaf adapted to darkness. The measurements were taken on 6 plants for each treatment. Parameters of F_v/F_m, DI_0/RC, ET_0/RC were measured, and each has a specific physiological indication (F_v: variable fluorescence; F_m: maximum fluorescence; DI_0: dissipated heat; RC: reaction center, ET_0: number of electrons transferred for the dark reaction of photosynthesis to fix the CO_2 on the Calvin cycle):

Fruit yield: at the end of the experiment; October 23rd, number of clusters were measured on 12 plants for each treatment. The cluster weight was recorded on 8 plants for each treatment.

Data analysis

Statistical analysis was performed using IBM-SPSS (version 21). For each evaluated parameter, replicates were taken for treatments. Means with standard deviations were used to determine the differences. The mean values obtained were compared by analysis of variance (ANOVA). The test of Duncan was used, and the significance level was $P < 0.05$.

RESULTS AND DISCUSSION

No significant difference was recorded for plants growth parameters between treatments (Table 1). Those parameters were: principal stem height, secondary stem number and the number of nodes taken at the level of the selected stem. However, the length of the third stem taken at the level of the sixth node was significantly reduced for T3 compared to the control and to T3. Regarding the values of the relative water content recorded on July 17th (Table 2), a significant decrease in RWC was recorded for T3 compared to T1 and T2. This means that water content in the leaves was increased (Soltys-Kalina et al., 2016) by the fertilizer 3 treatment.

Moreover, the stomatal conductance was significantly decreased for T2 compared to the control and to T3. Sheng et al., 2020 reported that amino acid and organic matter increased the stomatal conductance and in this case the opposite was occurred. Regarding the plants stress parameters, the ratios F_v/F_m, DI_0/RC, ET_0/RC didn't change with treatments during sunny and hot conditions day conditions (July 17th, at mid-day). In this case the ratio ET_0/RC which indicates that the number of electrons transferred from the light reaction from thylakoid membrane to stroma for the dark reaction and to fix the CO_2 was the same for all treatments.

Also, the parameter DI_0/RC shows that plants in all the treatments dissipated the same heat energy which indicate that and theirs stress status were the same. Contrary, previous work (Badiane et al., 2012; Gunes et al., 1994) showed that plant stress was reduced by the application of amino acid and organic fertilizer.

Regarding plant yield, the fruit weight was significantly increased for T2 compared to the control treatments (data not shown). This increase in T2 were supported by Mostafa et al., 2008 and Nikiforova et al. 2006 who showed that organic matter and amino acid increased plants yield.

Table 1. Parameters of plant growth measured on table grapes grown under the control (T1) and prototype treatments (T2 & T3) (recorded on July 7th, 2022).

Treatments/Parameters	Control (T1)	T2	T3
Principal stem height (cm)	1,27 ±0,07 a	1,33 ±0,09 a	1,30 ±0,08 a
Secondary stem number	6 ±1 a	6 ±1 a	7 ±1,7 a
Length of 3rd stem (at 6th node) (cm)	55,8 ±18 b	86,3 ±16 a*	60,1 ±16 b
Number of nodes/ selected stem	12 ±2,4 a	12 ±3,8 a	12 ±2,1 a

T1= without fertilizers 1, 2 & 3; T2= with fertilizers 1 & 2; T3= with fertilizer 3.
Data are mean of 12 repetitions ±standard deviation.
*Significant data; the Duncan test was used for comparisons between averages, with α=0,05.

Table 2. Leaf relative water content (RWC) of table grapes plants grown under the control (T1) and prototype treatments (T2 & T3) (measured on July 17th, 2022).

Treatments/Parameter	Control (T1)	T2	T3
RWC (%)	74 ±9 b	74 ±7 b*	84 ±4 a

T1= without fertilizers 1, 2 & 3; T2= with fertilizers 1 & 2; T3= with fertilizer 3.
Data are mean of 12 repetitions ±standard deviation.
*Significant data; the Duncan test was used for comparisons between averages, with α=0,05.
The 5th leaf from the apex of the 5th selected shoot of the selected stick was used as a sample.

Table 3. Stomatal conductance (g_s) and the stress index F_v/Fm, DI_0/RC, ET_0/RC, measured on leaves of the table grapes during a hot and sunny day (July 13th, 2022) for the control (T1) and prototype treatments (T2 & T3) (11:00-13:00).

Treatments/Parameters	Control (T1)	T2	T3
g_s (mmol/m^2/s)	316 ±71 a	226 ±58 b*	280 ±100 a
F_v/F_m	0,79 ±0,04 a	0,79 ±0,03 a	0,80 ±0,03 a
DI_0/RC	0,43 ±0,08 a	0,49 ±0,07 a	0,38 ±0,08 a
ET_0/RC	0,73 ±0,03 a	0,73 ±0,08 a	0,73 ±0,09 a

T1= without fertilizers 1, 2 & 3; T2= with fertilizers 1 & 2; T3= with fertilizer 3.
F_v= variable fluorescence; F_m= maximum fluorescence; DI_0= dissipated heat= RC= reaction center; ET_0= number of electrons transferred for the dark reaction of photosynthesis to fix the CO_2 on the Calvin cycle.
Data are mean of 6 repetitions ±standard deviation.
*Significant data; the Duncan test was used for comparisons between averages, with α=0,05.
The 5th leaf from the apex of the 5th selected shoot of the selected stick was used as a sample.

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CHLOROPHYLL METER BASED PRECISION NITROGEN MANAGEMENT IN MAIZE GROWN IN ALLUVIAL SOIL IN EGYPT
#9409

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ABSTRACT

Precision nitrogen (N) management is essential for profitable crop production and to minimize N losses to the environment that are a consequence of an excessive N supply. Chlorophyll meter-based N management can help to achieve high N use efficiency, as aquick and non-destructive spectral characteristics of leaves, which can be used to diagnose plant N deficiency and graduate N fertilization with improve N use efficiency. Field experiments were conducted during two consecutive years, 2019 and 2020 on maize (Zea mays L), Triple-cross hybrid 321 grown in an alluvial soil at the Experimental Farm of Faculty of Agriculture, Cairo University, Giza Governorate, Egypt to study the visibility of using chlorophyll meter (AtLeaf) for precision management of N in maize. In the first growing season, an increasing rate of N fertilizer (0, 70, 110, 150, 180, 190, 220, 240 and 280 kg N ha^{-1}) add in three equal split doses as ammonium nitrate was applied to establish the chlorophyll Index value with different yield potentials. In second growing season the validity of the established chlorophyll index was tested. The results of the first growing season revealed that at relative grain yields of 100, 80, and 70%, the Cate-Nelson graph technique was employed to determine the critical chlorophyll index value. These values were proposed for applying N fertilizer in increment dosages. The suggested critical values of chlorophyll index at 100, 80 and 70 % relative grain yield of maize were 60, 55 and 40, respectively. Accordingly, a strategy to refine N application dose was suggested to be applied at V9 growth stage of maize as guided by the chlorophyll meter. The suggested strategy is applying 0, 47, 95 or 142 kg N ha^{-1} corresponding to chlorophyll index values of more than 60, 60-55, 55-40 and less than 40. The result of second growing season indicted that grain yields obtained as guided by the chlorophyll meter is statistically higher than the other treatments. Meter-based N management was able to overcome variability in maize growth induced by varied prescriptive N management while using less N fertilizer. For instance, applying a total of 142 kg N ha^{-1} as prescriptive in two doses (71 and 71 kg ha^{-1}) then applying a corrective dose as guided by the chlorophyll meter at growth stage resulted in grain yield of 9734 kg ha^{-1}. Data pertaining to N recovery efficiency (REN) showed that the meter-guided N treatments resulted in higher use efficiency as compared to the general recommendation treatment. When appropriate prescriptive N fertilizer was applied (71 and 71 kg N ha^{-1}) followed by corrective dose, an average increase of REN by 10.7% compared with the general recommendation rate. In conclusion, using the chlorophyll meter to guide N management can help farmers manage N fertilizer more efficiently, resulting in greater yields, less N fertilizer application and higher N use efficiency.

INTRODUCTION

Nitrogen (N) fertilizer in maize in Egypt is managed in large areas following a prescriptive general recommendation. Yet, to ensure high yields, farmers often apply N fertilizer in quantities greater than the general guideline. Temporal and spatial variability, however, results in the application of N fertilizer more or less than the actual crop requirement. Maize in Egypt consumes about 23.8% of N fertilizer, representing the nation's largest N-consuming crop (Heffer, 2013). Based on worldwide assessment, the N fertilizer recovery efficiency has been found to be about 33% for maize (Krupink et al., 2004). It means that significant amounts of N fertilizer are lost from the soil. In addition to environmental degradation, the low recovery efficiency of N fertilizer is responsible for high costs (Bijay-Singh and Yadvinder-Singh, 2003; Fageria and Baligar, 2005).

To optimize nitrogen (N) fertilizer application, it is necessary to match the N supply to the N demand (Meisinger, et. al, 2008; Monostori, et. al, 2006). A potentially very effective approach would be the rapid and frequent on-farm assessment of crop N status that permits rapid adjustment of the N supply (Gianquinto, et. al, 2004; Padilla, et. al, 2015; Thompson, et. al, 2017). Proximal optical sensors are a broad group of non-destructive monitoring tools that can be used to assess crop N status (Thompson, et. al, 2017; Fox and Walthall, 2008; Padilla, et. al, 2008). One particularly promising group of proximal optical sensors are leaf chlorophyll meters.

Chlorophyll meters are relatively simple proximal optical sensors that indirectly assess relative leaf chlorophyll content by measuring the differential absorbance and transmittance of different radiation wavelengths by the leaf (Gianquinto, et. al, 2004; Padilla, et. al, 2008; Khoddamzadeh and Dunn, 2016). The leaf chlorophyll content is usually related to crop N content (Fox and Walthall, 2008; Schepers, et. al, 1996; Mastalerczuk, et. al, 2017), these measurements can be used to assess crop N status (Gianquinto, et. al, 2004; Padilla, et. al, 2008). The atLEAF+ (FT Green LLC, Wilmington, DE, USA) is cheapest commercially available chlorophyll meter (Thompson, et. al, 2017; Padilla, et. al, 2008; Padilla, et. al, 2018). It measures absorbance at 660 nm and 940 nm. Using the two absorbance values, the meter calculates a dimensionless numerical value, which is related to chlorophyll content (Padilla, et. al, 2018). The major practical advantages of chlorophyll meters as indicators of crop N status are that they are easy to use, do not require any training, and they make measurements very rapidly, with no or very little data processing (Gianquinto, et. al, 2004; Padilla, et. al, 2015; Padilla, et. al, 2008; Minotti, et. al, 1994).

Chlorophyll meter measurements do not directly indicate crop N status, so interpretation is required (Padilla, et. al, 2008). Two broad approaches have been proposed to interpret chlorophyll meter measurements to assess crop N status. First approach is the use of so-called “reference plots” (Westerveld, et. al, 2004; Zhu, et. al, 2011). This approach divides the measured values of the crop by those from a well-fertilized reference plot that has no N limitation (Tremblay, et. al, 2011). This is considered to isolate the effect of relative N status from other confounding factors that are common to both areas (Samborski, et. al, 2009), which could greatly facilitate the adoption of chlorophyll meters on farms. Second approach is the use of absolute sufficiency values based on direct measurement. The sufficiency value is an absolute value, below which the crop is deficient and responds to additional N fertilizer (Gianquinto, et. al, 2004; Padilla, et. al, 2017), and above which yield is not affected (Gianquinto, et. al, 2004) and the immediate N supply may be excessive (Thompson, et. al, 2017). Sufficiency values provide information on whether adjustments in N fertilization are required when absolute measurements deviate from sufficiency values (Olivier, et. al, 2006).

Therefore, the objectives of this research were to develop a logarithm to use chlorophyll meter readings in real-time N management for maize, to define the optimum prescriptive N applications preceding the corrective dose as guided by the chlorophyll meter sensor and to compare the developed strategies with the current general recommendation in terms of grain yield and N use efficiency under the experimental conditions.

MATERIALS AND METHODS

Two field experiments were carried out during 2019 and 2020 summer seasons on Maize (Zea mays L., Triple-cross hybrid 321) grown in an alluvial soil at the Experimental Farm of Faculty of Agriculture, Cairo University, Giza, Egypt. Prior to sowing, the soil was ploughed twice and divided into $15m^2$ plots. Maize was sown in a row spacing of 25 cm × 70 cm. In First season, maize plants were grown in field from 14 May to 20 September 2019. The N fertilizer treatments in this experiment varied from 0 to 280 kg N ha^{-1} (0, 70, 110, 150, 180, 190, 220, 240 and 280 kg N ha^{-1}) applied as ammonium nitrate (33.5 % N) in three equal split doses at 14, 30 and 50 days after sowing (DAS). This range aimed to create wide variability in yield potentials to create an algorithm that would translate the reading of the atLeaf sensors into equivalent quantities of N fertilizer, which will be used to develop management strategies in the second season using chlorophyll meter (atLeaf). The atLeaf readings were collected around 50 DAS at V9 growth stage (leaf 9 stage). The experiment in the second season was conducted to validate the developed sensor algorithm. Maize plants were grown in field from 17 May to 14 September 2020. A prescriptive N dosage of 95, 190, and 142 kg N ha^{-1} was combined with corrective N dose as indicated by the developed algorithm of atLeaf chlorophyll meter during the V9 growth stage of maize, in addition to control (zero-N) and the general recommendation (285 kg N ha^{-1}). The total rates as guided by the sensor were 315, 338, 260, 277, 277, 243, and 300 kg N ha^{-1}. In this experiment, the N-rich strip was maintained by applying 380 kg N ha^{-1} to ensure that N was not limited while calculating the sufficiency index (SI) of atleaf sensor. The experimental design in both seasons was a randomized complete block design with three replications. The Least Significant Test (LSD) was applied to test the mean differences at $P < 0.05$.

RESULTS AND DISCUSSION

Relationship between grain yield of maize and N uptake

The increasing rate of N fertilizer created a great grain yield and N uptake variability in the first season of the experiment. The relationship between N uptake and maize grain yield was best explained by a quadratic function. The maximum N uptake for maximum yield was determined by setting the first quadratic equation derivative to zero, and the result was 248 kg N ha^{-1} at around 8406 kg ha^{-1} grain yield. By setting the optimal yield at 95 % of the maximum yield, grain yields of 7986 kg ha^{-1} can be attained with N uptake of 260 kg ha^{-1}. As a result, the target uptake for which the N fertilizer application level can be estimated using the technique suggested in this work is 260 kg N ha^{-1}.

Establishment of threshold critical values of chlorophyll meter

At relative grain yields of 100, 80, and 60%, the Cate-Nelson graph technique was employed to determine the critical chlorophyll index values. These values were proposed for applying N fertilizer in increment dosages. For instance, when predicting 100% of maximum grain yield, there is no need to apply N fertilizer. While at 80 and 70% relative grain yield medium and high doses of N fertilizer need to be applied, respectively. The graph suggested that the critical values of chlorophyll index at 100, 80 and 60 % relative grain yield of wheat were 60, 55 and 40, respectively.

Accordingly, a strategy to refine N application dose was suggested to be applied at V9 growth stage of maize as guided by the chlorophyll meter. The suggested strategy was applying 0, 47, 95 or 142 kg N ha^{-1} corresponding to chlorophyll index values of more than 60, 60-55, 55-40 and less than 40, respectively. These N application dosage levels were proposed to oppose the existing blinded general recommendation, which ignores differences in field-to-field soil properties and other management practices that influence N fertilizer requirements.

Validation of the established threshold critical values of chlorophyll meter

The experiment conducted in the second season was designed to evaluate the performance of the critical threshold values of chlorophyll meter defined from the first season data. To create plant variability in biomass and N uptake at V9 growth stage of maize, different doses and timings of N fertilizer were practiced before applying the corrective dose as guided by the chlorophyll meter.

The data listed in Table 1 show that grain yields obtained as guided by the chlorophyll meter is statistically higher than the other treatments. Meter-based N management was able to overcome variability in maize growth induced by varied prescriptive N management while using less N fertilizer. For instance, applying a total of 142 kg N ha^{-1} as prescriptive in two doses (71 and 71 kg ha^{-1}) then applying a corrective dose as guided by the chlorophyll meter at V9 growth stage resulted in grain yield of 9734 kg ha^{-1}. Data pertaining to N recovery efficiency show that the meter-guided N treatments results in higher use efficiency as compared to the general recommendation. When appropriate prescriptive N fertilizer was applied (71and 71 kg N ha^{-1}) followed by corrective dose, an average increase of 10.7% REN compared with the general recommendation. As a result, utilizing the chlorophyll meter to guide N management should help farmers manage N fertilizer more efficiently, resulting in greater yields and higher N use efficiency.

Table 1. Maize grain yields, total N uptake and N recovery efficiency as influenced by different N fertilizer treatments as guided by the critical threshold values of chlorophyll meter.

Treatment	Prescriptive doses of N (kg ha^{-1})		Chlorophyll index at 50 DAS	Corrective dose (kg ha^{-1})	Total rate of N fertilizer applied (kg ha^{-1})	Grain yield (kg ha^{-1})	Total N uptake (kg ha^{-1})	RE_N (%)
	0 DAS	30 DAS		V9 50 DAS				
Treatment 1 (control)	0	0	44.3	0	0	3671 e	96 e	-
Treatment 2 (gen. recommendation)	95	95	56.0	95 (fixed)	285	9812 a	269 a	60.7 b
Treatment 3	95	0	47.4	95	190	7318 c	195 c	52.1 d
Treatment 4	47	47	48.1	95	189	8162 b	207 b	58.7 c
Treatment 5	142	0	55.8	47	189	8438 b	223 b	67.2 a
Treatment 6	71	71	51.1	95	237	9734 a	262 a	70.0 a
Treatment 7	0	0	44.1	95	95	6074 d	147 d	53.7 d
LSD ($P < 0.05$)	-	-	-	-	-	401	21.1	6.5

Sufficiency index approach

Varietal groups, seasons, and regions may all have different levels of leaf greenness. Therefore, a single set threshold value for a chlorophyll meter may not be effective. The sufficiency index technique (defined as the ratio of a tested plot's chlorophyll reading to that of a reference plot) allows precision N management to be practiced using dynamic values rather than a set threshold value. This method can self-calibrate in response to changes in soil conditions and seasons.

Keeping up these findings, a strategy to refine N application dose was suggested to be applied at V9 growth stage of maize as guided by the chlorophyll meter in the second season. An N-rich strip was maintained as a reference by applying N fertilizer at a rate of 380 kg N ha^{-1}. The suggested strategy is applying 0, 47, 95 or 142 kg N ha^{-1} corresponding to sufficiency index of chlorophyll meter values of more than 0.95, 0.95-0.75, 0.75-0.55 and less than 0.55. These ranges of N application doses were suggested to challenge the current general recommendation that does not account for the variation in field-to-field soil properties.

Validation of sufficiency index

The experiment in the second season was utilized to assess the performance of the sufficiency index of the chlorophyll meter, which was proposed in this study. To create growth variability in biomass and N uptake at jointing growth stage of maize, different doses and timings of N fertilizer were applied preceding applying the corrective dose as guided by the chlorophyll meter. The data listed in Table 2 show that grain yields obtained in Treatment #6 (applying 71 and 71 kg N ha^{-1} at 0 and 30 DAS, respectively, followed by a corrective dose as guided by the chlorophyll meter) is statistically comparable to the yield attained in the general recommendation, but takes 48 kg N ha^{-1} less fertilizer. Other treatments demonstrated the meter's ability to increase or decrease N fertilizer levels according to the plant's needs during the V9 growth stage. Meter-based N management was successful in overcoming variation in maize growth induced by varied prescriptive N management while using less N fertilizer. Data pertaining to recovery efficiency show that the meter-guided N treatments resulted in higher N recovery efficiency as compared to the general recommendation. For example, when the appropriate prescriptive N fertilizer was administered (Treatment #6), followed by a correction dose, the recovery efficiency increased by 23.2 % over the general recommendation.

Table 2. Maize grain yields, total N uptake and N recovery efficiency as influenced by different N fertilizer (kg N ha^{-1}) treatments as guided by Chlorophyll sufficiency index.

Treatment	Prescriptive doses of N (kg ha^{-1})		Chlorophyll sufficiency index at 50 DAS	Corrective dose (kg N ha^{-1})	Total rate of N fertilizer applied (kg ha^{-1})	Grain yield (kg ha^{-1})	Total N uptake (kg ha^{-1})	RE_N (%)
	0 DAS	30 DAS		at V9 50 DAS				
Treatment1 (control)	0	0	0.61	0	0	3463 e	89 d	-
Treatment2 (gen. recommendation)	95	95	0.83	95 (fixed)	285	9815 a	249 a	56.1 c
Treatment 3	95	0	0.72	95	190	6919 c	179 b	47.4 d
Treatment 4	47	47	0.69	95	189	7453 b	194 b	55.6 c
Treatment 5	142	0	0.74	95	237	7978 a	243 a	65.0 b
Treatment 6	71	71	0.79	47	189	9844 a	239 a	79.3 a
Treatment 7	0	0	0.63	95	95	5894 d	137 c	50.5 d
LSD ($P < 0.05$)	-	-	-	-	-	342	18.8	5.8

It can be concluded that, using the chlorophyll meter in guiding N management could effectively manage N fertilizer to obtain higher yield along applying less N fertilizer. As a result, the use of sensor-guided N-management could effectively prevent yield losses with using lower total N fertilizer rate.

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NITROGEN CO-REGULATED GROWTH, YIELD AND FIBRE QUALITY OF COTTON (GOSSYPIUM HIRSUTUM L.) UNDER DIFFERENT NUTRIENT COMBINATIONS
#9415

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ABSTRACT

Cotton has high requirements for nitrogen (N) phosphorus (P) and potassium (K), and the nutrients interact differently on yield and quality of this crop. This necessitates the precise combination of these nutrients to maximize yield and quality. Two cotton varieties (Bt cotton and a conventionally bred variety, HART 89M) were assessed for growth, yield and quality under different nutrient combinations in two contrasting environments in semi-arid Kenya. Nutrient combinations were NPK, NP, NK, PK, NPK + Zn + S and an unfertilized control. Treatments were laid out in split plot design and replicated three times, where varieties took the main plots while nutrient combinations assumed the sub plots. Nitrogen was applied at 150 Kg N/ha (urea, 46% N), P at 50 kg P/ha (single super phosphate, 20% P), K at 100 kg K/ha (muriate of potash, 60% K) while Zn and S were sourced from zinc sulphate. Crop phenology, growth traits, yield quality attributes were collected and analyzed using GenStat at 5% probability level. Variety Bt out-yielded HART 89M. Omission of N in all combinations delayed maturity. On the other hand, addition of N to either P, K or PK improved crop growth, yield and quality of cotton compared with treatments omitting N as well as the negative control. However, results did not show significant yield and quality improvement with the addition of Zn and S. Interactions between variety and nutrient combinations were marginal and inconsistent. Yield was a function of number of bolls (average $R^2 = 0.6892$) and bolls a function of the number of branches per plant (average $R^2 = 0.8741$). However, the recoverable lint quantity (% ginning out-turn) negatively associated with yield (average $R^2 = 0.8013$). These findings reinforce the importance of N in regulating growth, yield and quality of cotton. However, further studies are required to determine optimal NPK nutrient concentrations to maximize growth, yield and quality of cotton.

INTRODUCTION

Cotton is a cash crop that performs very well in ASALs providing a source of livelihood to the communities in these areas who may have limited economic opportunities to depend on. It is estimated that the current production in Kenya stands at 6,200 bales annually against a national requirement of 140,000 bales and against a potential of 260,000 bales. Some of the contributing factors to low yields at farm level include low soil fertility and water stress. Use of precision agriculture to efficiently manage crop nutrition is an important practice for optimum yields. This is because nutrients are easily lost via denitrification, surface run off, volatilization and leaching (Williams et al., 1999). Nitrogen has a strong effect in determining cotton yield variables such as plant size, number of flowers, boll retention rate, boll size and number of bolls per plant (Gerik et al 1994). Similar to N, P and K nutrition, as well trace elements also affect cotton growth and yield. However, N strongly interacts with other nutrients in crop growth and yield formation.

MATERIALS AND METHODS

Field experiments were conducted in the Agricultural Training Centre (ATC) farm and in farmers' field in Ndalani ward both in Machakos County. The treatments were different combinations of inorganic nitrogen, phosphorous and potassium and two contrasting varieties of cotton. Nutrient combinations were, NPK, NP, NK, PK, NPK+ Zn+ S and control was without the addition of fertilizer. Cotton varieties used as test crops were C571 BGII (genetically modified variety) and HART 89M (conventionally bred variety). Treatments were set out in a randomized complete block design with split plot arrangement and were replicated three times. Cotton varieties were allocated to the main plot and the different combinations of nutrients assumed the sub plots. N, P and K nutrients were supplied by urea, SSP and MOP respectively while zinc and sulphur micronutrients were supplied by zinc sulphate. The full dose of TSP (20 kg P ha^{-1}) was applied during sowing, while urea was applied in two splits as a 1/2 urea treatment was applied uniformly in rows at planting. The remaining 1/2 of each nitrogen fertilizer treatment was side dressed in the band during squaring.

RESULTS AND DISCUSSION

Effect of different combinations of N, P and K nutrients on crop phenology

Different combinations of N, P and K nutrients had a significant *(P< 0.05*) effect on the time taken to 50% boll formation. Fertilized plots took a significantly shorter period to form bolls unlike the negative control and the plot that omitted N nutrient Table 1. The results are similar with the previous findings, that nitrogen promotes and hastens vegetative growth (Brown 2002).

Table 1. Effect of fertilization on cotton boll formation.

Factor	Machakos ATC					Ndalani farm				
	Bl/f	Brs/p	Bls/p	Y/p (g)	GOT%	Bl/f	Br/p	Bls/p	Y/p (g)	GOT %
Variety										
Bt	91.0	34.0	34.0	62.7	40.9	85.0	25.0	19.0	31.0	44.0
HART	102.0	32.0	27.0	76.1	39.8	93.0	25.0	14.0	29.0	42.6
P value	<.001	0.309	0.055	0.107	0.781	0.027	0.804	0.387	0.308	0.654
LSD	1.242	7	7.872	20.54	14.77	5.403	13.9	22.773	5.3	11,37
Nutrient combinations										
NP	95.0	33.0	32.0	78.1	39.7	88.0	26.2	19.0	31.0	42.9
NK	95.0	34.0	34.0	70.7	40.8	87.0	26.9	20.0	30.0	43.9
PK	99.0	31.0	28.0	59.4	40.8	91.0	23.5	15.0	29.0	43.7
NPK	94.0	34.0	32.0	78.8	39.5	88.0	24.7	17.0	31.0	42.2
NPK+Zn+S	93.0	35.0	35.0	72.2	39.8	84.0	25.5	19.0	31.0	42.7
Control	102.0	31.0	22.0	57.0	41.4	96.0	22.3	11.0	28.0	44.3
P value	<.001	<.001	<.001	0.03	0.005	<.001	<0.001	0.011	0.01	0.021
LSD	1.17	1.50	4.46	15.43	1.04	2.49	1.98	4.76	2.20	1.23
Variety × nutrient interactions										
P. values	0.312	0.988	0.078	0.966	0.365	0.163	0.302	0.304	0.837	0.4

Means followed by the same letter within a column are not significantly different Bl/f-Boll formation, Brs/p –branches per plant, Bls-Bolls per plant, Y/p-Yield per plant and GOT % –ginning out turn percentage.

Effect of different combinations of N, P and K nutrients on the growth and yield components

This study found out that different combinations of N, P and K nutrients had a significant *($P \leq 0.05$)* effect on the number branches, number of bolls, yield and the ginning out turn of the two cotton varieties Table 1. The results revealed that the total cotton yield was significant and positively correlated with number of bolls per plant Fig. 1a and b. On the contrary, a higher yield resulting from the application of different combinations of N, P, and K nutrients negatively correlated with the GOT% Fig. 1e and f. In addition, the number of branches were significant and positively correlated with the number of bolls Fig. 1c and d. The results agreed with those of (Munir et al., 2014) who found out that agronomic traits like number of bolls, number of branches majorly contributes to cotton yield and have effect on yield.

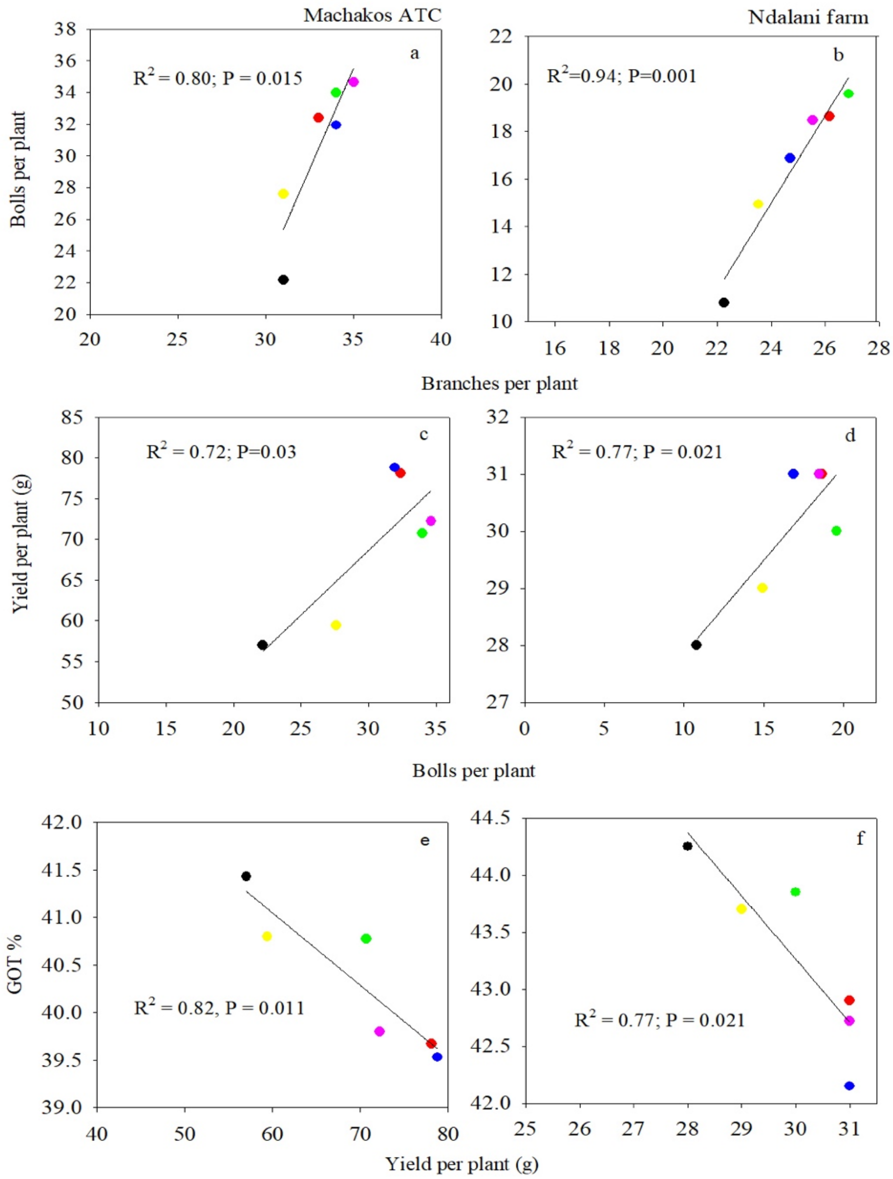

Fig. 1. a and b = Positive relationship between the number of branches and the number of bolls per plant; c and d = Positive relationship between the number of bolls and the yield per plant; e and f = Negative relationship between the yield and the ginning out turn percentage.

CONCLUSION

Nutrients play a very important role in growth, yield and fibre quality of cotton. N nutrient accelerates cotton crop growth, increases the number of branches, number of bolls and consequently the yield. Precision cotton nutrient management, therefore, is a very important practice that will ensure supply of the right nutrients, with right amounts and at the right time in order to increase the seed cotton yield. In addition, supply of nutrients at their optimum levels will ensure positive relationships that increase yield and counteract negative relationships that may lower the seed cotton yield and fibre quality.

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PRECISION MAIZE NUTRITION: EVIDENCES FROM ON-FARM EXPERIMENTATION OF QUEFTS ESTIMATED NUTRIENT REQUIREMENT FOR VARIABLE DENSITIES IN SMALLHOLDER FARMERS IN ETHIOPIA #9424

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ABSTRACT

Models are important for optimizing crop nutrient requirement. In this study QUantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model was used to estimate nutrient requirement of maize for two pant densities (farmers' practices and re-designed) on fields of three farmers wealth classes (poor, medium and wealth). The on-farm study was conducted in 2017 and 2018 with 3 x 2 x 3 fertilizer, plant density and wealth class in factorial combination. The result revealed that interaction effect among the factors is not significant. In 2017, fertilizer use, plant density and wealth class had a significant efficient on maize yield in CRV and in both seasons in Jimma. QUEFTS estimated nutrients resulted in higher yield, but the yield was not significantly higher compared to the farmers' fertilizer uses (FFU) in both regions. Redesigning plant density from farmers' practices to 53,333 plants/ha in CRV and to 62,000 plants/ha in Jimma resulted in significant yield improvement. The yield from fields of medium farm was significantly lower than rich fields of rich farms in Jimma. QE fertilizer use reduced maize yield variability only in Jimma. FFU and QE fertilizer uses were profitable in both regions. In addition, redesigned plant densities were also profitable in growing maize in both regions. This investigation gives insights the importance of using models to optimize nutrient requirement of crops for a better yield and profitability.

Keywords: Ethiopia, Maize, Model, Nutrient requirement, On-farm experiment, Profitability

INTRODUCTION

Food insecurity is a concern in sub-Saharan African countries including Ethiopia. A three-fold cereal production increase is projected to support the population in 2050 (Alexandratos and Bruinsma, 2012). Maize is a dominant and potential cereal crop for food security in Ethiopia (Abate *et al.*, 2015). Most smallholder farmers mainly grow the crop for subsistence. Improving the productivity of this crop is addressing the food security constraints of many people. Despite the large maize production potential (favorable climate, diverse genotypes for most of agro-ecologies and well-drained soil) of the country, the current maize yield is far below the potential yield. The current focus to increase production is improving cereal productivity with improved and farm context crop management technologies.

Low maize productivity in Ethiopia is mostly due to sub-optimal crop management such as nutrients (Getnet et al., 2022; Seyoum *et al.*, 2019; Seyoum *et al.*, 2018)). Agricultural models that follow target-oriented approach for example QUantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) are believed to optimize N, P and K nutrients in balanced proportion (Ponsioen *et al.*, 2006). However, previous research on maize management practices hardly addressed the use of models for optimizing nutrients. Planting density of the crop has been given less attention and land resources are not efficiently used in smallholder farmers. Moreover, farms are heterogeneous in their socio-economic conditions. They need different intervention approaches based on their constraints and opportunities (Descheemaeker et al., 2016; Giller *et al.*, 2011)). The objectives of this paper were to (1) test and evaluate QUEFTS estimated nutrient requirement of maize in relation to farmers, practices under farmers' practices and redesigned plant density at fields of variable farm class and (2) to assess the interaction of fertilizer use, plant density and wealth class on maize yield.

MATERIALS AND METHODS

Treatments: farmers' practices and nutrient estimation using QUEFTS model

Farmers' practices (fertilizer use and plant density) were obtained from the farm survey in the regions (Tesfaye *et al.*, 2019). Factors and levels were shown on Table 1. Nutrients estimation by QUEFTS was based on 50% of Yw target yield (van Ittersum and Rabbinge, 1997). The 50% of Yw in CRV and Jimma are 3.1and 7.5 t/ha respectively. Nutrient (N, P and K) uptake was estimated to the given target yield. Soil supplied nutrients (N, P and K) were estimated and were subtracted from the total uptake. The remaining uptake was supplied only from the fertilizer and then corrected for their recovery fractions. Farms were classified into three wealth classes such as poor, medium, and rich based on their resource endowment. A total of 12 farms (4 poor, 4 medium and 4 rich) were selected and their fields were used for the experimentation.

Table 1. Amounts of N, P and K in fertilizer use treatments and plant densities in CRV and Jimma.

Region	*Levels*	*Factors*	*Nutrients (kg/ha)*		
CRV		**Nutrient mgt**	N	P	K
	1	0 NPK	0.0	0.0	0.0
	2	FFU	21.5	12.8	0.0
	3	QUEFTS, 50%Yw	40.8	0.0	12.2
		Plant density (ha^{-1})			
	A	Farmers' practices	32,443		
	B	Redesigned	53,333		
		Nutrient mgt	N	P	K
Jimma	1	0 NPK	0.0	0.0	0.0
	2	FFU	53.2	30.0	0.0
	3	QUEFTS, 50% Yw	149.8	9.0	130.6
		Plant density (ha^{-1})			
	A	Farmers' practices	27,724		
	B	redesigned	62,000		

Variability of maize yield was assessed based on CV (%). It is the ratio of standard deviation to mean expressed in percentage. Profitability was assessed from value cost ratio. A value cost ratio greater than 1 is profitable whereas a value cost ratio less than or equal to 1 is non-profitable.

RESULTS

Overall, interaction effect among the factors was not significant. Farmers' fertilizer uses (FFU) and QUEFTS estimated (QE) fertilizer use significantly improved maize yield compared to the control in both seasons and regions but there was no significant difference between them. The effect of fertilizer was stronger (p=0.0002 in both seasons) in Jimma than CRV (p=0.002 in 2017 and p=0.007 in 2018) (Tesfaye et al., 2019). On average, FFU and QE fertilizer use improved maize yield by 53% and 57% respectively in CRV whereas in Jimma the yield advantage of these fertilizer uses compared to control were 42% and 69% respectively. QE fertilizer use resulted in 2.5% and 19% yield advantage compared to FFU. Similar to the ealier studies in the country (Seyoum *et al.*, 2019), plant density significantly improved yield (p=0.0003 in CRV in 2017; p=0.00002 and 0.001 in Jimma in 2017 and 2018). Though not consistent across regions, the effect of wealth class was significant (Fig.1). Fields of medium wealth class resulted in significantly lower yield in Jimma whereas in CRV, fields of rich farms resulted in significantly higher yield in 2017 season.

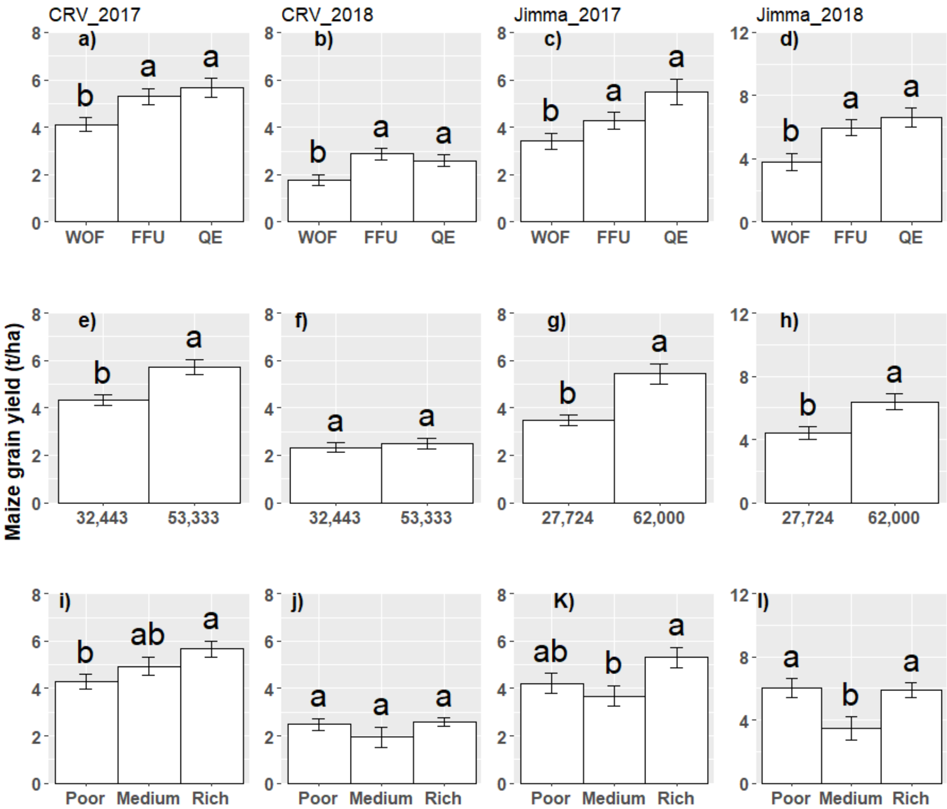

Fig. 1. Grain yield response of maize to fertilizer use (a, b, c, d), plant density (e, f, g, h) and wealth class (i, j, k, l) in 2017 and 2018 in CRV and Jimma regions in Ethiopia. WOF, FFU and QE stands for without fertilizer, farmers' fertilizer use, and QUEFTS estimated fertilizer use respectively.

Yield response variability

Growing maize without fertilizer was associated with high variability. In CRV, FFU resulted in low variability in both farmer's practice and redesigned plant densities whereas in Jimma, QE fertilizer requirement was resulted in low yield variability.

Table 2. Coefficient of variation of maize yield in CRV and Jimma areas under various fertilizer uses and plant densities.

Region	Fertilizer use	Farmer's practice density			Redesigned density		
		CV (%)			CV (%)		
		2017	2018	Average	2017	2018	Average
CRV	WOF	29.0	60.0	***44.5***	33.5	53.3	***43.4***
	FFU	24.0	29.3	***26.7***	25.4	44.9	***35.2***
	QE	25.0	43.8	***34.4***	33.7	40.8	***37.3***
Jimma	WOF	42.4	50.5	***46.5***	51.9	62.3	***57.1***
	FFU	32.7	46.9	***39.8***	34.2	29.8	***32.0***
	QE	37.4	30.1	***33.8***	32.4	27.2	***29.8***

Economic feasibility of fertilizer uses and plant densities

The value cost ratio of farmer's fertilizer use, and QE nutrient requirement of maize practices were greater than 1 in both regions under low density (farmers 'practices) and redesigned (intermediate) density (Fig. 2). This shows that fertilizer both FFU and QE fertilizer are profitable in maize production.

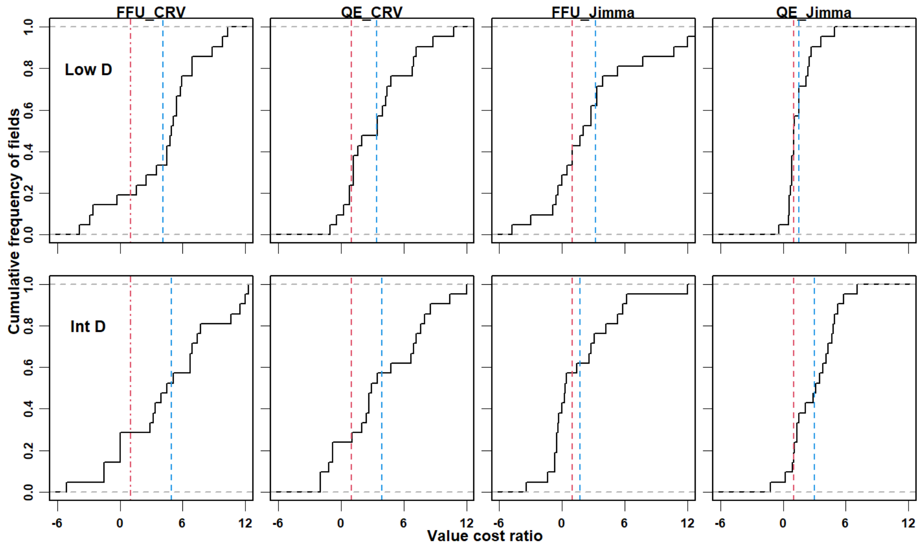

Fig. 2. Profitability of fertilizer uses of maize in CRV and Jimma under farmer practices and redesigned plant densities.

In CRV, redesigning plant density from 32,443 plants/ha to 53,333plants/ha was profitable under all fertilizers uses (without fertilizer, FFU and QE). However, in Jimma, redesigning plant density was profitable mostly under QE fertilizer use. In the same region, increasing plant density from farmers' practices (27,724 plant/ha) to redesigned (62,000 plant/ha) resulted in moderate profitability under control and FFU.

CONCLUSION

The study evaluated fertilizer use in maize using two plant densities on fields of variable wealth class farms in CRV and Jimma areas in Ethiopia. Farmers' fertilizer use (FFU) and QUEFTS estimated (QE) fertilizer requirement improved maize yield in both regions and were profitable based on market setup in the respective areas during the study period. Increasing planting density from farmers' practices to intermediate (32,443 plants/ha to 53,333 plant/ha in CRV and 27,724 plants/ha to 62,000 plants/ha in Jimma) highly improved maize yield and were profitable in both regions. QE fertilizer use reduced yield variability only in Jimma area.

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PERFORMANCE OF K* ALGORITHM IN YIELD PREDICTION AS A DECISION SUPPORT TOOL TO DERIVE SITE-SPECIFIC NUTRIENT MANAGEMENT RECOMMENDATIONS FOR MAIZE PRODUCTION
#9431

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ABSTRACT

Agriculture is the main source of food and income for rural communities in developing countries, especially in Africa. Given the current population growth, pressures on agricultural systems will continue to increase. Many countries have agricultural economies that are highly dependent on agricultural productivity. For example, several variables can influence fertilization for optimal grain yields. Quantifying the effects and relative importance of soil properties such as soil type, pH, climate, regional soil variability, and policy could provide a basis for optimizing fertilization to increase economic benefits and reduce nutrient losses.

For decades, maize (Zea mays L.) management decisions have been a conundrum in smallholder agriculture in tropical climates. Alternative management practices aim to achieve an optimal balance between environmental and economic outcomes. In this context, farmers need advice on predicting their future crop productivity and analysis to help them maximize production in their fields. Nutrient management is an important issue in agriculture. Despite significant recent advances, actual, practical, and accurate application is challenging. Conventional methods have many limitations related to both the actual problem and the problem itself. The selection of meaningful parameters is critical. Machine learning (ML) as an emerging technology can help identify patterns in huge datasets. This method extrapolates predictions directly from the data provided. ML Algorithms can predict production based on genetic information, environmental factors, land management, and fertilizer rates. Our study aims to develop a decision support system based on machine learning and integrated datasets. To achieve our goal, field variables (yield, varieties, and fertilization) were combined with environmental variables from soil mapping (soil texture, pH, and organic matter concentration) and gridded meteorological datasets (precipitation, temperature). The performance of K* algorithm to predict yield using these variables as input is explored. To address this problem, precision agriculture soon will likely require the merging of different disciplines and expertise, and the development of hybrid systems that incorporate different ML and agronomic techniques.

Keywords: Machine learning, Fertilization, Site-specific, Yield prediction, Maize.

INTRODUCTION

Machine learning approaches are widely used to study the factors that influence yield and crop yield prediction (Barbosa, et al. 2020; Qin, et al. 2018; Coulibali, et al. 2020). Integrating these methods into food production could increase the precision of nutrient management, sustainable cultivation, and food security. These tools could help conserve biodiversity while increasing crop yields under different cropping systems, soil, and climate conditions (Barbosa, et al. 2020).

Indeed, crop yield prediction is one of the key elements for sustainable cultivation and optimal use of mineral resources, but this prediction is extremely complex and influenced by several factors. This complexity makes it difficult for researchers, let alone farmers, to predict the economic benefits in both the short and long term. Corn (Zea mays L.) is considered a staple crop that plays an important role in the economy not only as food, but also as feed and fuel. Growth and yield of maize cobs are affected by various variables and environmental dynamics (Jiang, et al. 2017; Ogutu, et al. 2018). Conventional statistical models, field surveys, drones and simulation models have been used in different associations to predict and explain crop yield dynamics (Liakos, et al., 2018; Chlingaryan, et al. 2018). It has been reported that each of these techniques seems to look at complexity from different perspectives.

To gain further insight and understand many of these limitations, maize has been used as a model species in many studies. Yield and fertilization aspects have been analyzed in different experimental setups and locations around the world. Recent studies have integrated these methods into different hybrid combinations.

In this study, we investigate the performance of K* algorithm in predicting yield to gain a better understanding of these constraints. This algorithm has demonstrated a great ability to analyze and predict yields using high-dimensional data.

MATERIALS AND METHODS

Study area

China is the second largest producer and importer of maize in the world (FAO 2020). The demand for maize is continuously increasing due to the increased consumption of animal products caused by the modernization of human food systems. Therefore, corn production in China is critical to global supply and demand. Better knowledge of the impact of climate on maize production in China is therefore crucial. The hybrid Zhengdan 958 has been selected as one of the leading corn hybrids currently grown in China. Zhengdan958 has higher yield, planting density, and stress tolerance than most hybrids, but few studies evaluating yield parameters were found in the literature (Lai, et al. 2010; Li, et al. 2017; Li, et al. 2015).

Plant material and data collection

Summer maize was selected for this case study because it is important for the country's food security and is widely grown in larger areas of China. According to the conventional geographical classification based on the characteristics and regional distribution of maize growing systems, the summer maize growing areas in the study area were defined as the summer maize growing areas of the North China Plain (Wu, et al. 2014), based on their climatic, growing, topographic and soil conditions. Fig. 1 shows the occurrence of the data points used in this study. The database used for this study includes maize field experiments conducted in China from 2005 to 2010 using soil testing and fertilizer recommendations (Yan, et al. 2021). that we complemented by seven Weather features from a global weather API.

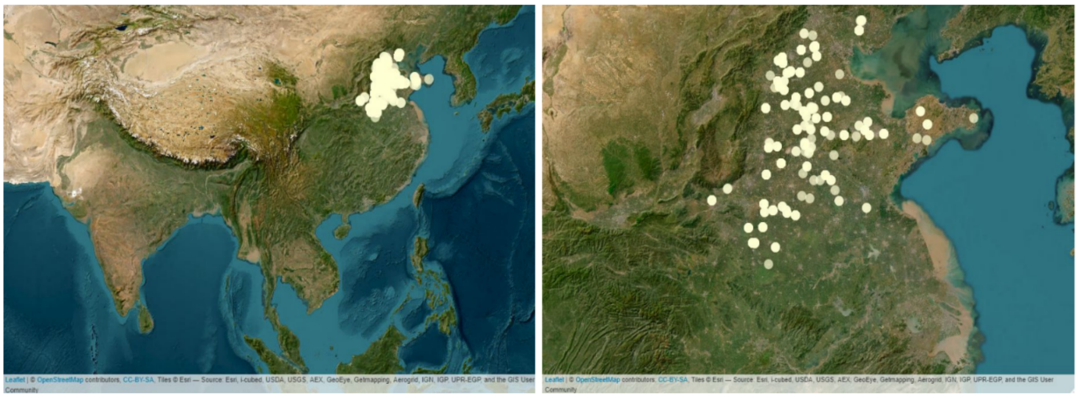

Fig. 1. The study zone in China, including the occurrence of the data points used in this study.

Data analysis

The K* algorithm was used to describe the collected and cleaned data. This machine learning algorithm was also used to evaluate the factors that influenced yield prediction (SOM (g kg^{-1}), Olsen P (mg kg^{-1}), Ava-K (mg kg^{-1}), N input (kg ha^{-1}), K_2O input (kg ha^{-1}), P_2O_5 input (kg ha^{-1}), temperature at 2 meter elevation (C), temperature at 2 meter elevation maximum, temperature at 2 meter elevation minimum, temperature at 2 meter elevation, relative humidity at 2 meter elevation, precipitation corrected (mm/day), and surface pressure (kPa) on corn yield (kg ha^{-1}). Farmers apply a mix of technologies to improve declining soil fertility and reduce yield loss. This implies that the decision to apply technologies is inherently multivariate and that attempting machine learning modeling would incorporate useful decision support functions to derive site-specific recommendations for nutrient management in corn production. Ignoring these interdependencies can lead to conflicting policy recommendations (Marenya and Barrett, 2007). Therefore, the use of multivariate models is essential. The hyperparameters of the algorithm were tuned to the best result of the 10-fold cross-validation by searching the hyperparameter space (grid search).

The performance of the trained models was determined using an independent testing dataset including 20% of the total number of data using MAE and RMSE.

RESULTS AND DISCUSSION

A comparison of actual maize yields and predicted values, including new weather features derived from the weather API, is shown in Fig. 2. This scatter plot shows that a good correlation was achieved. These results prove that integrated experimental datasets collected from various published studies can be used to perform more complex analyzes using machine learning techniques (such as the instance-based classifier K*) than in standard meta-analyzes, which are usually based on linear models. K* showed good classification performance, with values of relative absolute error and relative root mean square error of 7.05% and 14.41%, respectively. This algorithm achieved a correlation coefficient of 0.98 MAE and RMSE were 73.31 and 188.48 (kg ha^{-1}), respectively. The feature selection results emphasized the effect of independent weather features by including precipitation and temperature in the best prediction configurations. This algorithm and the proposed pipeline have shown that it can be adapted as a decision support tool for the analysis of numerous outcomes or land management systems, even with large and spatially diverse data points.

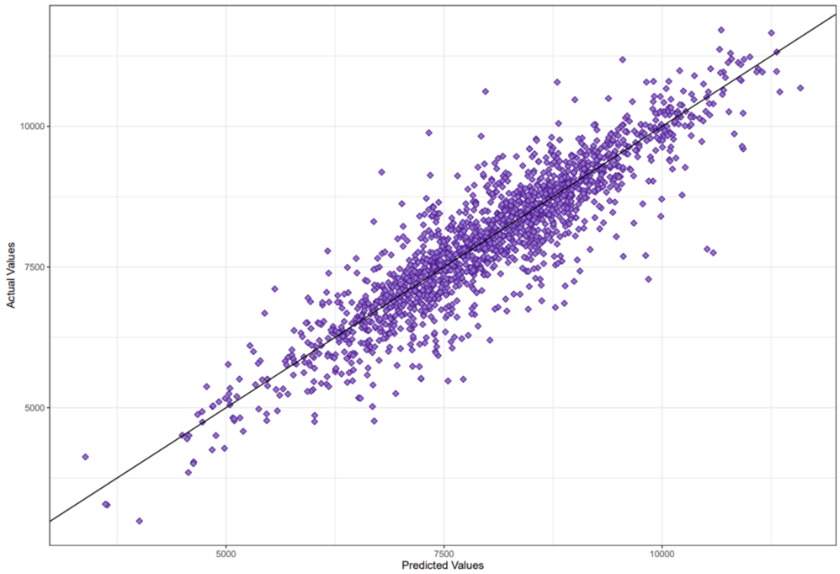

Fig. 2. Scatter-plot of measured against predicted yield (kg/ha) by K*.

CONCLUSIONS

Many maize data sets from China were used to summarize the changes in yield responses under different fertilizer rates, growing regions, and soil properties. The summer corn planting system type and the variety ZhengDan958 were used as case study plants. This study demonstrated that it is possible to generate spatially explicit yield responses for this hybrid using machine learning. This technique will aid in the development of decision support systems for smallholder farmers to make site-specific yield predictions, improve nutrient use efficiency, and increase yield, increase the economic return on fertilizer investments while reducing environmental problems. Fig. 1 provides detailed geographic information on the distribution of data points used in this study. This wide spatial diversity alongside the proposed pipeline shows that this algorithm can be adapted as a decision support tool for analyzing numerous outcomes or land management systems.

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RICE PRODUCTION SYSTEM AND MAJOR NUTRIENT BALANCE ASSESSMENT IN RICE GROWING IN THE IRRIGATED PERIMETER OF THE ZIO VALLEY
#9484

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ABSTRACT

The knowledge of cropping systems and farming practices are essential towards improving crop yields. This study aims to characterize rice production systems, analyse fertilization practices, and assess the impact of irrigated rice on the balance of major nutrients in Zio valley. The characterization of production systems and fertilization practices were carried out through a survey of a sample of 192 randomly selected producers, i.e. 34% of the total number of farmers in the four (4) villages of the irrigated perimeter of the Zio valley: 83 in Kovié, 59 in Mission Tové, 26 in Assomé and 24 in Ziowonou. The simplified approach for estimating the partial nutrient balance was used for the mineral nutrient balance, involving only as "input" the contribution of nutrients by the mineral fertilizers used and as "output", the exports of the paddy and rice straw. For nutrient balance assessment, three farmers was selected in each village. These farmers were monitored during two crops cycles to collect necessary data for the calculation of the partial balance (fertilizers inputs and exports of biomass). An analysis of the composition of paddy rice and straw samples was carried out to measure N, P, and K content. Results showed that 80% of farmers are between 20 and 50 years old, the farm size average is 1.2 ha and the average yield is low at 3.3 t/ha. The practice of fertilization essentially consists of adding chemical fertilizers (NPK15-15-15 and Urea 46%N). On average, the quantities of fertilizers applied are 220 kg/ha of NPK and 222 kg/ha of urea, i.e., excess of 20 kg/ha for NPK and 122 kg/ha for urea compared to the recommended formulas. The partial balance is positive for N (+51.38 kg/ha) and deficient for P and K with respectively -8.93 and -15.01 kg/ha. Physico-chemical characterization of soils as well as an adaptation of fertilization formulas are necessary to improve fertilizer use efficiency and increase crop yields.

Keywords: Production systems, fertilization practices, irrigated rice, nutrient balance.

INTRODUCTION

Declining soil fertility is a major cause of low agricultural yields in sub-Saharan Africa. This phenomenon is due to the gradual disappearance of traditional shifting cultivation due to land pressure due to increasing population and competing demands for land use (Sogbedji et al., 2006). In Togo, the decline of soil fertility, becomes one of the main constraints of the agricultural sector, particularly in irrigated rice production where the soil is used each year without fallowing (Sanou & Soule, 2017). According to Wopereis et al. (1999), increasing the doses of fertilizers, especially nitrogenous fertilizers, would improve yields. However, there is a growing need to assess not only the profitability and financial risks of fertilizer use, but also cropping systems that limit sustainable management practices in irrigated rice production (Donovan et al., 1999). In fact, poor fertilization practices can limit fertilizer's efficacity and contribute to a drop in the profitability of farms. Kintche (2011), mentions inappropriate traditional practices, population growth, export of crop residues through burning, common grazing, and the low mineral return to the soil to explain the decline in the fertility of soils in Africa.

In the Zio Valley, rice production has been practiced continuously since 1964 without fallowing. Indeed, with irrigation, the traditional long-term fallow system no longer exists. This leads to land depletion and induces a decrease in yields, a drop in agricultural income and an increase in food insecurity (Sanou & Soule, 2017). Under these conditions, despite the heavy investments made both by the State and by the farmers, the yields observed are still low (about 3.5 t/ha), compared to the potentials of most of the varieties used on the irrigated site of the Zio valley between 6 and 8 t/ha. It is therefore necessary to assess cropping practices and their impact on soil fertility. The objectives of this study are to characterize production systems, analyze fertilization practices and assess nutrient balance in the irrigated perimeter of the Zio valley.

MATERIALS AND METHODS

Analysis of production systems and fertilization practices

The study was carried out in the irrigated perimeter of the Zio valley. A survey was conducted between September and October 2021 among 192 farmers including 35 women and 157 men chosen at random, i.e., 34% of the total number of farmers in the four (4) villages of the irrigated perimeter of the Zio valley: 83 Kovie, 59 at Mission Tove, 26 at Assome and 24 at Ziowonou. The choice of rice farmers was made by random draw based on the list of rice farmers. The information collected relates to the socio-demographic characteristics of producers (age, level of education, household size), the production system (size of farms, yields, periods of activity and fertilization practices).

Evaluation of the partial balance of nutrients N, P and K

The simplified partial nutrient balance estimation approach was used. For this, twelve (12) farms were monitored and data on the inputs of mineral fertilizers, organic matter as well as grain production and the export of crop residues were collected. Samples of paddy and straw were also taken to evaluate the exports of Nitrogen, phosphorus, and potassium from the farms to the "Soil-Water- Vegetals-Fertilizers" laboratory of the Togolese Institute for Agronomic Research (ITRA). The N, P and K concentrations were measured by using the micro-Kjeldahl procedure, vanadate molybdate-yellow colorimeter and flame spectrophotometer, respectively (Jiang et al., 2017).

RESULTS AND DISCUSSION

Farms characteristics and fertilization practices

Irrigated rice producers in the Zio valley are mostly young. It appears that nearly 80% of producers are between 20 and 50 years old with an average age of 42.23±9.26 years. The average farm size is 1.2±0,6 ha per producer and the average yield is 3.3±0.8 t/ha, i.e., 55% of the potential of the IR841 variety grown by 94% of producers. For chemical fertilization, producers declare using an average of 220 kg/ha of NPK (15-15-15) and 222 kg/ha of urea (46%), i.e., a respective excess of 20 kg/ha and 122 kg/ha of NPK (15-15-15) and urea recommended. For NPK (15-15-15), only 42% of farmers use the recommended 200 kg/ha dose and for urea, barely 8% still use the recommended 100 kg/ha. These increases are made by growers to compensate for the continued decline in soil fertility that results in low yields.

Table 1. Sociodemographic characteristics of rice producers in the Zio Valley irrigated perimeter.

Parameters	Modality	Frequency	Percentage
Age	below 20	0	-
	20 to 35 years old	54	34,4
	36 to 50 years old	72	45,9
	51 to 75 years old	29	18,5
	75 and over	2	100
Exploited areas (ha)	less than 1	75	39
	From 1 to 5	115	60
	More than 5	2	1
Yields obtained (t/ha)	$x \leq 2$	23	12
	$2< x \leq 4$	107	12
	$4< x \leq 5$	49	56
	More than 5	13	26
Quantity of NPK (15-15-15)	$X \leq 200$kg	43	22,4
	200kg	81	42,2
	200kg< $X \leq 300$kg	55	28,6
	More than de 300kg	13	6,8
Urée (46%)	$x \leq 100$kg	1	0,5
	100kg	15	7,8
	100kg< $x \leq 200$kg	103	53,6
	200kg< $x \leq 300$kg	54	28,1
	More than 300kg	19	9,9

Assessment of farm nutrient balance

Estimates of N, P, and K budget inputs and outputs are shown in Table 2. For the study period, N input from fertilizer in each village exceeded rice N uptake. For P and K, fertilizer input did not exceed crop uptake. This result indicates that the amount of nitrogen provided by the mineral fertilizers used by farmers is greater than the export needs of rice plants for current yields. As this result does not consider the other factors of nutrient loss such as leaching and gaseous losses, it is not possible to conclude on the effectiveness of nitrogen inputs. Thus, to know more about the sustainability of the system, a complete nutrient balance would be necessary. However, for P and K, mineral fertilizer inputs from producers are lower than export needs. Current yields are therefore due to a contribution of these nutrients by the soil.

Thus, the rice monoculture system and the practice of unsuitable fertilization contribute to a continuous depletion of the soil nutrient and to a potential pollution of water in nitrogen. These results confirm those of Drabo (2009) who observed soil depletion due to cereal monoculture combined with unsuitable mineral fertilization.

Table 2. Nutrient balances.

Villages	Balance sheet items	N (kg/ha)	P(kg/ha)	K(kg/ha)
Ziowonou	Input NPK	17.50	7.64	14.58
	Input Urea	61.33	0.00	0.00
	Grain export	23.02	10.18	5.56
	Straw export	18.93	5.03	24.95
	Balance	**+ 36.88**	**-7.57**	**-15.92**
Mission Tove	Input NPK	32.50	14.19	27.08
	Input Urea	84.33	0.00	0.00
	Grain export	42.33	18.72	10.21
	Straw export	26.02	6.92	34.30
	Balance	**+48.48**	**-11.44**	**-17.43**
Kovie	Input NPK	35.00	15.28	29.17
	Input Urea	84.33	0.00	0.00
	Grain export	35.32	15.62	8.52
	Straw export	22.91	6.09	30.19
	Balance	**+61.11**	**-6.42**	**-9.55**
Assome	Input NPK	30.50	13.32	25.42
	Input Urea	92.00	0.00	0.00
	Grain export	38.12	16.86	9.20
	Straw export	25.31	6.73	33.36
	Balance	**+59.07**	**-10.26**	**-17.14**
Mean	Input NPK	28.88	12.61	24.06
	Input Urea	80.50	0.00	0.00
	Grain export	34.70	15.34	8.37
	Straw export	23.29	6.19	30.70
	Balance	**+51.38**	**-8.93**	**-15.01**

CONCLUSION

This study has made it possible to update cultural practices in irrigated rice cultivation in the Zio valley, particularly in terms of fertilization. Rice yields are still low despite the permanent availability of water. Although other factors such as the quality of the seeds used and the control of pests can be used to explain these low yields, the study notes that the unsuitability of the fertilization formulas at the site is a factor in the depletion of soil nutrients and a source of nitrate pollution. To improve the efficiency of fertilizers and increase yields, an evaluation of the physico-chemical state of the soil and an adaptation of the fertilization formulas is important. In addition, it will be necessary to support farmers in identifying the best strategies for preserving the nutritional quality of soils adapted to the conditions of irrigated rice cultivation.

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FIELD PERFORMANCE OF COMMON BEAN (*PHASEOLUS VULGARIS* L.) UNDER MYCORRHIZAL INOCULATION AND PHOSPHORUS LEVEL APPLICATION IN KASHUSHA, EASTERN DR CONGO
#9533

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ABSTRACT

The positive effects of arbuscular mycorrhizal fungi (AMF) on yield and phosphorus uptake have already been widely studied. However, the response of common bean (*Phaseolus vulgaris* L) to mycorrhizal inoculation under phosphorus supply conditions is still poorly documented in South-Kivu, where the use of fungal biofertilizers is not yet tested. This study was initiated to assess the effect of AMF inoculation and increasing phosphorus doses on common bean performance and yield in South Kivu to reduce phosphate input. The study was conducted during the A 2021 cropping season at the experimental field of the "Université Evangélique en Afrique" at Kashusha, Kabare territory. A split-plot design was used to compare two levels of mycorrhizal inoculation (with and without inoculation) with three rates of increasing phosphorus (0, 30, 60 and 120 kg P ha^{-1}). Growth, yield and mycorrhizal colonization parameters were recorded. Inoculation with *R. irregularis* significantly improved root mycorrhization rate, biomass, yield and harvest index (HI) of bean at 0 kg P ha^{-1} and 30 kg P ha^{-1}. The performance of bean plants inoculated with *R. irregularis*, in terms of collar diameter, aboveground biomass, total biomass, yield and HI at 30 kg P ha^{-1}, was superior to those non-inoculated and inoculated plants at the doses of 60 kg P ha^{-1} and 120 kg P ha^{-1}, suggesting the potential of AMF in reducing phosphate fertilizer input. The results indicate that P levels significantly affected the mycorrhization rate of bean. The application of 60 and 120 kg P ha^{-1} drastically reduced the mycorrhization rate confirming the influence of inorganic P on the establishment of mycorrhizal symbiosis. Therefore, the responses induced by AMF were also dependent on the applied P dose. Mycorrhizal inoculation with *R. irregularis* could be an important lever to boost bean yield and ensure phosphate fertilizer saving in ferralitic soils of Kashusha.

Keywords: *Phaseolus vulgaris L.*, Arbuscular mycorrhizal fungi, Phosphorus nutrition, South-Kivu

INTRODUCTION

Land degradation and declining soil fertility are the major constraints to crop productivity, especially for legumes. Common bean is more dependent on macronutrient availability in the soil, especially phosphorus, which determines its performance and yield. In terms of nutrient uptake, beans consume more phosphorus than other nutrients (Chekanai *et al.,* 2018). It was also demonstrated that a significant increase in yield was obtained with increasing doses of phosphate fertilizers on common bean. Thus, under phosphorus deficiency conditions, plants remain weak, and deformation of organ development occurs as a result of defective cell division (Liang *et al.,* 2022). According to Chekanai *et al.* (2018), phosphorus supply in legumes can doubles the biomass production and consequently increase the bean yield. In addition, soil microorganisms, such as arbuscular mycorrhizal fungi (AMF), play an important role in improving plant mineral nutrition and nutrient cycling in the soil. Accordingly, they are actively involved in phosphorus absorption and solubilization in different agro systems (Veresoglou *et al.,* 2012). On common bean, it has been shown that AMFs contribute effectively to yield improvement by enhancing pod development and productivity (Chekanai *et al.,* 2018). Therefore, inoculation with efficient strains of AMF could enhance phosphorus use efficiency and biological nitrogen fixation on bean and thus, ensure phosphate fertilizer savings. However, the response of common bean (*Phaseolus vulgaris* L) to mycorrhizal inoculation under phosphorus supply conditions is still poorly documented in South-Kivu province where the use of fungal biofertilizers is not yet tested. Furthermore, the optimal phosphorus dose to combine with AMF inoculation for successful bean performance is not yet determined. Based on the above background, this study was initiated to determine the effect of AMF inoculation and increasing doses of phosphorus on common bean performance in South-Kivu to reduce phosphate input.

MATERIALS AND METHODS

The study site was located at the experimental field of the "Université Evangélique en Afrique" at Kashusha in the territory of Kabare. The study was conducted during the A cropping season (2021) as a split-plot design to compare two levels of mycorrhizal inoculation (with and without inoculation with AMF *Rhizophagus irregularis* strain), and three increasing phosphorus doses (0, 30, 60 and 120 P kg ha^{-1}, corresponding to D_0, D_1, D_2, and D_3 respectively). The combination of factors resulted in a total of eight treatments which were randomly arranged as a bloc. Inoculation was placed on large plots while phosphorus doses were assigned to small plots. The treatments tested in this study are described as follows; T1: Myc+D_0, T2: Myc+D_1, T3: Myc+D_2, T4: Myc+D_3, T5: NonMyc+D_0, T6: NonMyc+ D_1, T7: NonMyc +D_2, T8: NonMyc+D_3. Phosphorus was applied as Triple Superphosphate (TSP). The optimal rate of 60 P_2O_5 kg ha^{-1} was considered as a reference rate from which the other rates were established (Chuma *et al.,* 2022). A localized application of fertilizer was made in each plot according to the different treatments studied. Mycorrhizal inoculum was applied to the plots at the same time as the fertilization using 20 g of soil inoculum per hole, containing AMF concentration of 10 spores g^{-1} soil. For fertilized and inoculated treatments, the inoculum was placed just above the fertilizer in direct contact with the seed while being separated from the fertilizer by a small amount of soil. Sowing was done at 40 cm × 20 cm to maintain a density of 60 plants ha^{-1} on all the elementary plots. After three months, the plants were harvested, and the different parameters were measured.

Growth parameters were measured 1 month before the physiological maturity, and a week before harvest. These include plant height, collar diameter, leaf area and aboveground and root biomass. While yield parameters were evaluated during harvesting time (number of pods, number of grains per pod, 100-seed weight, harvest index and yield). Mycorrhizal colonization under the different treatments under study was assessed according to the method of Trouvelot *et al.* as described by Ndeko *et al.* (2022). A portion of the roots (~2g) was retained for this purpose.

RESULTS AND DISCUSSIONS

Mycorrhizal colonization under treatments application

In the control treatment, bean plants showed low mycorrhization regardless of the applied phosphorus rate. By contrast, in plants inoculated with *R. irregularis*, mycorrhizal inoculation significantly increased root colonization and a significant interaction between the factors was observed as attested by the two-way ANOVA test (Table 1). The result indicated that P levels drastically reduced the mycorrhizal colonization rate (mycorrhization frequency and intensity) at the rate of 60 and 120 kg of P. In addition, fertilizer application rate has negative effects on the mycorrhizal colonization, arbuscule and vesicle formation in agro systems (Tanwar *et al.,* 2013).

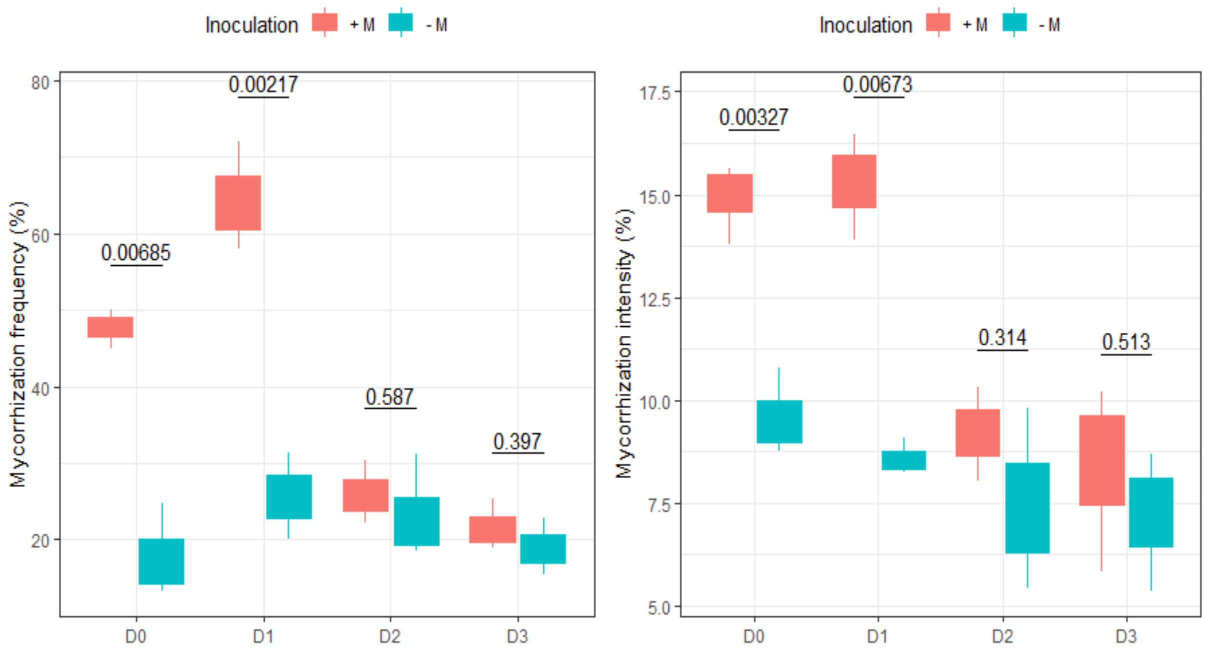

Fig. 1. Arbuscular Mycorrhizal Fungal (AMF) colonized root length in percent of the total root length (mycorrhizal frequency and mycorrhizal intensity). The plants were supplied with triple superphosphate at three fertilization levels: 0, 30, 60 and 120 P kg ha^{-1}.

Effect of mycorrhizal inoculation and P fertilizer application rate on growth of common bean

The relationship between growth parameters and treatments were plotted in the Fig. 1. The results showed that mycorrhizal inoculation significantly improved plant growth at the rate of 0 and 30 kg P ha^{-1} (Table 1). The performance of inoculated plants, in terms of collar diameter, aboveground biomass and total biomass at the dose of 30 kg P ha^{-1}, was superior compared to non-inoculated plants and inoculated plants at the doses of 60 and 120 kg P ha^{-1}. However, the leaf area was not affected by the mycorrhizal inoculation regardless the P dose applied. These results suggest that mycorrhizal inoculation has a potential role in improvement of common bean growth and ensuring phosphate fertilizer input.

Effect of mycorrhizal inoculation and P Fertilizer application rate on grain yield of bean

Compared to non-inoculated plants, mycorrhizal inoculation increased bean yield and harvest index at the rate of 0 and 30 kg P ha^{-1} (Fig. 2). But at the rate of 60 and 120 kg P ha^{-1}, mycorrhizal efficiency decreased with P level application. *R. irregularis* mycorrhizal inoculations increased bean yield, even at the high P level application (60 kg P ha^{-1}), the grain yield is higher than in non-inoculated treatments but not statistically different. In most legumes, mycorrhizal inoculation increases nutrient uptake and biofortification and consequently crop yield (Liang *et al.,* 2022). The lack of the effects of mycorrhizal inoculation in the other treatments may be linked to the suppression of mycorrhizal development at a height P supply.

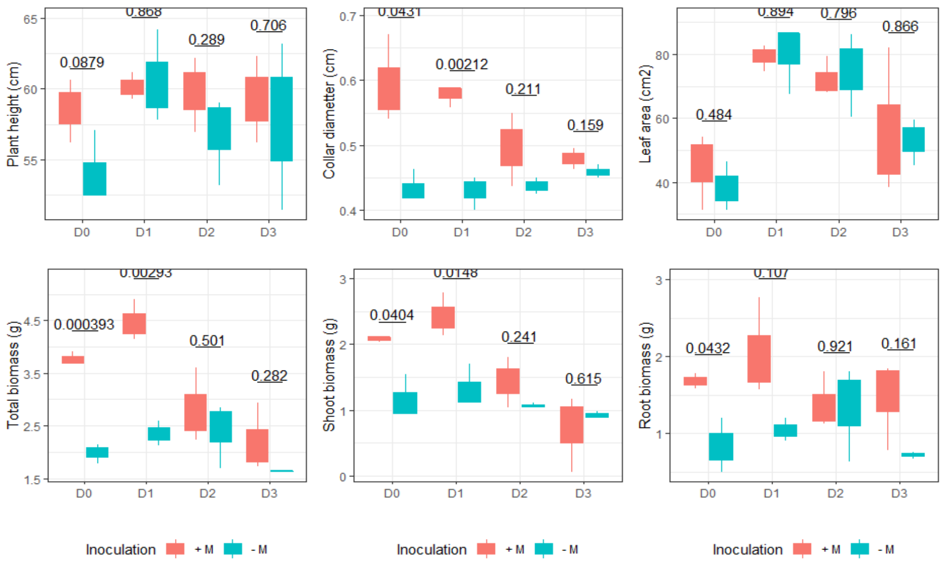

Fig. 2. Plant height, collar diameter, leaf area, total biomass, shoot biomass and root biomass of common bean under mycorrhizal inoculation (+M and –M) and phosphorus doses application (D_0=0, D_1=30, D_2=60 and D_3=120 kg P ha^{-1}).

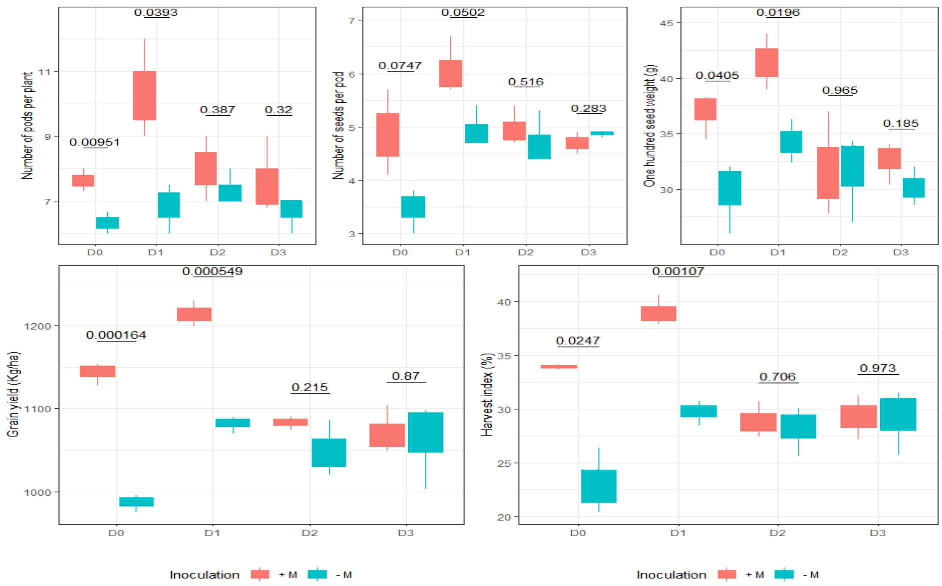

Fig. 3. Bean yield parameters (number of pods per plant, number of seeds per pod, one hundred weight, average grain yield and harvest index) as affected by *R. irregularis* mycorrhizal inoculation and phosphorus levels application.

CONCLUSIONS

The result revealed that mycorrhizal inoculation increased common bean growth and yield, especially at low phosphorus application and in the control treatments. Mycorrhizal inoculation with *R. irregularis* strain could be an important lever to boost bean yield and ensure phosphate fertilizer saving in ferralitic soils of Kashusha.

Table 1. Analysis of variance for plant growth and yield parameters of mycorrhizal (+AM) and non-mycorrhizal (−AM) bean plants grown under different phosphorus fertilization levels (0, 30, 60 and 120 kg P ha^{-1}).

Indicators	**P doses (df=3)**		**AMF (df=1)**		**P doses*AMF (df=3)**	
	F	***P*-value**	***F***	***P*-value**	***F***	***P*-value**
Mycorrhizal colonization						
Frequency (%)	8.03	*0.002*	133	*< 0,001*	7.39	*0.003*
Intensity (%)	5.59	*0.008*	7.4	*0.015*	1.48	*0.26*
Growth parameters						
Aboveground biomass	13.45	*0.000*	49.91	*< 0,001*	8.44	*0.001*
Belowground biomass	0.69	*0.57*	68.7	*< 0,001*	1.03	*0.4*
Total Biomass	20.38	*< 0,001*	309.24	*< 0,001*	18.04	*< 0,001*
Plant heigh	5.75	*0.007*	12.19	*0.003*	2.18	*0.12*
Collar diameter	3.93	*0.028*	14.91	*0.001*	5.44	*0.009*
Leaf area	12.9	*0.000*	0.13	*0.71*	0.15	*0.92*
Yield and yield components						
NGP	5.8	*0.007*	30.57	*< 0,001*	0.59	*0.62*
NGG	7.57	*0.002*	11.57	*0.004*	3.59	*0.037*
P100	16.17	*< 0,001*	21.56	*< 0,001*	1.8	*0.18*
Yield (Kg/ha)	12.07	*0.000*	166.77	*< 0,001*	2.27	*0.12*
IR	0.64	*0.59*	4.68	*0.046*	0.95	*0.43*

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PRECISION WATER MANAGEMENT

OPTIMIZING WATER USE EFFICIENCY IN FLOOD IRRIGATION SYSTEMS IN UGANDA: A CASE OF DOHO RICE IRRIGATION SCHEME (DRIS) #9423

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ABSTRACT

There is growing demand for water across different sectors of production. Yet the extent of water wastage to furnish inefficient irrigation systems especially in flood irrigated rice systems, is not known. In developing countries and in Uganda in particular, most irrigation scheduling in the irrigation schemes is based on rotational system of water access rather than crop water needs. In Doho Rice Irrigation Scheme (DRIS) in eastern Uganda for example, farmers' plots receive up to 50mm ponding of irrigation water for three days in a week for four months which translates to about 2,400mm of water applied way above average rice water requirements of 700 mm in a season. Too much water not only compromises nutrient use efficiency but has also been associated with a wide spread of water snail, a pest that eats up the young rice seedlings and transmits bilharzia. Though System of Rice Intensification (SRI) has been found to not only reduce greenhouse gas emissions, water and nutrient wastage but also increase rice yields, its benefits in flooded rice systems in Uganda have not fully been explored. The overall objective of this study was to optimize water and nutrient use efficiencies under the system of rice intensification (SRI) in flood irrigated systems in Uganda. The specific objectives were (i) establish the minimum flooding depth for optimal water use efficiencies and grain yields (ii) determine the effect of spacing and plant population on rice growth parameters, grain yield and water use efficiency and water use efficiency. Field experiments were established for two seasons (December 2021– March 2022 and May - September 2022) in DRIS in eastern Uganda. The main treatments included four flooding depths (0mm / Field Capacity, 10 mm, 20mm and 40mm) and within each flooding depths were split plots that included (i) the number of seedlings per hill (1 or 3) and (ii) two plant spacings (20 cm x 20cm or 25 cm x 25 cm). Crop parameters measured included plant height, number of leaves, number of tillers, number of panicles, above ground biomass, root biomass and grain yield. Our preliminary analysis of results indicates no significant differences in biomass and grain yields among the four flooding depths. Planting one seedling per hill at a spacing of 25 cm x 25 cm led to a higher number of tillers, panicles and consequently biomass and grain yields. We conclude that ponding of up to 10 mm of water every three days and planting of 1 seedling per hole at a spacing 25 cm x 25 cm leads to optimum water use efficiency and increased rice grain yields this was selected as the plant looks vigorous without undergoing water stress as observed in the field.

INTRODUCTION

Water resources are continuously under immense pressure from all sectors of production and in the phase of climate change, optimizing the use of this important resource cannot be over emphasized. Water use efficiencies in flooded irrigation systems, especially in developing countries remain very low (<50%) and the question of how much water is needed to produce rice in a season remains unanswered. In Doho Rice Irrigation Scheme (DRIS) for example, farmers flood their fields to a depth of 50 mm of water, every three days in a week translating into 2,400mm of water used in a rice season. This amount of water is way above the estimated rice crop water requirement of 700mm in a season (Koffi Djaman et al, 2016).

Direct implications of excessive water use include reduced crop yields, reduced nutrient use efficiencies, conflicts, waterborne diseases, degradation, and reduced ecosystem services. Thus, there should be deliberate efforts to promote practices that help to reduce water use, nutrient losses and pollution of aquatic life yet enhance yields.

There is sufficient literature that System of Rice Intensification (SRI) leads to optimal water and nutrient use, reduced greenhouse gas emissions and increased yields (Sato and Uphoff, 2007; Sinha and Talati, 2007). The System of Rice Intensification (SRI), developed in Madagascar in the 1980s, has proved to be one of the most important recent agricultural innovations which is being adopted across farmers' fields around the globe (Sinha and Talati 2007). It modifies conventional practices of paddy cultivation by managing plant, water, soil, and nutrients in more effective ways, which increase the productivity of available land, labor, water, and energy and improve food security for vulnerable farming communities. Studies in some countries have shown a significant increase in rice yield, with substantial savings of seed (80-90%), water (25-50%), and cost (10-20%) compared to conventional methods (Lhendup, 2008).

One way to reduce N loss through leaching and washing away from rice fields might be to practice alternate wetting and drying (AWD) forms of irrigation, maintaining a shallow water depth with intermittent drying rather than continuous flooding (Thakur et al., 2013). Reliance on organic sources of nutrients as opposed to inorganic sources is one of the principles under SRI, seeking to enhance soil structure and functioning as well as soil microbial abundance and activity. However, this practice is not known and not yet adopted to rice farmers in Uganda. The overall objective of this study was therefore to optimize water and Nitrogen Use Efficiencies under SRI in paddy rice systems in Uganda. Specifically, the study sought to (i) establish the minimum flooding depth for optimal grain yields and water use efficiency and (ii) assess the effect of spacing and seedling rate on water use efficiency.

MATERIALS AND METHODS

In order to achieve these objectives, we implemented the following key activities; Matching supply with requirements in increasing WUE under the System of Rice Intensification (SRI): Transplanting seedlings at 14Days After Emergencies (DAE) vs >30days (farmers' practice); use of organic fertilizer, alternate wetting and drying and wider spacing (25 cm x 25 cm one seedling) vs farmers' 20cm x 20 (>3) (Laulani´e, 1993; Katambara *et al*., 2013). Field experiments were established for two seasons (December 2021– March 2022 and May - September 2022) in DRIS in eastern Uganda. The experimental design was a randomized complete block design with split plot (RCBD-split plots), where ponding depth was a main treatment while spacing and seedling rate were split plots. Four levels of ponding depth included: FC (0 mm), 10 mm, 20 mm and 40 mm while plant spacing and seedling rate were both at two levels of 20 X 20 and 25 X 25, 1 seedling per hole and 3 seedlings per hole respectively.

Key practices implemented include: (i) use of soil moisture sensors (tensiometers) only in field capacity plots, (ii) transplanting seedling 14 DAE vs 30 DAE (iii) Incorporating rice straws + Municipal Solid Waste Compost (MSWC) in the soil, (iv) planting 1 seedling per hole vs >3 and (v) water management trials.

RESULTS AND DISCUSSION

Water use efficiency was defined as grain yield divided by water used. As per results, there was a general decrease in the water use efficiency with the increase in the amount of water use under different treatment and also as the season changes there is a general improvement in the water use efficiency as a results of soil ammendment that is use of organic fertilisers from the municipal solid waste (Fig. 1).

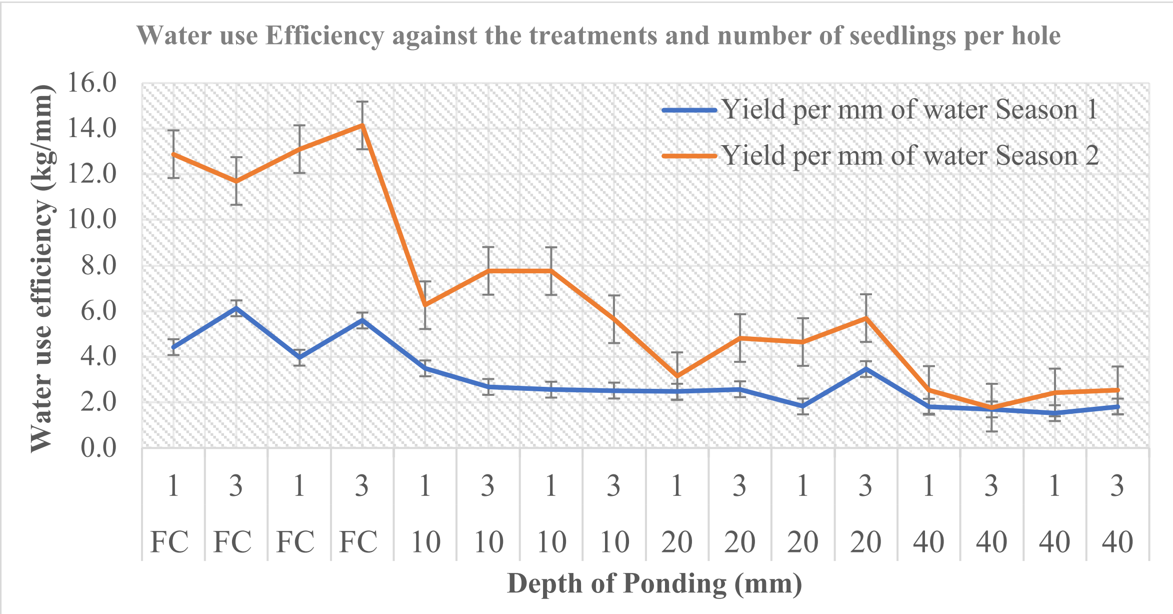

Fig. 2. Water use efficiency across contrasting flooding depths and number of seedlings per hole in Doho Rice Irrigation Scheme as of December 2021 – September 2022.

As observed in the water use efficiency graph, there is better water use efficiency as we reduce the quantity of water use hence the best water use efficiency for both the two season were recorded under field capacity treatment 6.1 and 14.1 kg/mm of water used for season one and two respectively. This is in-line with the study conducted by Limei *et al* in 2011 under minimum watering regimes with the best results. However, we recommend 10mm depth of ponding which does not allow the paddy rice to show signs of water stress.

There was no significant difference in term of biomass yield and grain yield between one seedling per hole and three as this was attributed to compensation through increased tillering, number panicles and grain yield. This could also translate into savings in terms of seeds, better yield under one seedling per hole and best use efficiencies (Fig. 1).

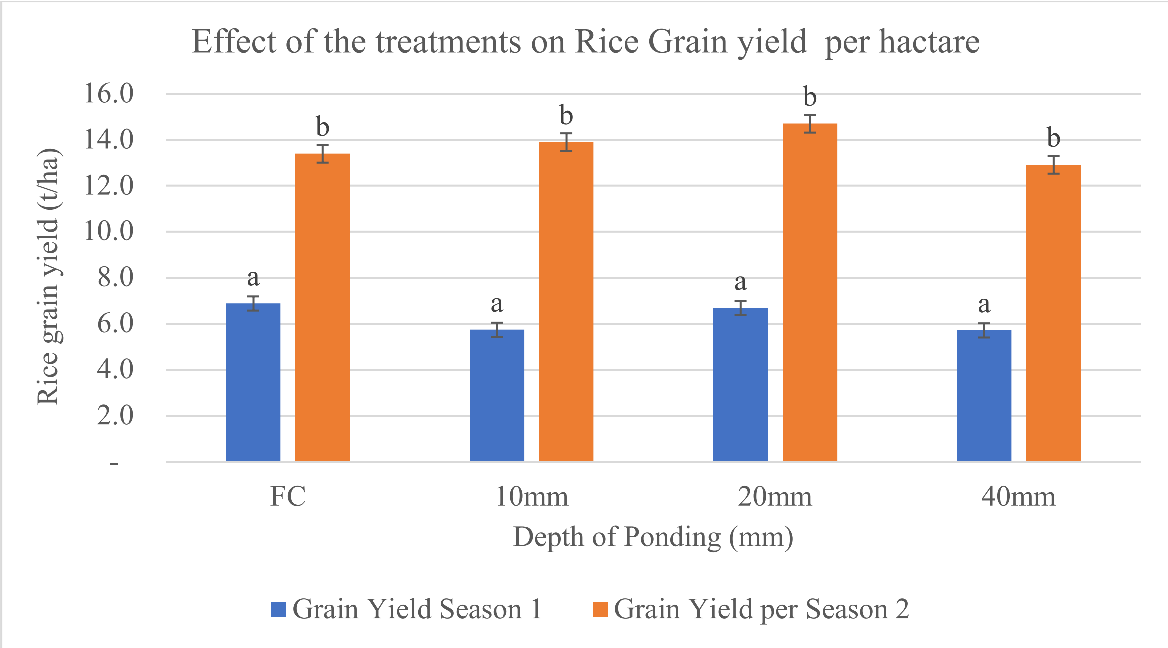

Fig. 3. Grain yields across the water regimes / treatments in Doho Rice Irrigation Scheme as of December 2021 – September 2022.

The general trend of yield increase in season two is attributed to continued good practices of Systems of Rice Intensification (SRI); planting young seedlings of 14 days, wider spacing, in cooperating the rice straws as organic fertilizers, user of organic fertilizer from municipal solid waste which act as soil amendment hence and slowly releases its nutrients hence the cumulated effect being observed in second season's yield. This agrees with the findings from Anitha and Chellappan (2011) giving the optimal yield under the SRI recommendations.

Better yield recorded under FC (field capacity) treatment in season one, this could be attributed to increased decomposition of the organic fertilizer as the soil is well drained hence improving the work of soil microbes.

The good performance under the field capacity has greatly indicated that we can save a lot of water that can bring more land under production, use for ecological services, and also prevent leaching, and washing away of the nutrients in the tail water from the irrigation field.

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DELINEATION OF MANAGEMENT ZONES OF IRRIGATION SCHEMES IN NIGERIA BASED ON SELECTED SOIL PROPERTIES
#9517

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ABSTRACT

Effective field management is required to maximize economic returns and environmental control and soil and crop management. This study was conducted to delineate the management zones (MZ) of Oke-Oyi and Eiyenkorin Irrigation Schemes (EOIS) based on selected soil properties to aid efficient water and fertilizers use and enhance productivity. Soil samples were taken at geo-referenced grid-sampling points. Total soil samples collected for each location at 0 – 20 cm and 20 – 40 cm depths were Sixty-two which were analyzed for pH, particle size distribution, and clay ratio estimate (CR). Total soil core samples (0 – 15 cm) collected were 31 in each location to determine soil bulk density (BD), saturated hydraulic conductivity (K_S), and soil total porosity (TP). Variability of measured clay content (%), BD (g/cm^3), K_S (mm/hr), and TP (%) were analyzed using Paleontological statistical software (PAST 3.14) and their maps produced using ArcGIS 10.5 tools. Management zone delineation was performed based on highly associated data using Management zone analyst software (MZA 1.0). The results revealed that there was a high correlation between the clay content measured and other measured and estimated soil properties – sand contents, BD, SHC, TP, and CR in EOIS. This source of the association was computed for MZs delineation of EIOS. The optimum numbers of MZs for EIOS were three and six (Eiyenkorin and Oke-Oyi irrigation scheme respectively). Water and nutrient transmission soil properties can be combined to give specific management zones based on their codetermined correlation.

Keywords: soil properties, irrigated fields, Management Zones, clay ratio

INTRODUCTION

Water and soil which are some of the major components of Irrigation Agriculture, do not only play an essential role in agricultural practices but specifically in sustainable management, and their important environmental effects on farming are related to their availability and quality. As such rainfall, a major source of water for agriculture which had tagged farming activities in major parts of Sub-Sahara Africa (SSA) as rain-fed, uniquely enriched soil moisture levels. However, the world is undergoing climate change (Middleton, 1997) and consequences of such changes by implication are increased in moisture deficit particularly in semi-arid and even the more humid areas (Gbadegesin and Oriola, 2004). The need for irrigation becomes more critical given several factors which include an increase in population, management of scarce resources like good planting materials, the knowledge of distribution, and variability in the soil. It also impacts the yearning of governments to reassure food security and improve rural welfare despite climate change effects and goal two of the sustainable development goals which is Zero hunger (UNDP, 2015).

According to FAO (1987) working document on the “Need and Justification of Irrigation Development in Nigeria” which classified the available irrigable land in the country into shorter (2.00 million hectares) that is irrigable lands within 0 – 1 km to the source of the irrigation water: meaning water transport distances were limited to those within one agro-ecological zone while longer (3.73 million hectares) transport irrigable lands, on the other hand, referred to land further away from the water source (more than 500 km) which means irrigation water may be transported from one agro-ecological zone to another. Although, the potentials calculated were for the levels of inputs, namely, low level of inputs, intermediate level of input, and high level of input this implies that Nigeria has substantial resources for both rain-fed and irrigable land.

However, the FAO report (2003) listed Nigeria among nations that are technically unable to meet their food needs from rain-fed production at the low level of inputs and appear likely to remain so even at intermediate levels of inputs at some time between 2000 and 2025. This further emphasizes that Nigeria cannot depend on rain-fed agriculture and expect to feed its high population except it employs in an irrigation system. Though she has established twelve (12) river basin development authorities charged with the responsibilities of developing water resources for irrigation agriculture purposes food shortage persists due to an increase in population and poor utilization of developed irrigated fields. Among the factors attributed to poor utilization of the irrigation facilities in Nigeria according to Fagbamiye (2009) is a lack of coherent irrigation subsector development policy and strategy, inadequate funding, inadequate farm support services, high capital, and operating costs, and insufficient attention to management systems. Therefore, special attention to the irrigated fields' management is required, mainly about effective soil management.

Henrique and Luis (2016) opined that knowledge of the spatial variability of soil physical and hydraulic properties influence the understanding of soil water dynamics to improve irrigated field management. In SSA, research has shown that despite the productive potential of irrigated fields, characteristics such as the uneven distribution of rainfall, high rates of evaporation, and frequently shallow and sandy soils increases the risk of soil compaction and salt accumulation (Montenegro and Montenegro, 2006). A study on an irrigated field in Nigeria which focused on the evaluation of irrigation farming at Oke-Oyi, Kwara state was therefore conducted by Gbadegesin and Oriola, (2004) who reported that the soil of the irrigation scheme was sandy and fertility status is low to adequately support sustainable maize production.

Ortega *et al*., (2007); however, reported that the improved irrigated field management is achievable by site-specific management application of crop inputs such as plant nutrients, seeds, pesticides, water, and tillage through the identification of management zones (MZ). Identification of MZ defined by field boundaries do not only aid management practices but prompt adequate planning for present and future land use thereby reducing food insecurity. This leads to reduced input costs, minimal adverse environmental effects, and improved crop yield and quality (Gemtos *et al*., 2011).

Generally, the management of soil physical attributes on a site-specific basis as described by Peralta *et al*., (2015) is an attractive and intuitive approach for increasing the input efficiency of agricultural systems by adjusting fertilizer and water rates based on the soil characteristics. Thus, the concept of management zones can be introduced to irrigation field management, which is sub-regions of a crop field that may differ in factors such as soil type, topography, water, or nutrient availability (Bullock *et al*., 2009). Valente *et al*., (2012) also submitted that management zones should be defined by evaluating more than one soil property. Delineating management zones entail the study of various soil properties (Henrique and Luis 2016) to derive the economical and functional viability of the Irrigation field. Therefore, delineating water management zones based on soil attributes can be an important technique to optimize the use of irrigated water and fertilizers in irrigated agricultural fields. The aim of this study was therefore to delineate management zones of Oke-Oyi and Eiyenkorin irrigation schemes using management zone analysis software (MZA) 1.0 and production of a map of the various management units based on the selected soil properties; this is to aid efficient use of water and fertilizers in those fields and enhance adequate productivity.

MATERIALS AND METHODS

Sites description

The study sites were Oke-Oyi and Eiyenkorin Irrigation schemes under Lower Niger River Basin Development Authority, Ilorin Kwara State, Nigeria. These areas lie approximately between longitudes 4^0 43' 49" and 4^0 45' 23" East of the Greenwich Meridian; Latitude 8^0 36'59" and 8^0 37' 20" North of the equator (Oke-Oyi Irrigation scheme) and longitude 4^0 26' 0" and 4^0 26' 10" East of the Greenwich Meridian; Latitude 8^0 23'48" and 8^0 23'16" North of the equator (Eiyenkorin Irrigation scheme). Their elevations are 383 m and 307 m above sea level respectively. The total land area of the Oke-Oyi Irrigation scheme is 250 ha (Gbadegesin and Oriola, 2004) while that of the Eiyenkorin Irrigation scheme is 150 ha.

Generally, the two locations have two main seasons: dry and wet season with an intervening co-harmattan period usually experienced from December to January. The natural vegetation of these two locations consists of forest and wooded savannah with annual rainfall which ranges from 1000 – 1500 mm while the maximum average temperature ranges between 30 and 35 ^{0}C (Ogunleye and Oyediji, 2012).

Source and techniques of data collection

Soil sampling and analysis

Soil samples were taken at 7 × 6 m geo-referenced grid-sampling points in each of the two fields. The geo-referenced grid sampling points were determined using ArcGIS 10.5 tools. The soil sampling activities were carried out at the beginning of cropping seasoning in the two Irrigation schemes (May/June). One representative sample was collected at each grid and geo-referenced using a global positioning system (GPS). The satellite views of the areas sampled were presented in Plate 1- Oke Oyi and 2- Eiyenkorin irrigation project stations respectively with their coordinate points (Google Earth, 2016). The variability in selected soil physical properties of each point was determined by taking undisturbed soil core samples at depth of 0 to 15 cm in each point using a core sampler. Saturated hydraulic conductivity (K_s), total porosity (TP), and soil bulk density were determined from each sample using the conversational methods as described by Flint and Flint (2002).

Also, soil samples of each point were taken from the 0 to 20 cm and 20 to 40 cm layers using soil auger which gave 31 soil samples each from 0 – 20 cm and 20 – 40cm. The total soil samples were 62 at each location. On each sample, particle size distribution was determined by the Hydrometer method (Gee and Or, 2002). Soil pH was determined in water using a 1:1 soil – solution ratio with a pH meter.

Clay ratio, one of the indices for soil erodibility was determined as indicated below:

Clay ratio = (% sand + % silt) / % clay) according to Oshunsanya *et al.*, (2012)

Statistical analysis

Measured variables were analyzed using descriptive statistical methods to obtain values for the mean, standard deviation (SD), minimum, maximum, coefficient of variation, skewness, and correlations analysis in Paleontological statistics software package (PAST 3.14). The statistical package was used to express the association within and among measured and estimated selected soil physical data before delineating management zones. Selected soil physical properties were used in delineation based on their role in determining nutrients and water availability for crop and plant growth as well as acting as a conduit between the soil surface and groundwater (Marcos *et al*., 2015). ArcGIS 10.5 software was employed to produce spatial distribution maps of selected soil properties (Hou-Long *et al*., 2012).

Management zones were delineated in Management Zone Analyst software 1.0 (MZA) by using the most correlated soil properties values. The management zones delineation using Management Zone Analyst 1.0 (MZA) (Fridgen et al. 2004), analysis data, and construct models to find the relationship among different variables without prior experience aided by a powerful unsupervised method characterized by Fuzzy clustering. It can be used to divide a field into different groups with multiple attributes, which can reduce distortion by outliers (Brown 1988). At the same time, fuzzy clustering used a weighting exponent to control the degree to which membership sharing occurs between classes (Bezdek 1981). The technique of fuzzy clustering has been used to classify soil, landscape data (Burrough et al. 1992; Reyniers et al. 2006) and yield data (Lark 1998). Unsupervised clustering algorithms have been proposed for delineating MZs from yield monitor data (Lark and Stafford 1997; Stafford *et al*. 1998).

The fuzzy performance index (FPI) (Hou-Long *et al*., 2012) and normalized classification entropy (NCE) (Boydell and McBratney 1999) were used to determine the optimal number of clusters. The FPI is a measure of the degree to which different classes share membership (Fridgen *et al*., 2004). Values approaching 0 indicate distinct classes with little membership sharing, while values near 1 indicate non-distinct classes with a large degree of membership sharing.

The value of NCE was then calculated for each classification (Lark, 2001). FPI and NCE were calculated according to Fridgen *et al*. (2004) using MZA 1.0 software.

The best classification was determined when each index is at a maximum, representing the least membership sharing (FPI) and the greatest amount of organization (NCE) because of the clustering process (Fridgen *et al*. 2004).

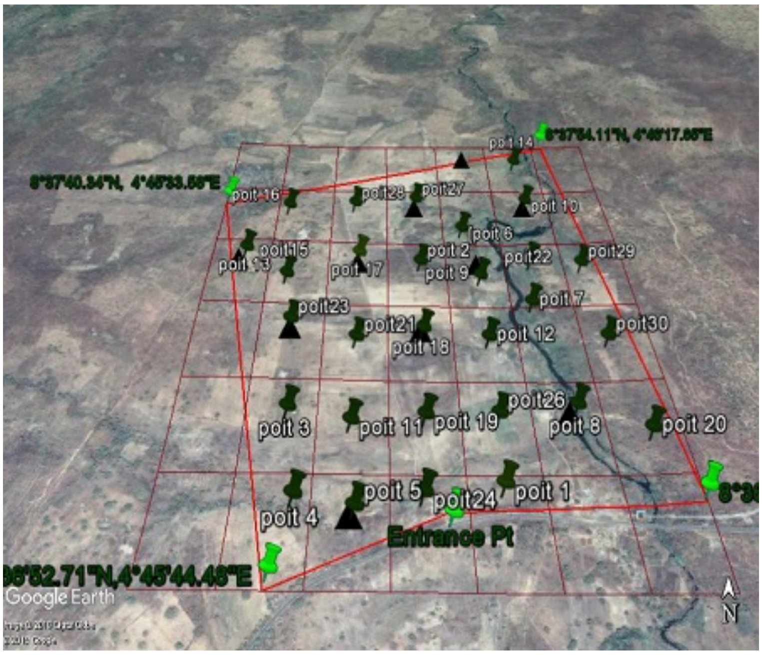

Plate 1. Satellite view of Cultivated Area under Oke-oyi Irrigation Project Station-Lower Niger River Basin Development Authority

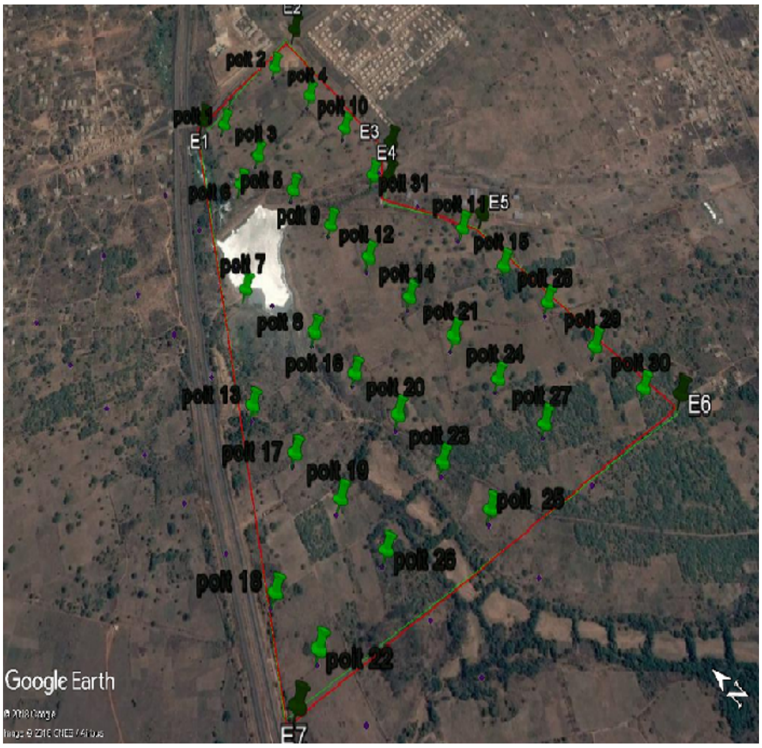

Plate 2. Satellite view of Cultivated Area under Eiyenkorin Irrigation Project Station- Lower Niger River Basin Development Authority

RESULTS

Descriptive statistics of soil variables at 0 – 20 cm and 20 – 40 cm depths of the studied areas were reported in Table 1 and 2. It was evident that the two sites, Eiyenkorin and Oke-Oyi Irrigation schemes (EIOS) soils (0 – 20 cm and 20 – 40 cm soil depth) are slightly acidic, with a mean pH value of 5.89; 6.05; 6.41, and 6.30 respectively. The highest clay ratio (CR) - 47.24 %, and TP – 24.10 % were recorded in the Oke-Oyi Irrigation scheme when compared to the Eiyenkorin Irrigation scheme CR percent of 46.34 and 16.34 at depth of 0 – 20 cm (Table 1). At 20 – 40 cm, the Eiyenkorin Irrigation scheme had the highest sand content, K_S and TP. Most of the soil properties were moderately skewed except the K_S in the Eiyenkorin field at 0 – 20 cm (Table 1) which was indicated by 0.00 skewed value, the meaning is normally distributed at that depth. The distribution of all the variables was only slightly skewed (Skewness $-1 \leq X \leq 1$).

The results also revealed that the distribution of sand content of the EOIS ranged from 76 % to 92 % with a mean value of 84.40 % and 76.82 % (Table 1); 84.6 % and 76.9 % (Table 2) respectively. This indicates that the soil of EIOS is coarse-textured soils. The mean silt and clay content was however higher in the Oke-Oyi Irrigation scheme (8.61% and 14.5%) compared to that of Eiyenkorin (4.50 % and 11.00 %). The lowest coefficient of variation (CoV) was recorded for the BD variable with a mean value of 1.47 g/cm^3 and 1.49 g/cm^3 respectively. The range of BD for the EIOS was 1.42 g/cm^3 to 1.7 g/cm^3. The highest and the lowest SD value was recorded at Oke-Oyi Irrigation schemes (21.17 and 0.02) with K_S and BD variables respectively. The skewness of all samples from 20 – 40 cm ranged from - 0.62 to 2.12. This implies that most of the variables had Skewness between -1 and 2 which implies that most of the results are moderately skewed while few were highly skewed. Based on CoV values, BD and TP were classified as low (CoV < 10%) and their mean varied from 1.46 to 1.49 g cm^{-3} BD; 43.60% to 44.60%TP (Table 1) and 1.47 g cm^{-3} to 1.49 g cm^{-3}BD; 43.60% to 44.15%TP (Table 2) which are characteristics of sandy soils (Saxton *et al.*, 2006).

Correlation analysis of almost all the selected soil properties at 0 – 20 cm depth of the Eiyenkorin Irrigation scheme was significantly correlated (Table 3). The clay content of the fields was highly positively correlated with sand content (0.638) and BD (0.493), while it was highly negatively correlated with K_S (- 0.948), TP (- 0.493), and CR (- 0.947).

Soil pH was not significantly correlated with the rest of the variables considered. BD was negatively correlated to TP ($P < 0.01$) and it had the highest correlation observed.

The correlation coefficient of CR and TP was consistently negative at $p<0.01$ in all correlation analysis tables presented. This implies that a unit increase in CR value will result in a unit decrease in TP. Also, a significant increase in clay content will cause a significant decrease in BD as shown in all the correlation analysis shown.

Similar trends were also observed in Tables 4, 5, and 6 where correlation analysis of selected soil properties at 20 – 40 cm depth of Eiyenkorin Irrigation schemes, 0 – 20 cm, and 20 – 40 cm for Oke-Oyi Irrigation scheme as presented respectively.

Spatial variability maps of selected soil properties- textural class, clay content, BD, K_S, and TP for EOIS were presented in Fig. 3 (A, B, C, and D) and 4 (A, B, C, and D) respectively. The distribution of soil types in the Eiyenkorin Irrigation scheme as determined were Sandy, Sandy Loam, and Loamy sand textural classes. While the most common textural class in the Oke-Oyi Irrigation scheme is loamy sand (LS), sandy clay loam (SCL), and Sandy loam (SL), and the least common is Sandy soils (S) as well as in the Eiyenkorin Irrigation field. The clay content and K_s for the EOIS varied with five unique values classes whereas BD and TP showed three distinctive classes. The spatial distribution of the most or highly spread ranged of the soil properties was indicated by brown color on each of the maps while the least was often indicated by either white or green colors. The range of BD for Eiyenkorin was 1.42 g cm^{-3} to 1.51 g cm^{-3} while that of Oke-Oyi ranged from 1.41 g cm^{-3} to 1.93 g cm^{-3}. There is a close similarity in the variation observed in TP for EOIS as both values ranged from 42 % to 46.21 % (Eiyenkorin) and 42 % to 46.59 % (Oke-Oyi). On the other hand, wide variation was observed in K_s value for the Oke-Oyi Irrigation scheme which ranged from 5.9 mm/hr to 121.34 mm/hr whereas the variation in K_s in Eiyenkorin Irrigation scheme as observed was close, ranging from 35.48 mm/hr to 99.11 mm/hr. However, the clay content for each scheme ranged from 6.00 % to 16.00 % (Eiyenkorin) and 4.02 % to 30.15 % (Oke-Oyi).

Clay contents measured data for EOIS were tabulated and regarded as the input data of MZA software. The fuzziness performance index (FPI) and normalized classification entropy (NCE) when the clustering number was 2, 3, 4, 5, and 6 respectively were obtained from MZA and shown in Fig. 5 (A and B). FPI and NCE achieved the smallest values while the number of management zones was 4 in Fig. 5 A and B. The classification effect was strongly best when the study area was partitioned into 3 management zones (Fig. 5A) while the classification effect was best when the study area was partitioned into 6 management zones (Fig. 5B). The management zones map was obtained from ArcGIS software with the input data of the selected soil properties values.

Fig. 5A and B shows changes in two performance indices with an increasing number of management zones using clay content data for Oke-Oyi (A) and Eiyenkorin (B) Irrigation scheme. The highest value for the management zone in A was 0.036 at the FPI when the number of zones reached 3 whereas the NCE value was highest at 0.019 at the same number of the zone. However, the highest NCE value recorded at B was 0.0028 when the number of zones reached 6 which is the same number of zones recorded at FPI (0.0021) of B.

Table 1. Descriptive statistics of selected soil variables at 0 – 20cm depth (n=31) of the study area.

Variables	Mean		SD		Minimum		Maximum		CoV		Skewness	
	E	O	E	O	E	O	E	O	E	O	E	O
pH (H_2O) 1:1	5.89	6.41	0.45	0.49	5.14	5.47	7.83	8.45	0.2	0.2	-0.22	0.62
Silt (%)	5.44	7.10	2.11	3.26	1.00	2.00	10.00	14.00	4.5	10.6	-0.18	0.49
Clay (%)	10.00	16.10	2.57	7.74	6.00	4.00	16.00	31.00	6.6	59.9	0.65	0.55
Sand (%)	84.40	76.82	2.66	9.58	80.00	62.50	91.50	90.70	7.1	91.7	0.38	-0.31
BD (g cm^{-3})	1.46	1.49	0.02	0.03	1.43	1.42	1.60	1.55	0.0	0.1	0.04	-0.70
K_S (mm/hr)	67.20	45.00	17.75	30.00	35.53	5.96	99.01	121.00	315	918.2	-0.00	0.40
TP (%)	44.60	43.60	0.91	1.10	43.68	42.15	46.34	47.24	0.8	1.12	-0.04	0.69
Clay ratio (%)	9.60	6.90	2.73	4.40	5.20	2.05	16.30	24.10	7.4	19.5	0.71	1.99

Note: E = Eiyenkorin Irrigation scheme study area; O = Oke-oyi Irrigation scheme study area; SD = standard deviation; CoV = Co-efficient of Variation; BD = Bulk density; K_S = Saturated hydraulic conductivity; TP = Total porosity

Table 2. Descriptive statistics of selected soil variables at 20 – 40cm depth (n=31) of the study area.

Variables	Mean		SD		Minimum		Maximum		CoV		Skewness	
	E	O	E	O	E	O	E	O	E	O	E	O
pH (H_2O) 1:1	6.05	6.30	0.47	0.59	5.00	5.19	7.57	7.63	0.2	0.4	-0.46	0.34
Silt (%)	4.50	8.61	2.10	6.94	0.00	0.00	9.00	28.00	4.3	48.2	-0.15	1.24
Clay (%)	11.00	14.45	2.61	6.46	6.00	6.48	16.50	38.48	6.8	41.8	-0.01	2.12
Sand (%)	84.6	76.9	0.47	10.05	80.00	47.52	90.00	89.52	8.3	101.1	0.13	-1.27
BD (g cm^{-3})	1.47	1.49	0.03	0.02	1.42	1.45	1.75	1.53	0.0	0.0	-0.62	-0.39
K_S (mm/hr)	63.10	45.41	18.12	21.17	36.00	1.48	99.50	88.39	328	448	0.36	0.04
TP (%)	44.13	43.60	1.00	0.77	42.00	42.05	47.35	45.08	1.0	0.5	0.62	0.39
Clay ratio (%)	8.70	6.99	2.64	2.94	5.00	1.60	16.30	14.43	7.0	8.7	1.16	0.88

Note: E = Eiyenkorin Irrigation scheme study area; O = Oke-Oyi Irrigation scheme study area; SD = standard deviation; CoV = Co-efficient of Variation; BD = Bulk density; K_S = Saturated hydraulic conductivity; TP = Total porosity

Table 3. Correlation analysis of selected soil properties at 0 – 20 cm depth of Eiyenkorin Irrigation schemes.

	pH (H_2O)	Silt (%)	Clay (%)	Sand (%)	BD	K_S	TP	CR
pH (H_2O)	1							
Silt (%)	0.027	1						
Clay (%)	-0.082	-0.389*	1					
Sand (%)	0.081	-0.450**	-0.638**	1				
BD	0.329	-0.113	0.493**	-0.387*	1			
K_S	0.001	0.220	-0.948**	0.730**	-0.385*	1		
TP	0.329	0.113	-0.493**	0.387*	-1.000**	0.385**	1	
CR	0.048	0.351*	-0.947**	0.630**	-0.464**	0.948**	0.464**	1

* and **Significant at the 0.05 and 0.01 probability level respectively.
Note: BD = Bulk density; SHC = Saturated hydraulic conductivity; TP = Total porosity; CR = clay ratio

Table 4. Correlation analysis of selected soil properties at 20 – 40cm depth of Eiyenkorin Irrigation schemes.

	pH (H_2O)	Silt (%)	Clay (%)	Sand (%)	BD	K_S	TP	CR
pH (H_2O)	1							
Silt (%)	0.021	1						
Clay (%)	0.084	-0.235	1					
Sand (%)	-0.074	-0.471**	-0.735**	1				
BD	-0.012	-0.206	0.611**	-0.384**	1			
K_S	-0.107	0.006	-0.947**	0.838**	-0.638**	1		
TP	0.012	0.206	-0.611**	0.384**	-1.000**	0.638**	1	
CR	-0.002	0.224	-0.956**	0.699**	-0.596**	0.931**	0.596**	1

* and **Significant at the 0.05 and 0.01 probability level respectively.
Note: BD = Bulk density; SHC = Saturated hydraulic conductivity; TP = Total porosity; CR = clay ratio

Table 5. Correlation analysis of selected soil properties at 0 – 20cm depth of Oke-Oyi Irrigation schemes.

	pH (H_2O)	Silt (%)	Clay (%)	Sand (%)	BD	K_S	TP	CR
pH (H_2O)	1							
Silt (%)	0.233	1						
Clay (%)	-0.248	0.711**	1					
Sand (%)	-0.139	0.491**	-0.956**	1				
BD	-0.103	0.406*	0.891**	-0.839**	1			
K_S	-0.101	-0.565**	-0.948**	0.942**	-0.965**	1		
TP	0.103	-0.407*	-0.891**	0.840**	-1.000**	0.965**	1	
CR	0.042	-0.403*	0.832**	0.806**	-0.940	0.943**	0.939**	1

* and **Significant at the 0.05 and 0.01 probability level respectively.
Note: BD = Bulk density; SHC = Saturated hydraulic conductivity; TP = Total porosity; CR = clay ratio

Table 6. Correlation analysis of selected soil properties at 20 – 40 cm depth of Oke-Oyi Irrigation schemes.

	pH (H_2O)	Silt (%)	Clay (%)	Sand (%)	BD	K_S	TP	CR
pH (H_2O)	1							
Silt (%)	-0.005	1						
Clay (%)	0.025	-0.182	1					
Sand (%)	-0.005	-0.780**	-0.685**	1				
BD	0.109	-0.258	0.696**	-0.235	1			
K_S	-0.023	-0.373*	-0.967**	0.813**	0.385*	1		
TP	-0.109	0.258	-0.696**	0.387*	-1.000**	0.627**	1	
CR	0.025	0.182	-1.000**	0.630**	-0.696**	0.967**	0.696**	1

* and **Significant at the 0.05 and 0.01 probability level respectively.
Note: BD = Bulk density; SHC = Saturated hydraulic conductivity; TP = Total porosity; CR = clay ratio

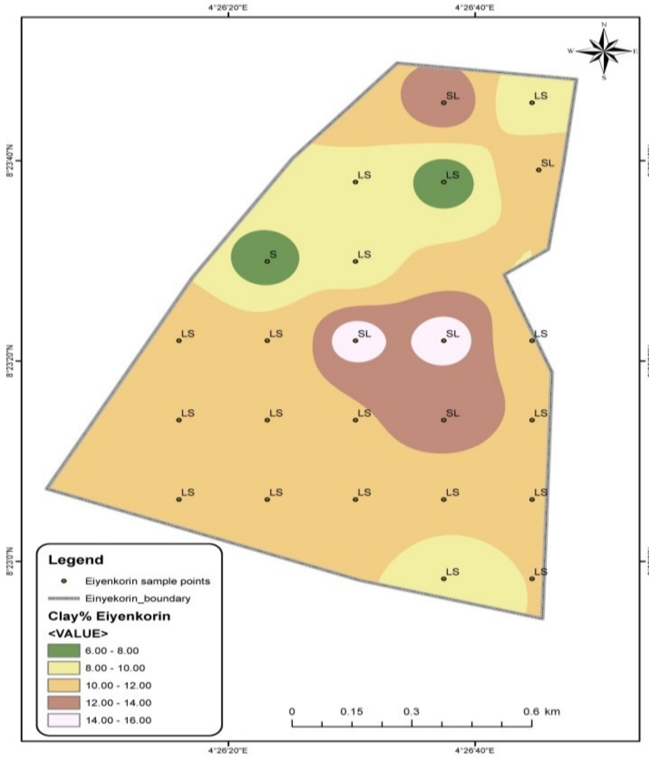

Fig. 3A. Spatial variability map of clay content for Eiyenkorin Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy.

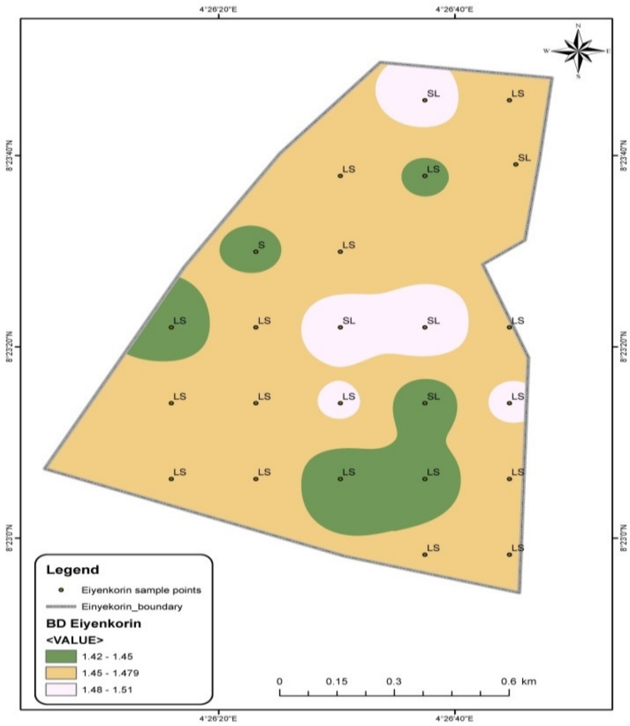

Fig. 3B. Spatial variability map of BD for Eiyenkorin Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy.

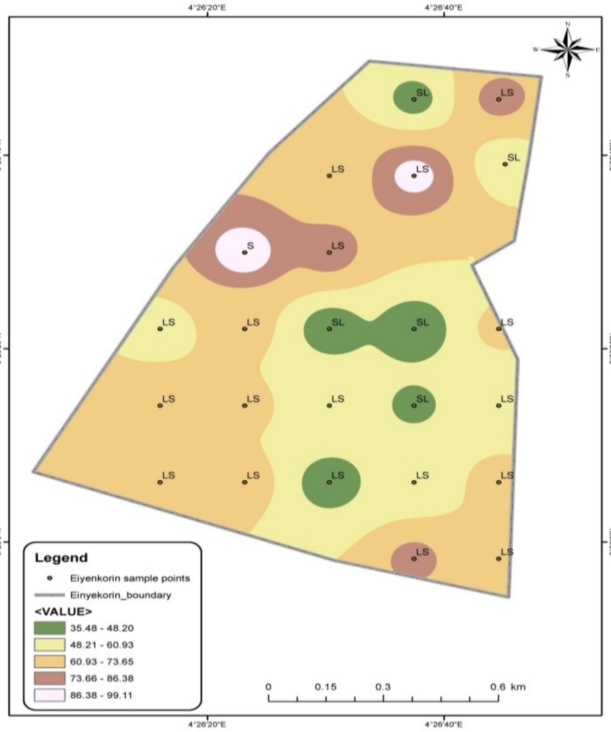

Fig. 3C. Spatial variability map of K_S for Eiyenkorin Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy.

Fig. 3D. Spatial variability map of TP for Eiyenkorin Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy.

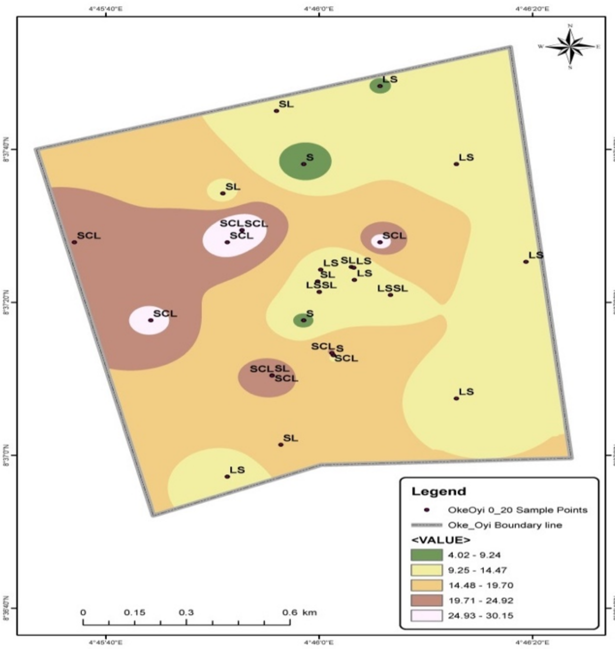

Fig. 4A. Spatial variability map of clay content for Oke-Oyi Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy; SCL = Sandy clay loam.

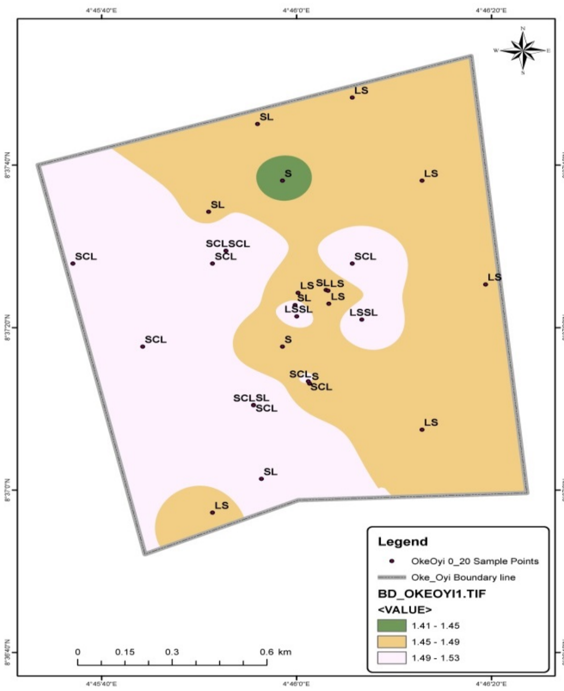

Fig. 4B. Spatial variability BD for Oke-Oyi Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy; SCL = Sandy clay loam.

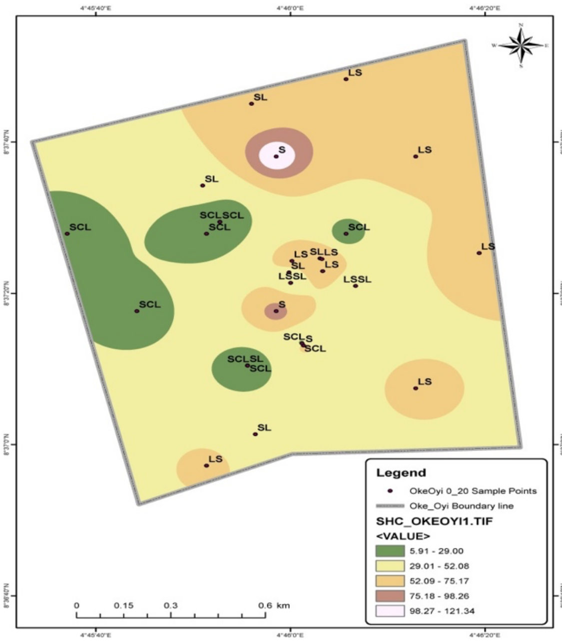

Fig. 4C. Spatial variability map of K_S for Oke-Oyi Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy; SCL = Sandy clay loam.

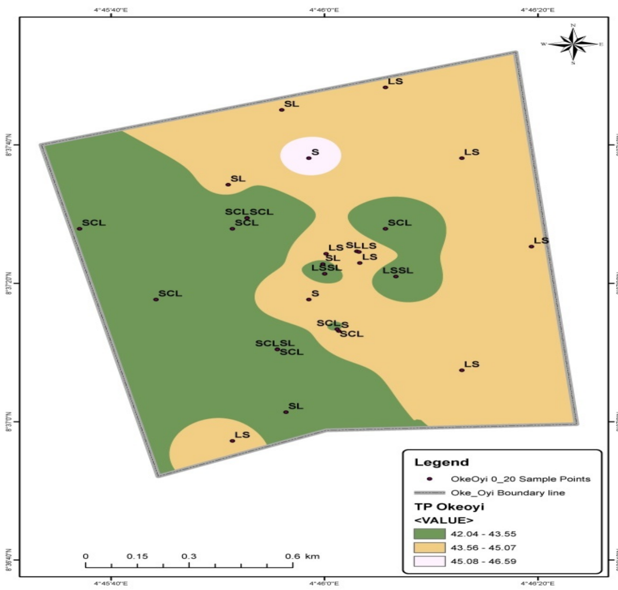

Fig. 4D. Spatial variability map of TP for Oke-Oyi Irrigation Scheme. Note: LS = Loamy sand; SL = Sandy loam; S = Sandy; SCL = Sandy clay loam.

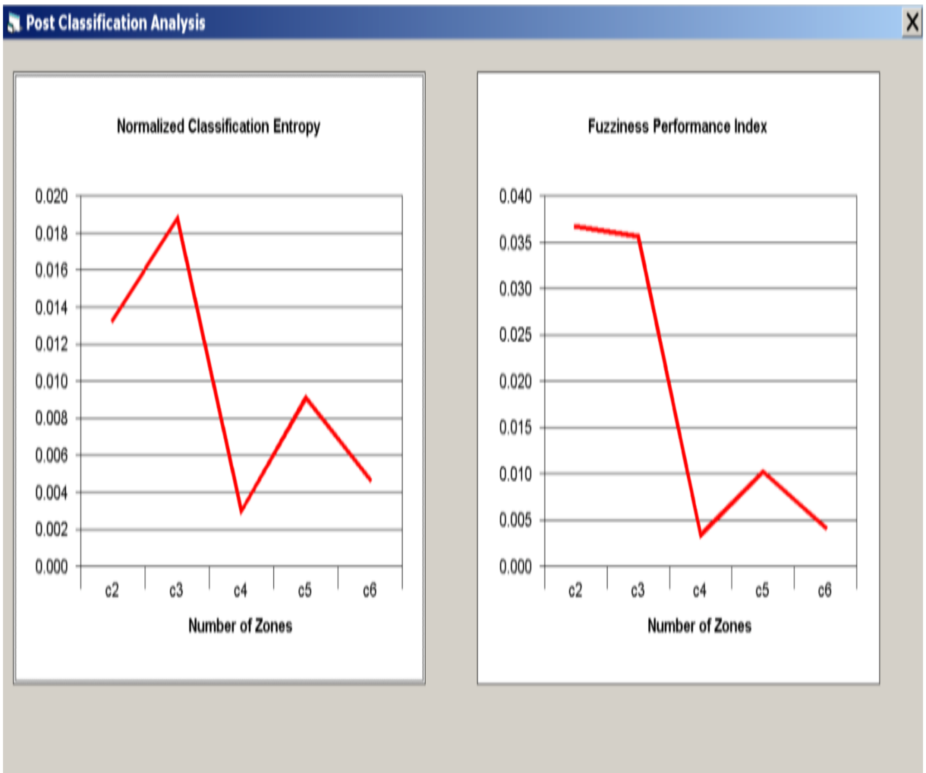

Fig. 5A. Changes in two performance indices with an increasing number of management zones using clay content data for Oke-Oyi Irrigation scheme.

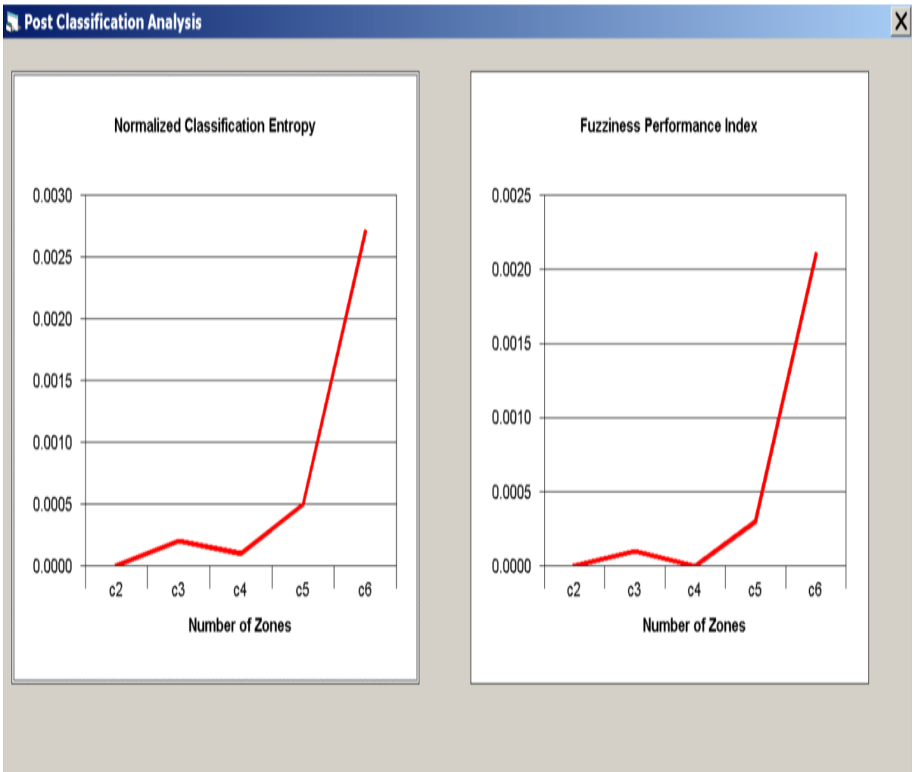

Fig. 5B. Changes in two performance indices with an increasing number of management zones using clay content data for Eiyenkorin Irrigation scheme.

DISCUSSION

Sites characteristics

Soil ph, soil bulk density, total porosity, and saturated hydraulic conductivity

The selected soil properties of the study sites (EIOS) at two different depths (0 – 20 cm and 20 – 40 cm) reflected that the soil reactions ranged from slightly acidic to slightly alkaline. This is an indication that the reaction of the soil will support most crops like maize, potatoes, okra, pepper, garden egg, cassava, and yam commonly cultivated in the area. Okalebo *et al*., (2002) reported improved plant productivity of some cereals and vegetable crops with a soil pH range from the acidic to alkaline. Since the pH in the water for all the samples irrespective of the horizons are above 5.0, thus the fields will have a direct impact on plant productivity. This find is in line with H.-L. Jiang *et al.* (2012) submission that the change in soil pH, soil bulk density, total porosity, and K_S within the specific agronomical field are often caused by frequently altered planting patterns, irregular crop growth, and different management practices, leading to a marked alteration in topsoil quality and health status over small distances.

Most of the soil properties were not moderately distributed except the K_S in the Eiyenkorin field at the topsoil level that is normally distributed. This is indicated that most of the soil properties measured were either high or low at short distances and depth which often lead to either Negative Skewness (when the tail of the left side of the distribution is longer or fatter than the tail on the right side) or Positive Skewness means when the tail on the right side of the distribution is longer or fatter. According to Young *et al.* (1999) findings, the long tails of skewed distributions imply that there are inclusions or outliers within a studied field, because of distinct change in the environmental deposition and/or the asymmetric effects of the pedogenic or hydrologic process.

The variation in soil bulk density (BD) suggested that there are regions in the study sites that BD values are higher and moderately varies both in-depth and location within EIOS but not necessarily higher than the critical interval (1.60 to 1.80 g cm^{-3}) for sandy soils as proposed by Reichert *et al*., (2003). Soil total porosity (TP) values also showed moderately high variability, indicating that plants survive water and/or air stress in most of the study fields (Reichert *et al*., 2003). Based on CoV values, the EIOS field had the low BD and TP which agrees with Saxton and Rawls, (2006) findings which they used to characteristics coarse-textured or sandy soils.

The higher variability in EIOS saturated hydraulic conductivity (K_S) affirmed the fact the field is sandy (Rodrigues *et al*., 2015). This also implies that the field will be moderately saturated, and plants will survive water and/or air stress especially during waterlogged conditions because of a heavy downpour or water application through irrigation (Oshunsanya *et al*., 2012; Rodrigues *et al*., 2015). The need for effective water and nutrient management becomes imperative as the EIOS soil characteristics required adequate management of nutrient amendments and water availability for optimum crop growth and yield as described in separate reports by Gbadegesin and Oriola (2004) and Foth (2014).

Particle size distribution

The texture of the soils was largely determined along a linear sequence of the textural class by the relative proportion of sand, silt, and clay fractions. The soil types/textural class determined in EOIS were sandy clay loam, loam sand, loam, sandy loam, and sand. The linear sequence of textural class determined could be linked to lower clay and silt fraction within EIOS irrespective of the depth of the soil. The main reason for this is due to the inherent capacity of the field because of the pedogenic process and rock constituents. Although the clay content was generally low within EIOS, the Eiyenkorin field had some of the areas with significantly higher clay fraction which explain the feasible waterlogged area within the field which the farmers classed as Fadama that they used for cultivation when dry soil had fully established. However, the EIOS soils were generally dominated by loamy sand.

Spatial distribution of selected soil properties

Generally, the maps showed the distribution of soil textural class of the study site on which the distribution of highly correlated selected soil properties was reflected thus, served as the base map for the spatial distribution of soil properties. The soil textural class range from sandy to sandy clay loam. The most distributed selected soil properties were indicated by brown color while the least was indicated by white and green color. The deduction from this is that all the selected soil properties had unique spatial variability and heterogeneous spatial distributions which often resulted in three (BD and TP) and five (K_s and clay contents) boundaries classes in the EIOS. However, it can also be deduced that less than 25 % of the Eiyenkorin field is degraded while close to 40 % of the Oke-Oyi field is degraded. This could be a link to the period of cultivation, management practices, and cropping patterns. However, there was clear evidence of adequate management practices and non-uniform cropping patterns on the EIOS. It was observed that the orientation for the tillage operation was along the slope as against the standard which is across the slope as well as inadequate cropping sequence and fertilizer application. This agrees with H.-L. Jiang *et al.* (2012) study that refilled that the determinant for the spatial correlation of soil properties is a function of the structural factors that include soil parent material, topography, fertilizer application, crop planting pattern, soil management, and water table.

This implies that the most distributed soil properties can be used as a basic range for the adequate guide to determine the rate of water and nutrient applications. This will also provide adequate support for the choice of effective management practice that will not only lead to precision agriculture but a sustainable management approach to the agronomical field.

Correlation analysis

The consistently negative correlation coefficient of CR and TP implies that a unit increase in CR value will result in an impact decrease in TP. Also, a significant increase in clay content will cause a significant impact in BD of the EIOS field. This could be attributed to the role of clay particles in soil structure, textural formation, and aggregation. Generally, extremely significant correlations were observed between sand content, SHC, TP, CR properties of EOIS ($P<1\%$) with clay content. Thus, clay content measured data for EOIS was used for delineating management zones. According to Henrique and Luis (2016), clay attribute was found to have the greatest heterogeneity in their studied area, Quartzipsamment of the Brazilian semiarid region.

Delineating management zones

The MZs for EIOS was indicated by changes in two performance indices with an increasing number of management zones using clay content data for Oke-Oyi (A) and Eiyenkorin (B) Irrigation scheme. The implication of this is that EOIS can be managed effectively with 3 and 6 distinctive MZs based on the clay content attributes that related significantly with the water and nutrient transmission (SHC) (Rockstro¨m *et al*., 2007) indices such as soil erodibility (CR) (Oshunsanya *et al*., 2012); water and air pores (TP) and soil bulk density (Rodrigues *et al*., 2015).

CONCLUSIONS

The soil in the study area was characterized by high variation and correlated soil properties like clay content, SHC, BD, TP, and CR. This resulted in the creation of 3 MZs for the Okeoyi Irrigation scheme and 6 MZs for the Eiyenkorin Irrigation scheme. This could be due to the cultivation history and/or anthropogenic processes of the study sites as the Eiyenkorin Irrigation scheme is just approaching its 12 years of continuous cultivation while Oke-oyi Irrigation had been experiencing crop intensification for more than twenty-five years. Therefore, the delineated MZs will not only promote effective fertilizers and water management for the study sites but also guide management decision for the precision agriculture and sustainable use of the EOIS.

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PROXIMAL AND REMOTE SENSING

AN OPEN-SOURCE MULTISPECTRAL CAMERA FOR CROP MONITORING #9281

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ABSTRACT

Precision agriculture is one of the most important economic issues of the 21st century because it will make it possible to respond to the new challenges of agriculture, which are population growth, global warming, global epidemics, and inflation, to name a few. Remote sensing makes it possible to monitor the plantation from a distance and makes it possible to know the level of growth and the state of health and hydration of the plants. This paper outlines an affordable and open-source multispectral camera to calculate the biomass of crops. The camera can be fixed in a corner of the field. It can be carried by a mobile robot that moves across the field, it can also be attached to a drone-type flying device to cover more territory and for tree crops. The system is based on a raspberry pi board, an infrared camera to which we add color filters and an RGB camera. The luminance is corrected thanks to a luminescence sensor. We add to this a rechargeable battery for the power supply. The shots are stored on an SD card and can be transferred to a computer. The camera can connect to the internet, and we can observe the field in real time from anywhere on the globe. The raspberry pi board is a nano-computer, we could program it in python. An application has also been developed to read and process the images. Thanks to the latter, we can mosaic the images, extract the indices, and compare with older images. It is also possible to observe cultures in real time by streaming. The application can also deliver displays in the form of graphs, tables, and maps. The tests were carried out on different data sets and on different crops and the results were compared with the values given by agronomists, which turned out to be closely related.

Keywords: Remote sensing, multispectral camera, biomass, raspberry pi, open-source, crop monitoring.

INTRODUCTION

Precision agriculture is a new field, there are currently few farms using this technology, due to the high cost. In the field of agriculture, water management, farming systems and agri-food value chain are key domain [1, 2, 4]. Precision agriculture makes it possible to save water, insecticide, and fertilizer. Remote-management makes it possible to reduce field displacements in the case of arid zones and in these times of COVID-19 [3]. In this work we present a new prototype of crop remote monitoring station that is solar (self-powering), open-source and available for small-scale farms. This station can be settled on fields and provides information about the soil and weather thanks to a set of sensors, and biomass information thanks to a multispectral camera module and a real time camera. We can see in Fig.1 the station schema. In this paper we describe firstly the station, after we present some results and then we finish with a conclusion and outlook.

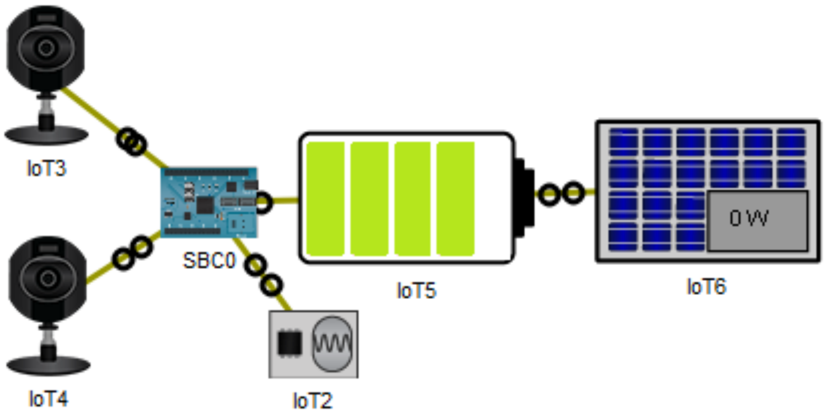


Fig. 1. The camera schema realized with cisco packet tracer software.

MATERIALS AND METHODS

The station is composed of four modules: a power module, a sensors module, a wind sensor module, and a multispectral camera module. The power module is made up of a solar panel, batteries, and a battery charger component. It provides the current to the other modules. The sensors module is made up of a set of sensors: a capacitive soil moisture sensor, a rain sensor, a pressure sensor, fire sensors, a humidity sensor, a light sensor, and a temperature sensor. The multispectral camera module is made up by multiplexing Pi daylight camera and PiNoIR cameras, with the use of color filters to obtain different light spectra. Fig. 2 presents the components of this module.

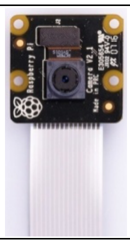
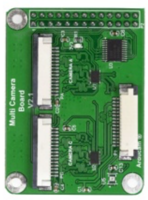
PiNoIR Camera	Pi Camera v1.3	Multiplexer	Camera filters
			
Solar panel	TSL2561 Luminosity Sensor	Raspberry pi 4	
			

Fig. 2. Multispectral camera elements.

The entire sensors are commended by a nano computer (model Rapberry Pi 4). It is this computer which also saves and sends the data to the server every hour of the day.

RESULTS AND DISCUSSION

The station modules can be simply installed in every field or zone on any support; however, the camera module must be installed in a high support to enlarge the view. It can be also set in a drone.

The application provides different kind of display. We can display graphics of the sensors data by hour, day, month, season, and year and by field, zone, or station and naturally by sensor (Fig. 3). We can also display the cameras photos or the real time capture.

Fig. 3. display graphics of the sensors.

Nowadays, the remote crop monitoring is important, among the benefits we can cite: the increase of production and the production quality, the water saving, the accurate field evaluation, the reduction of environmental footprint, the real time monitoring, and the reduction of displacement to prevent exposure to COVID-19. We presented in this paper a new prototype of affordable and open-source sensor solar station connected to the internet for small scale farms. This station provides soil and weather information of the fields. It allows also tracking the crop via real-time images and getting information about biomass via a multispectral camera. This work can be improved by the proposal of an open-source model of agricultural drone for the monitoring and mapping of crops.

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APPROACHES TO ESTIMATE PHOSPHORUS AND POTASSIUM CONTENT OF WHEAT LEAVES #9390

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ABSTRACT

The assessment of plant nutrient status to provide sufficient fertilization for rapid and continuous uptake by plants has been based on visual diagnosis in the field, which is quick but demands a lot of experience and has a low operability. Visible near-infrared spectroscopy (VNIS) has shown to be a quick, non-destructive, accurate, and cost-effective analytical method in precision agriculture. In this study, we assessed the potential of this technology to predict phosphorus and potassium content in the wheat leaves using different multivariate regression methods. The hyperspectral and the reference measurements were taken from wheat plant leaves grown in a long-term fertilization trial under contrasted concentrations of phosphorus and potassium. The leaf proximal and hyperspectral data were collected using an ASD FieldSpec4 spectroradiometer operating in the spectral range from 350 to 2500 nm. Before conducting the analysis, the leaves spectra were preprocessed with a Savitzky–Golay smooth filter and a Standard Normal Variate normalization method. A total of 60 samples, collected between flowering and maturity stages, combined with the preprocessed spectra were used to develop support vector regression (SVR), random forest (RF), and principal component regression (PCR) prediction models for estimating leaves phosphorus content (LPC) and leaves potassium content (LKC). The entire sample set was randomly split into a training set (70%) and a test set (30%), and the performances of the different prediction models were compared using normalized root mean square error (NRMSE) and coefficient of determination (R2) in both cross-validation and testing processes. The results showed that LPC prediction models outperformed the LKC models, with high accuracies (R^2) in cross-validation in the order of 0.84, 0.85, and 0.79 for SVR, PCR, and RF, respectively. For potassium, the coefficient of determination of cross-validation was 0.64, 0.59, and 0.54 for SVR, PCR, and RF, respectively. The highest validation results were returned by the RF algorithm for both LPC and LKC predictions, with moderate R^2 values equal to 0.56 and 0.53, respectively. In the RF model, phosphorus and potassium in wheat leaves can be predicted with errors of 19 and 13%, respectively.

Keywords: Phosphorus, Potassium, Visible Near Infrared Spectroscopy, Random Forest, Support Vector Regression, Principal Component regression

INTRODUCTION

The visible, near infrared, and short-wave infrared (Vis-NIR-SWIR) spectroscopy is an emerging technique that has been widely used for soil and plant analysis. The spectroscopy technique uses the reflectance in the wavelength range from the visible to the SWIR for a non-destructive and effective plant characterization (Ge et al. 2019; Muehling et al. 2015). It is based on the interaction between plant leaves and the incident light in the Vis-NIR-SWIR spectral regions. In plant leaf cells, photosynthetic pigments such as chlorophylls, carotenoids, and anthocyanins absorb strongly in the VIS region. On the other hand, phosphorus (P) and potassium (K) are important and essential elements for plant growth and development and strongly involved in physiological processes (Jiaying et al. 2022). P plays an important role in energy metabolism and K is the most abundant cation in plants. Therefore, it is important to estimate and monitor the contents of P and K. Their deficiency affects pigments biosynthesis in wheat which allows application of Vis-NIR spectroscopy for non-destructive prediction of phosphorus and potassium in plants (Thornburg et al. 2020). The P and K were estimated using spectral reflectance and partial least square regression (PLSR) with an R^2 of 0.643 and 0.541, respectively. However, the support vector machine regression (SVMR) method had higher accuracy with R^2 values of 0.722 and 0.704 for P and K, respectively (Zhai et al. 2013). Using PLS, Mishra et al. (2021) accurately predicted the K content dried and prepared samples of pepper leaves, with an R^2 value of 0.82 and an RMSEP of 0.53%. The PLS Regression Analysis is a commonly used method to model Vis-NIR data but the non-linear regressions have been proved to handle better the non-linear relationships that exist between the response variable and predictor variables in soil and plants (Nawar and Mouazen, 2019; Zhai et al., 2013). Moreover, It has been demonstrated that the choice of calibration method can impact the measurement accuracy when using visible and near-infrared spectroscopy (Vasques et al. 2008). In this study, we aimed to estimate indirectly phosphorus and potassium content in wheat leaves using leaf-proximal hyperspectral data and different multivariate modeling techniques.

MATERIAL AND METHODS

The study was conducted on a long-term trial located in Gembloux-Belgium (50.564121, 4.698802), called the law of the minimum trial. It has been installed up and monitored the same way since 1896 with an objective to study for the long term the effect of nitrogen, phosphate, and potassium on field crop yields. In our study we focused on the plots presenting an interesting contrasts and variability of phosphorus and potassium contents. The area of interest is 5 sets of 10 microplots, each set represent a different fertilization treatment. The treatments are NPK (nitrogen, phosphorus, and potassium fertilization), PK (phosphorus and potassium fertilization), NK (nitrogen and potassium fertilization), NP (nitrogen and phosphorus fertilization), and 0 treatment (no application of the three macronutrients).

The data collection consisted of spectra acquisition using ASD FieldSpec4 spectroradiometer (Malvern Panalytical Ltd., Formerly Analytical Spectral Devices) with spectral range from 350 to 2500 nm and a spectral sampling of 1 nm. The reflectance measurements were done on the flag leaf. In parallel to spectra acquisition, biomass samples were taken from the different treatments for chemical analysis of P and K leaves content. The recorded spectra were preprocessed prior the multivariate analysis, the spectra were smoothed using Savitzky-Golay filter and normalized using the Standard Normal Variate. After the preprocessing, three predictive models were developed for P and K using support vector regression (SVR), random forest (RF), and principal component regression (PCR). The models' performances were evaluated using the statistical metrics such as coefficient of determination (R^2), normalized root mean square error (NRMSE), and mean absolute error (MAE).

RESULTS AND DISCUSSION

LPC and LKC prediction

The cross-validation yielded higher coefficient of determination, lower normalized root mean square error, and lower mean absolute error for the three predictive models, whereas the validation results were moderate (**Table 1**). The random forest model for predicting LPC had the highest predictive performance in the validation process, a coefficient of determination equal to 0.56, a NRMSE of 0.19, and a MAE equal to 0.71 mg/g, followed by the principal component regression, and the support vector regression model with respective performances (R^2_v = 0.534, $NRMSE_v$ = 0.202, MAE_v = 0.875) and (R^2_v = 0.503, $NRMSE_v$ = 0.203, MAE_v = 0.897). Compared to phosphorus, the developed models for estimating potassium content in wheat leaves had lower predictive performances in both cross-validation and validation processes. The highest performance was obtained by RF model, it predicted LKC with a coefficient of determination of 0.531, $NRMSE_v$ of 0.114, and MAE_v of 1.856 mg/g. The principal component regression had the lowest performance (R^2_v = 0.359, $NRMSE_v$ = 0.196, and MAE_v = 3.41 mg/g). The phosphorus predictive models fared better in cross-validation and validation compared to the potassium predictive models, as the phosphorus concentration in wheat leaves might be higher than the potassium concentration. The SVR had higher performances in cross-validation than in validation process. Xiong et al. (2020) attributed the low prediction performances of SVR model to the nonlinear principle of SVR that increases the complexity of the prediction model. On the other hand, random forest outperformed PLSR models in a study conducted by Nawar and Mouazen, (2019) to estimate soil total nitrogen using Vis-NIR spectroscopy suggesting that RF handles better the nonlinear relationships that exist between the response variable and predictor variables in soils. Based on Vis-NIR reflectance, SVRs outperformed PLSRs in a different comparison, with R^2 values of 0.722 and 0.704 for P and K, respectively, which has been explained by the ability of SVR to model the non-linearity between the reflectance data and plant biochemical variables (Zhai et al. 2013).

Table 1. Cross-validation and validation performances.

Nutrient	model	Cross- validation			Validation		
		R^2	NRMSE	MAE	R^2	NRMSE	MAE
LPC	SVR	0.84	0.156	0.739	0.503	0.203	0.897
	PCR	0.85	0.14	0.661	0.534	0.202	0.875
	RF	0.79	0.18	0.91	**0.56**	**0.192**	**0.713**
LKC	SVR	0.637	0.207	3.643	0.43	0.133	2.139
	PCR	0.591	0.243	3.715	0.359	0.196	3.41
	RF	0.542	0.241	4.29	**0.531**	**0.114**	**1.856**

Wavelength importance

Fig.1 shows the importance of each wavelength in explaining the variation in our phosphorus and potassium data. The most informative wavelengths have high importance values. The wavelength importance has overlapping peaks for SVR and PCR models for both phosphorus and potassium. For phosphorus, the SVR and PCR developed models have the most important wavelengths in the spectral ranges from 710 to 730 nm and in the SWIR region from 2022 to 2036 nm, whereas the most informative wavelengths are 716, 738, and 727 nm for random forest (Fig 1A). The most effective wavelengths for determining potassium levels using SVR and PCR were primarily in the blue part of the spectrum, specifically between 494-500 nm, 470-480 nm, and 2040-2060 nm. For the random forest model, the most informative wavelengths were at 1472, 1480, and 1485 nm. Similarly, Siedliska et al. (2021) found that certain wavelengths in the red (715 and 723 nm) and short-wave infrared (2301 and 2332 nm) regions were important for identifying different levels of P treatment in strawberry plants. The absorption peaks at the red and far-red regions of the electromagnetic spectrum were primarily attributed to the chlorophyll a absorption. Pimstein et al. (2011) observed significant correlation in the spectral ranges 1400–1500 nm and 1900–2100 nm for phosphorus and suggested a spectral index based on wavelengths 1645 nm and 1715 nm for both potassium and phosphorus estimation. Malmir et al. (2020) reported important wavelengths for P prediction at 700–1000-nm region and higher β-coefficient values in the wavelength range 730–1000 nm for K prediction. Xiong et al. (2020) found several sensitive wavelengths in the region from 550 nm to 970 nm for potassium prediction in green leaves. The authors stated that the third overtone of the vibration of the C-H and O-H bonds is generally linked to the wavelength range of 730–900 nm.

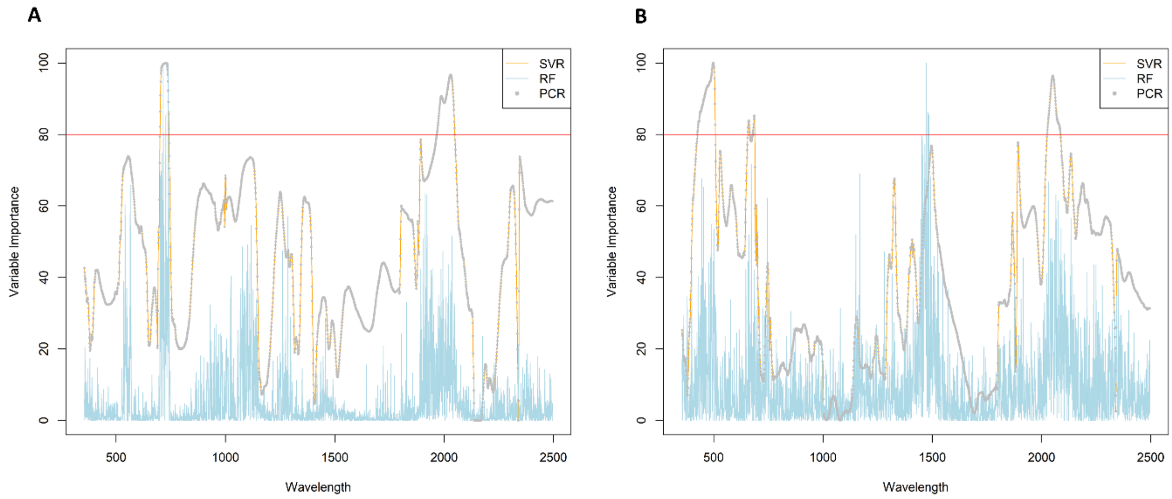

Fig. 1. Important wavelengths for the prediction of LPC (A) and LKC (B) content using support vector regression (SVR), random forest (RF), and principal component regression (PCR).

In our study, phosphorus models fared better than potassium and random forest analysis had the best predictive performances in validation for both phosphorus and potassium. In addition, a few variables gave very high variable importance values in RF models compared to SVR and PCR models, this suggests that our proposed RF models mainly focus on the important variables for modeling while neglecting the influence of noisy variables.

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FROM DRONE TO SATELLITE – DOES IT WORK? #9398

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ABSTRACT

In order to assess the possibilities to transfer crop property prediction models generated from data collected with drone-mounted multispectral cameras to satellite image-based decision support systems, data from two multispectral drone cameras – a five-band camera (Micasense Rededge, AgEagle, USA), and a nine-band camera (MAIA, Eoptis, Italy) mounted on the same drone – were compared with surface reflectance data from the Sentinel-2 satellites. Data were collected in cereal crops in south Sweden during 2020-2022 at 30 different locations and dates. The time difference between the Sentinel-2 images and the corresponding drone flights was maximum two days. Comparisons were made both for individual bands and for a range of vegetation indices (VIs). Results calculated as average reflectance for each flight and location showed that individual bands of the drone cameras were often well correlated with the Sentinel-2 bands, but with an offset from the 1:1 line (as indicated by low Nash-Sutcliffe modeling efficiency E). For many VIs, the bias was much lower (e.g., for NDVI, R^2 was 0.90 and 0.96, and E was 0.69 and 0.93, for MAIA and Micasense Rededge respectively). Hence, models based on these drone sensors may be possible to apply on satellite image data but may require some adjustments to correct for systematic differences, depending on bands or indices used.

INTRODUCTION

Drones (unmanned aerial vehicles, UAVs) equipped with multispectral cameras can efficiently collect detailed crop canopy reflectance data in small-plot field trails (e.g., Prey and Schmidthalder, 2019), thereby reducing costs for manual field work. Additionally, this provides possibilities for the development of crop status prediction models based on spectral data, that may be of relevance in practical precision agriculture, e.g., for optimising nitrogen (N) input (Piikki et al., 2022) or protein concentration (Wolters et al., 2022). To make such models widely available, one option is to apply them in decision support systems (DSS) based on satellite images data (such as CropSAT.com (Dataväxt, Sweden); Söderström et al., 2017). If such a transfer of models should be successful, there must be a consistent and established relationship between crop reflectance registered by the drone camera and the satellite sensor. In earlier research, comparisons between data from drone sensors and Sentinel-2 data (e.g., Bukowiecki et al., 2021; Matese et al., 2015; Rasmussen et al. 2020) have shown variable results, partly depending on different strategies in the data collection, and how data was compared.

In this study the aim was to compare reflectance data (both individual bands and a selection of vegetation indices (VIs)) from two drone sensors with Sentinel-2 satellite data. Data was collected over a period of three years in different locations south Sweden, and the difference in time between drone and satellite acquisition was not more than two days. Based on this criterion, we tried to establish consistent sensor relationships. Ultimately, we assess whether transfer of prediction models developed by the drone sensor data to satellite images used in agricultural DSSs is possible.

MATERIALS AND METHODS

Two drone cameras were used: a nine-band sensor (MAIA, Eoptis, Italy), and a five-band sensor (Micasense Rededge-3, AgEagle, USA). Both were mounted on the same drone (a custom-made octocopter (Explorian 8, Pitchup, Sweden). The bands of these cameras cover the visible to near infrared (NIR) portion of the electromagnetic spectrum, bandwidths are shown in Fig. 1. Sentinel-2 has bands with the same specification as those of MAIA. Drone flights were carried out over small areas (1-4 ha in size) which included small-plot field trials in wheat, oats, and barley, with at least 80% image overlap, at 80-m height above ground, and with a speed of 5 m s^{-1}. Further details of flights and data processing are found in e.g. Piikki et al. (2022). Orthomosaics were generated with the Solvi.ag web application (Solvi, Sweden). Two methods were used for calculation reflectance for the drone sensors. For MAIA, 50 cm × 50 cm target panels (MosaicMill, Finland) with different reflectance characteristics were placed in the field. These were used to recalculate digital numbers in the orthomosaic to reflectance. For Micasense Rededge, a provided small target panel was photographed before and after the flight and used for deriving reflectance.

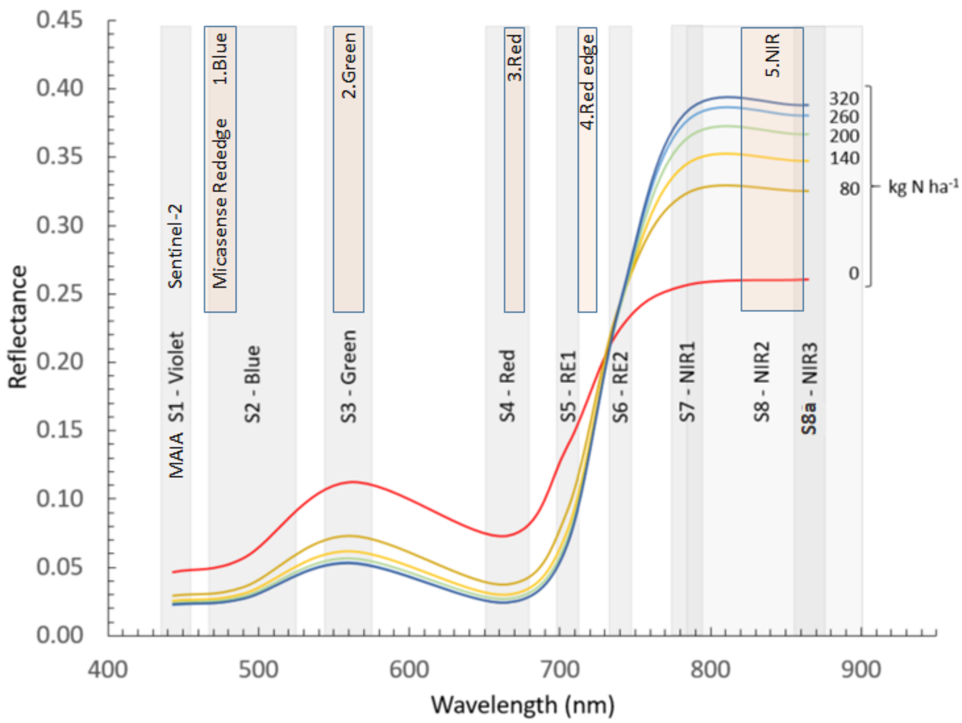

Fig. 1. Example spectral signatures of wheat in the spectral region 400-900 nm (visible to near infrared). Different curves represent data from after flowering in trial plots with different N rates applied. Shaded areas show the bands of different sensors (UAV: MAIA and Micasense Rededge; Satellite: Sentinel-2).

To georeference the drone mosaics, we used a national orthomosaic based on aerial photography provided by the Swedish Land Survey (Lantmäteriet, Sweden), which had a reported positional error of less than 20 cm. Only flights done within two days from an available Sentinel-2 image free from haze, clouds, and cloud shadows (as judged manually) were used. Thirty-two flights carried out over wheat, barley, and oats during the period 2020-2022 from start of the stem elongation period to end of flowering fulfilled these criteria.

Sentinel-2 L2A processed images (atmospherically corrected orthomosaics with ground reflectance) downloaded from European Space Agency's web site (https://scihub.copernicus.eu) were used. These were not further georeferenced but used as provided.

In this study, data extracted from the trial parcels (which was the initial aim of the projects within which the drone flights were carried out) were not used. Instead, average reflectance data for each band across all 20 m × 20 m areas coinciding with pixels of the Sentinel-2 satellite were calculated. Calculations were made for all individual bands (Fig. 1) and the VIs: NDVI (Rouse et al., 1973); MSAVI2 (Qi et al., 1994); NDRE (Barnes et al., 2000); NGRDI (Bannari et al., 1995); ChlI (Gitelson et al., 2003); and TGI (Hunt et al., 2013). In two cases, there were problems with the calculations of reflectance for the visible bands of the MAIA camera. These two flights were omitted. To derive general sensor-sensor relationships, and reducing impact of differences in e.g., georeferencing, averages of reflectance in bands and VIs for each flight was used in the analyses. Comparisons were analysed statistically with the determination coefficient R^2 of a linear regression line between reflectance data from the two sensors, as well as the modeling efficiency E (Nash and Sutcliffe, 1970; how well the data follows the 1:1-line). In a perfect relationship both R^2 and E are approaching 1.0. If the data are well correlated, but not close to the 1:1-line, the R^2 is high but E is low and can even be negative if the bias is large.

RESULTS AND DISCUSSION

Results from the analyses are shown in Table 1. Individual bands are often well correlated (relatively high R^2), notably the Micasense Rededge bands 1-4 and MAIA bands 2, 4 and 5 with an $R^2 > 0.70$, but in some cases, there is a bias, resulting in a low or negative E. Among the individual bands, only MAIA band 5 and Micasense Rededge bands 1 and 3 had an E > 0.50. For some of the tested VI's, this bias was removed, and both E and R^2 were high, e.g. the Micasense Rededge indices NDVI and NGRDI, and for MAIA, the indices MSAVI2, NDRE and ChlI. The index TGI (based on the visible bands) was only well correlated to the Micasense Rededge sensor (still with a very large bias).

The results indicate that for some of the best performing VIs, it should be possible to a apply a prediction model from drone sensor data that is based on one or more of these indices on Sentinel-2 satellite images, directly or with some linear adjustment. Especially simple indices based on ratios and quotients between two bands seem to be well correlated between the sensors and producing very similar values. The more complex TGI index did not work equally well.

When data from individual flights (the 20 m × 20 m pixels, on average 40 pixels per flight; n=1188 in total) were analysed (data not shown here), it is evident that the relationships vary between flights. The reasons for this can be many. With this type of dataset, which consists of orthomosaics of agricultural fields, but each of which includes small-plot field trials with small areas with considerable variation in reflectance, including areas of bare ground, it is likely that also minor variation in the position of the Sentinel-2 images will have a large impact on the relationship with data from the drone flight. The drone orthomosaics are very accurately positioned, whereas it is difficult to be sure of the correct position of the satellite image. Some other issues may be related to the radiometric corrections, both for the Sentinel-2 images and certainly for the drone images. In this case, drone flights were done in as uniform weather as possible, but still light conditions may fluctuate during a flight. Incoming light sensors were used on the drone, which can correct for this to some extent. In addition, flights were carried out with slightly varying solar altitude. On average it was 48° but ranging between 31° and 54°. Such varying conditions may impact on the results (e.g., de Souza et al., 2021). Still, the high R^2 and E for some indices on average, suggest that the procedures used generate useful drone sensor data. To minimize variation between flights, it is recommended to carefully follow a predetermined protocol in terms of flight height, speed, and image overlap, avoid data collection in varying weather conditions, and also use the same method for geometric and radiometric corrections (see further discussion in e.g., Maes and Steppe, 2019).

Table 1. Modeling efficiency (E) and coefficient of determination (R^2) between data (individual bands, see Fig. 1, and selected indices) from Sentinel-2 and two drone cameras. The table shows averages from 30 flights (2020-2022; date between drone flight and satellite image is max 2 days).

	MAIA			Micasense Rededge		
Band or index	Band(s) used	E	R^2	Band(s) used	E	R^2
Blue	2	-0.09	0.70	1	0.56	0.83
Green	3	-0.09	0.40	2	-0.36	0.86
Red	4	0.49	0.87	3	0.63	0.93
RE1	5	0.84	0.86	4	-2.09	0.88
RE2	6	0.39	0.59	-	-	-
NIR1	7	0.22	0.48	-	-	-
NIR2	8	-0.01	0.43	5	-2.68	0.40
NIR3	8a	-0.09	0.46	-	-	-
MSAVI2	4, 8	0.79	0.83	3, 5	-0.32	0.81
NDVI	4, 8	0.69	0.90	3, 5	0.93	0.96
NDRE	5, 8	0.83	0.90	4, 5	0.49	0.95
NGRDI	3, 8	0.29	0.55	2, 5	0.88	0.93
ChlI	6, 7	0.85	0.90	-	-	-
TGI	2, 3, 4	1.34	0.12	1, 2, 3	-10.15	0.78

CONCLUSIONS

As judged by the comparisons with the L2A calibrated Sentinel-2 satellite images, both drone cameras used in this study seemed to produce rather consistent orthomosaics. This was achieved with drone data collected over several seasons, during varying conditions and locations. In this study, average reflectance from different bands and indices were computed from this range of flights and was used in the comparisons. Individual bands were in most cases well correlated between drone sensor orthomosaics and satellite images, but with a bias. Simple indices of the normalized difference type (NDVI, NDRE etc.) showed smaller biases, and in some cases the computed index values were very similar from the different platforms. This indicates that models of various crop properties calculated based on drone data collected in field trials, may well be transferred to Sentinel-2 image based DSSs, possibly with some correction factor depending on the indices included in the model.

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PERFORMANCE OF REMOTE SENSING DATA AND MACHINE LERNING FOR WHEAT DISEASE DETECTION
#9422

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ABSTRACT

The evolution of remote sensing applications in precision agriculture may lead to a reduction in phytochemical use. The development of data processing techniques allows speeding up the treatment of the information then making it possible to apply the right amount of chemical at the right place and time. In this study, the use of spectral information from remote sensing data using camera sensors coupled with artificial intelligence techniques at the field scale to detect wheat diseases is evaluated. In this study a Region based Convolutional Neural Network (R-CNN) model was evaluated for wheat disease detection. Besides, the methodology considered environmental variability during data collection to simulate real conditions during data acquisition in the field. The preliminary results of the model show a mean average precision of 0.45 and a precision between 0.2 to 0.6 for each image. Considering limitations in terms of data annotations for training the model, these results look promising on the way to consider further improvement of the model to reach higher accuracies and precisions. Furthermore, the study aims to develop a methodology for treatments reduction based on the enhanced version of the R-CNN model. Therefore, wheat disease detection and localized treatment in the field have a strong potential to reduce the use of chemicals. The developed methodology will optimize the costs and the use of chemicals over agricultural fields.

INTRODUCTION

French agriculture has reached high yield levels in many field crops. However, to reach them, it has required an intensive use of plant protection products (PPP) during the last decades. This intensive use of PPP situates France as one of the first users within the European countries (Eurostat, 2022). Since 2008 European and national policies have been trying to reduce the use of PPP to develop a more sustainable agriculture (European Parliament 2009). The development of precision agriculture may have an important impact on the reduction of PPP application, especially with the spot application technique (e.g., only when and where it is necessary), which reduces the use of PPP. Major progress has been made in weed detection and herbicides localized application (Nikolić et al, 2021) with the development of sprayers or weeders carrying cameras to detect weeds. On the contrary, the reduction of fungicides used to control diseases in plants has been the object of less studies, because of cumulated difficulties encountered in the implementation process. The first step has been to discriminate leaves with symptoms of diseases from healthy leaves (Sujatha et al. 2021), here the main difficulty was the diversity of symptoms within the diseases and along the development of the disease on the leaves. The second step has been to discriminate different plant diseases (Martinelli et al. 2015), to treat with more efficient treatment. Next difficulty will be to find diseased leaves on a field crop at different growing stages of the crop. The last step will be to be able to modulate the fungicides doses in function of the disease pressure or to make localized applications that may be able to stop or slow down the progression of the disease. For these reasons, this study will discuss the possibilities of wheat disease detection based on camera sensors and machine learning algorithms to identify diseased areas and variable rate application of treatment.

MATERIALS AND METHODS

In France there are decision support systems for farmers to alert the risk of diseases on the crops based on rainfall events, presences of spores, soil type, rotation, and the level of resistance of the variety to each disease. This study discusses the possibility, once there is a disease risk in a field, to implement a modulation of the dose of fungicides to be applied based on direct identification of the presence of the disease (Colbach et al 1997).

The wheat diseases considered in this study are the Septoria leaf blotch (*Mycosphaerella graminicola*) and the yellow rust (*Puccinia striiformis f.sp. tritici*). These two diseases affect the wheat leaves and cause important reductions in yields.

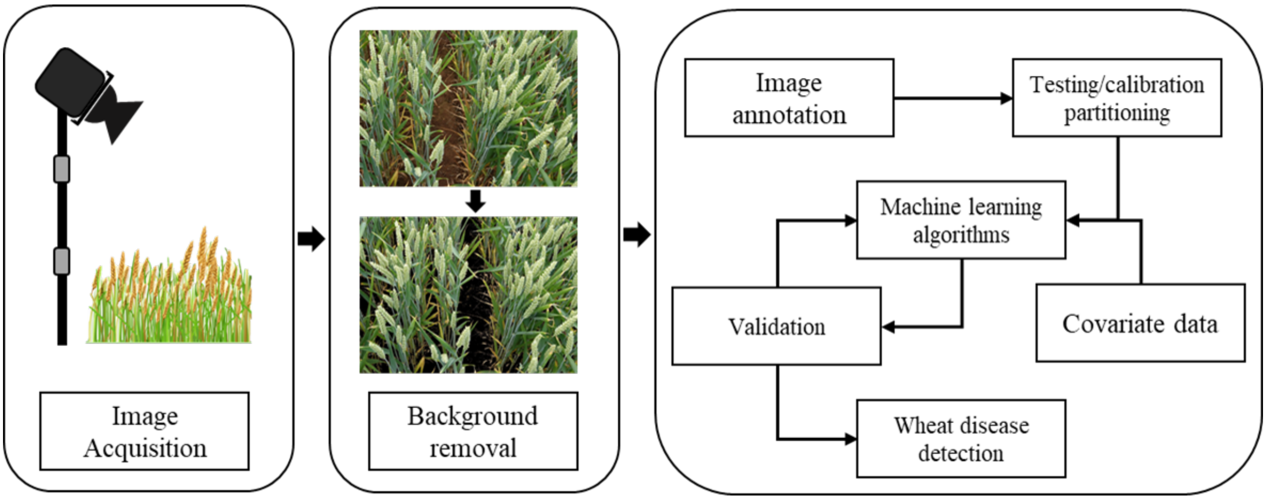

Fig. 1. General methodology for wheat disease detection. a) data collection using field camera with a 45° tilt, b) methodology of background removal based on the Colour Index of Vegetation Extraction (CIVE) vegetation index, c) general machine learning steps to perform wheat disease detection.

Many sensor types have been used in literature for plant disease detection (Fahey et al. 2020). However, the use of sensors for spot application of fungicide was reported in limited studies (Esau et al. 2018; Hussain et al. 2020). The methodology discussed here is based on the use of an RGB sensor from a Sony camera which will be mounted on a support and tilted to 45° degrees to simulate the position of sensors on the sprayer boom (Fig. 1).

After field data collection, the pre-processing steps will be conducted to make data ready for implementing in the machine learning algorithm. The first pre-processing step consists of soil background removal using the CIVE index. The formula used for CIVE computing is indicated below:

$$CIVE = 0.441 * R - 0.811 * G + 0.385 * B + 18.787 \qquad \text{(Eq 1)}$$

Where R, G and B represent spectral bands in red, green, and blue, respectively.

Mask-RCNN model was employed in this study to automatically segment and classify the diseased areas of wheat fields. The Mask-RCNN is based on two stages which are object detection and segmentation. It consists of three parts mainly a backbone, Region Proposal Network RPN, and feature branches (Su et al. 2020). A Residual Neural Network (ResNet) model with 101 layers (ResNet-101) was employed in this study. Model training was carried out using a limited number of annotated images.

RESULTS AND DISCUSSION

Fig. 2 presents the result of wheat diseases detection using Mask-RCNN model. The predictions were performed on validation dataset. The confidence values of detected objects vary between 0.3 and 0.65. The average precisions of the model for each image were relatively low and were between 0.2 to 0.6. In addition, the mean average precision (mAP) is about 0.43.

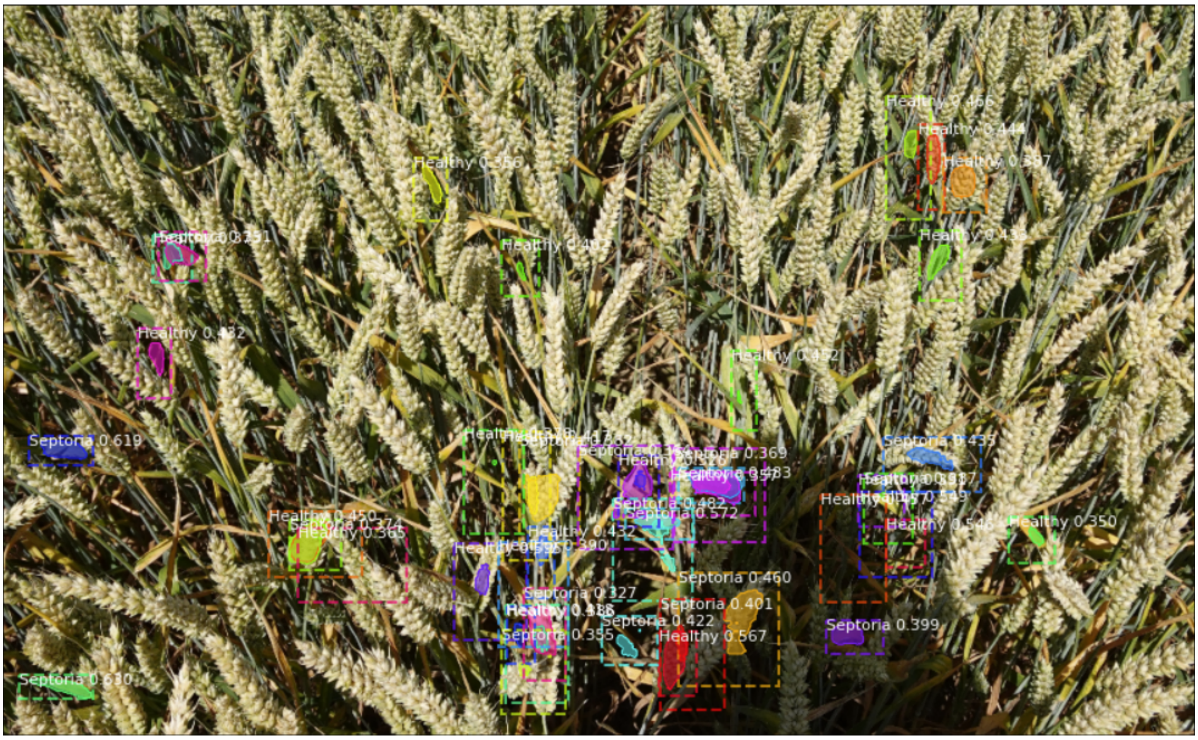

Fig. 2. Result of wheat disease detection using the validation dataset with the Mask-RCNN model.

Regarding the results obtained and precisions of the model, we can conclude that the model did not perform well for detecting diseased leaves. These raised errors could be originated from many issues that should be reviewed for the next application of the model. The intense presence of wheat heads in the images is the main source of errors during segmentation and identification of objects, as during the labelling step wheat heads were not labelled as a separate class to avoid mismatching with other classes. Moreover, related to some scheduling constraints the field data collection was performed during a late stage of phenological development where most leaves reach the senescence phase which makes the identification of leaves more difficult.

Different data acquisition platforms for plant disease detection were reported in previous studies, by using satellites, UAVs, land robots or handheld sensors (Mahlein, 2016) which allowed unequal diseases detection and time required for data acquisition and treatment. In this study, a handled sensor was chosen to provide accurate acquisition of images and simulate the configuration of sensors on the engine boom. Some studies have used UAV images to detect disease on wheat crops (Bohnenkamp et al. 2019; Deng et al. 2022). However, the use of drones is usually related to technical limitations, such as flight planification for data acquisition, limitations related to weather conditions and the time needed from data acquisition to action release at the field.

Machine learning algorithms for identification of wheat disease using images from sensors, especially deep learning, have provided significant advances to accurately identify and monitor diseased plants. Recently, Convolutional Neural Networks (CNNs), a subset of machine learning techniques, have gained popularity as a flexible tool for operating on large and diverse amounts of data and producing accurate predictions of difficult and complex problems (Su et al. 2020). Besides, many datasets have contributed to the training of algorithms to enhance predictions, such as Plant Village (PV) (Martinelli et al. 2015), Global Wheat Head Detection dataset (GWHD) (David et al. 2021), and IPM and Bing datasets (Ahmad, et al. 2022).

These preliminary results obtained during this study and made with a limited number of images are promising to use machine learning to detect disease and spray localized chemicals on the high yield compromised section of the field.

CONCLUSION

The use of machine learning techniques and data from sensors for plant disease detection combine the expertise and knowledge of agronomists and data scientists for better decision making and the understanding of the plant's behaviour during phenological cycle. These kinds of applications are encouraged especially for transitioning towards a rational use of chemicals and adapting new strategies for yield enhancement and preserving soil and human health in a climate changing situation.

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PHOTOGRAMMETRICALLY ASSESSED SMALLHOLDER PINEAPPLE FIELDS IN GHANA USING SMALL UNMANNED AIRCRAFT SYSTEMS #9439

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ABSTRACT

Ultra-high-resolution imagery taken by small, unmanned aircraft systems (sUAS, drones) has been proven beneficial for the monitoring of agricultural crops in conventional farming especially in the context of precision farming. For smallholder pineapple cultivation, the use of sUAS imagery is still sparsely evaluated. However, technical developments in low cost sUAS-sensor combinations make assessments of agricultural areas by service providers more and more affordable for Africa. In this study, we assessed pineapple fields of smallholder farmers in Ghana with sUAS imagery based on a multispectral-thermal camera combination.

In this preliminary study, first results show that this promising technology will have great advantages for the monitoring of pineapple fields in Ghana. The resulting sUAS imagery show distinguishable single pineapple plants for red, green, and blue (RGB) and normalized difference vegetation index (NDVI). Thermal resolution was less detailed but provided a good overview of surface temperatures. The imagery would enable plant-wise level processing of agronomic parameters to assess e.g., plant health. Another option is to use resulting 3D point clouds for the structural analysis of the terrain for a broader landscape assessment, e.g., geomorphology or erosion. This might also help to estimate ecosystem services affecting the pineapple fields in more detail than with sparse reference ground information or poorly resolved satellite imagery. Because sUAS provides so much more details for monitoring, this easy-to-use technique should be used more widely in the context of small-scale agriculture.

Keywords: Remote Sensing, Multi spectral, Thermal, Ortho image, 3D point cloud, Smallholder farmer, Pineapple, Ghana

INTRODUCTION

The usage of small unmanned aerial systems (sUAS) for precise agricultural practices became increasingly common over the last years. Among other approaches it is used for field mapping, plant stress detection, biomass estimation, weed management, inventory counting and chemical spraying (Hassler and Baysal-Gurel, 2019; Khanal et al., 2020). One reason for this development is the drop in prices for the sUAS hardware and belonging sensors (Szczepanski and Purushothaman, 2021) but also a more user-friendly handling for recently developed drones grant access to this technology for more and more users. Further, this technology is mostly independent from power or internet connection on field and can therefore be used in remote areas. All these advantages and the possibilities in knowledge gain make the use of sUAS for smallholder pineapple farms in Ghana beneficial.

MATERIALS AND METHODS

Seven organic and seven conventional farmed fields were assessed in the Central region in Ghana. In summary, all sites cover an area of more than 6 ha for organic and more than 2 ha for conventional fields. Flights with the sUAS were conducted at an altitude of 100 m above ground level and nadir images were taken with a multispectral and thermal sensor combination (Altum, MicaSense, USA). The 3.2 mega pixel sensor used a lens with a focal length of 7.84 mm for spectral and 1.77 mm for the thermal sensor and consisted of 5 spectral bands (blue, green, red, red edge, near infrared) as well as a thermal infrared band. The centered spectral bandwidths were 475, 560, 668, 717, 842 nm and 8-14 µm for the thermal sensor. This setting allowed a ground sample distance of about 4.4 cm/pixel and 67.5 cm/pixel, for spectral and thermal bands, respectively. The sensor was attached directly to the drone (Matrice 300 RTK, DJI, China) without a gimbal. The collected images were taken with an ≥80% forward and side-overlap and subjected to structure-from-motion photogrammetry to create ortho images and 3D surfaces for RGB, NDVI and thermal data of the pineapple fields.

RESULTS AND DISCUSSION

Visual

Multispectral datasets from smallholder pineapple fields can be used for different approaches. It is possible to create undistorted ortho images of the visual RGB spectrum granting an overview of the fields in general, plant density or spot disease symptoms. The latter is possible for data collected from flights with lower altitudes providing higher ground sample resolution. However even these UAV flights in 100m altitude provide plant specific insights.

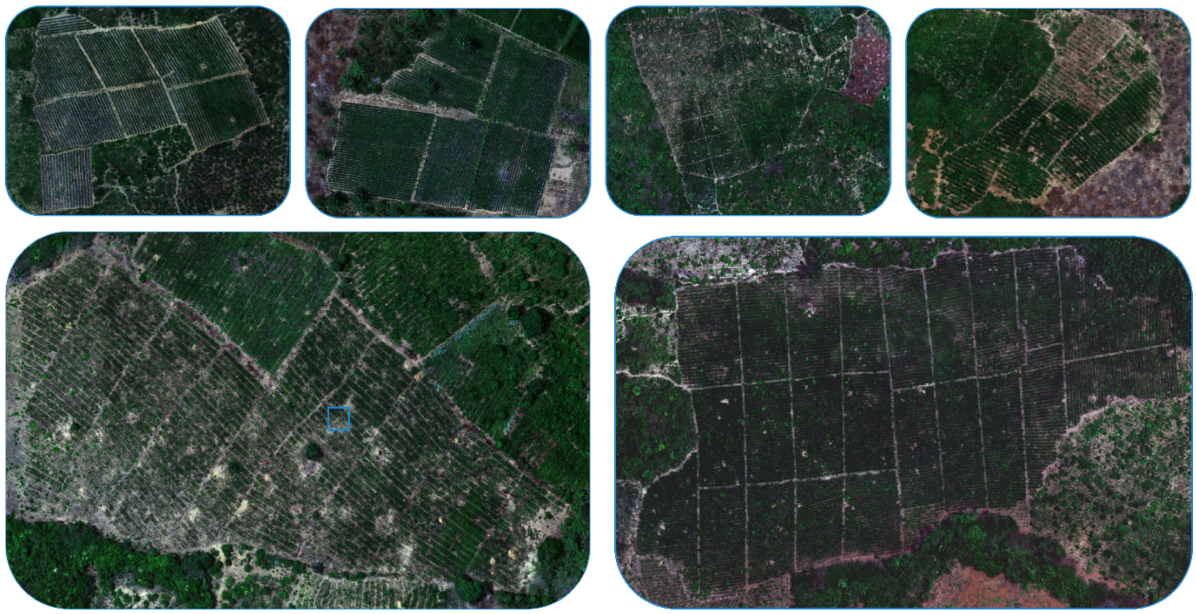

Fig. 4. RGB ortho images of smallholder farmer pineapple fields in central region, Ghana (Field A – down, left; Field B – down, right). Area marked with blue square is shown in detail in Fig. 5.

Spectral indices

Visual information can be helpful to get a good overview of the fields. However, to highlight areas of stressed plants spectral indices will be used. One of the accessed indices here was the NDVI, which refers to the general plant health. It is calculated by the equation $NDVI =$

$\frac{NIR-Red}{NIR+Red}$, for which *NIR* refers to the reflectance information from the NIR channel and *Red* refers to the reflectance value from the red channel. As shown in Fig. 5, this index grants a good overview of plant health status over a field and is therefore able to identify areas of different environmental conditions. This information can help with management decisions, treatments and lay the basis for site specific approaches.

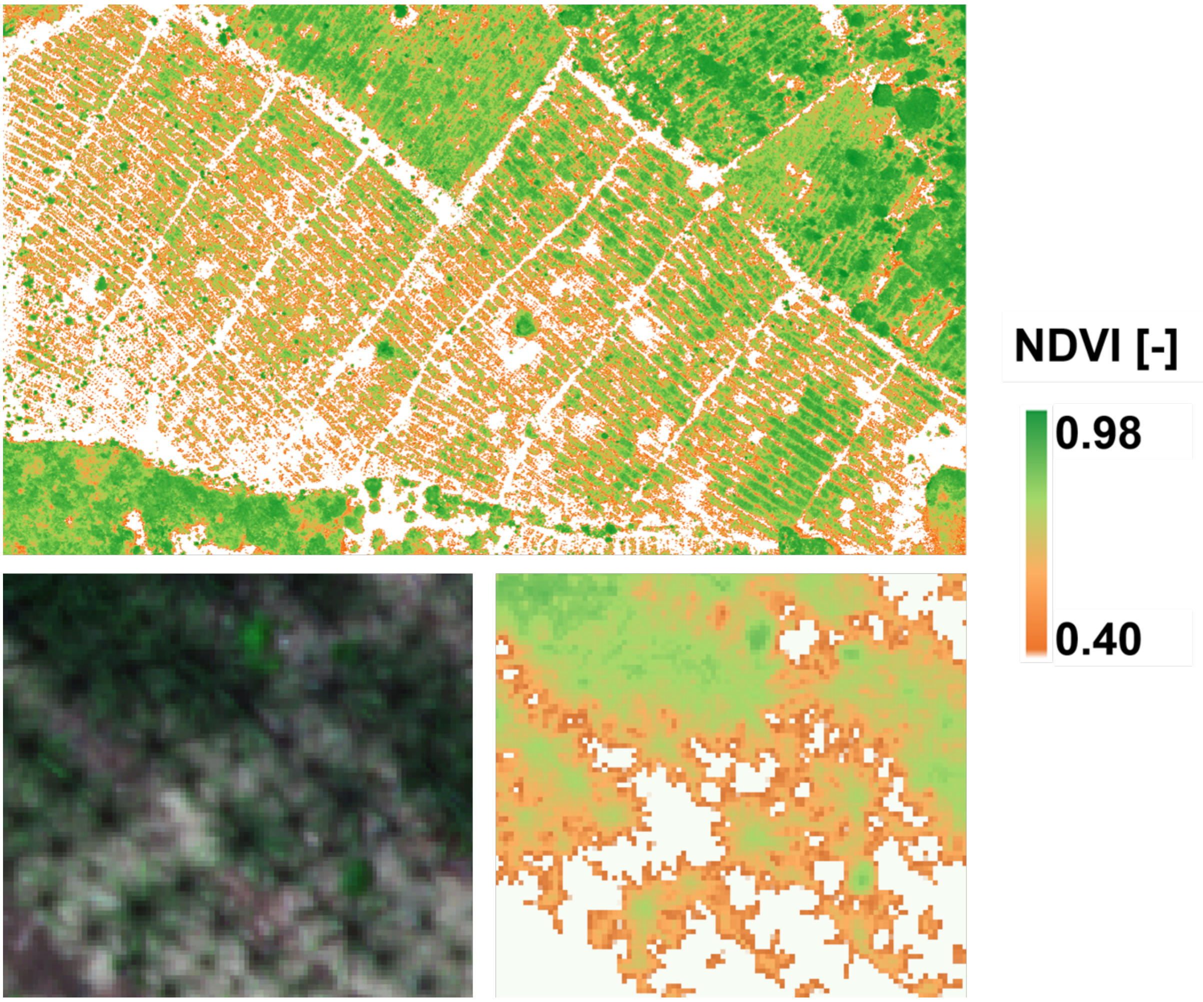

Fig. 5. NDVI calculated for field A from ortho image shown in Fig. 1 (top) and a magnified detail view for RGB (bottom, left) and NDVI (bottom, right) results.

In Fig. 5 a magnified view of field A is given for RGB and NDVI data. You can identify plant rows and spots of denser and sparser plant coverage. Also, you can see that the spectral bands of this assessment method provide a sufficient resolution to extract plant specific information from the datasets.

Another spectral index commonly used is the leaf chlorophyll index (LCI). It is similar to the NDVI but adds some information of the reflectance around the red edge into the equation. It is calculated by $LCI = \frac{NIR-Red\ edge}{NIR+Red}$, for which *NIR, Red Edge* and *Red* refers to the reflectance information from the NIR, the red edge and the red channel, respectively. The LCI grants better information on chlorophyll content but has some limitations for areas without a closed plant canopy. Neither less, also this spectral index can provide a good overview for smallholder pineapple fields. It shows areas of better grown, more dense pineapple plants and areas of weaker growth, as shown in Fig. 6.

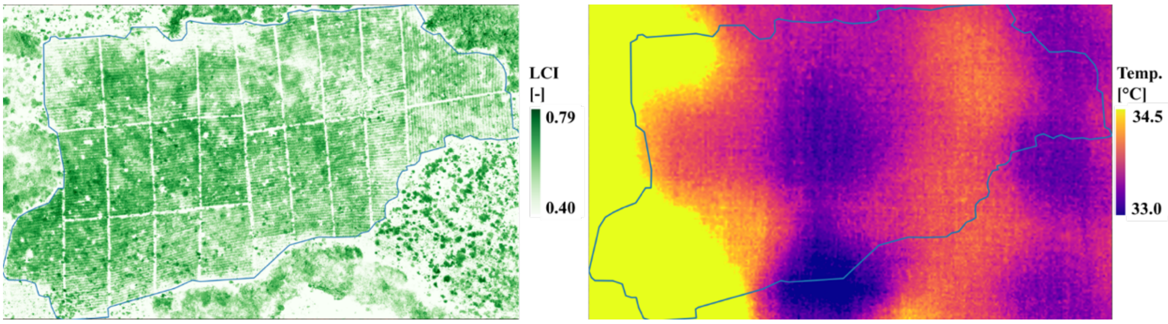

Fig. 6. LCI (left) and temperature data (right) calculated for field B from ortho image shown in Fig. 1.

Thermal

Another useful source of information can be delineated from thermal data. It can be useful for field adapted irrigation and provide information about microclimate data. Thermal data in agricultural landscapes are closely linked to water needs and drought stress of crops. However, the used sensors in this regard are not as highly resolved as spectral bands. For that reason, just overview information areas within the field can be drawn from UAV based thermal data assessments, as shown in Fig. 6. To provide better insights lower flight altitudes will lead to a higher resolution.

CONCLUSION

The variety of UAV based sensor information and the small effort that is necessary to achieve these data make this technology increasingly common in agriculture. Also, for pineapple smallholder farmers sUAS grant a huge potential for monitoring and site-specific approaches. When conducted by a third-party service provider the deployment is minimal effort, quick and should be affordable. Investment returns for these services can be achieved from better quality of the produce and therefore higher prizes as well as higher yields or resource savings for less productive field areas. Even overview flights conducted in high altitudes provide plant specific spectral information. Delineated spectral or thermal information can be used to define different management areas. Further this highly efficient technology can lay the data basis for site specific approaches.

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A COMPARATIVE ESTIMATION OF MAIZE LEAF MOISTURE CONTENT ON SMALLHOLDER FARMING SYSTEMS USING UNMANNED AERIAL VEHICLE (UAV) BASED PROXIMAL REMOTE SENSING
#9733

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ABSTRACT

Understanding maize moisture conditions is necessary for crop monitoring and developing early warning systems to optimise agricultural production in smallholder farms. Therefore, this study evaluated the utility of UAV derived multispectral imagery and machine learning techniques in estimating maize leaf moisture indicators; equivalent water thickness (EWT), fuel moisture content (FMC) and specific leaf area (SLA). The results illustrated that both NIR and red-edge derived spectral variables were critical in characterising maize moisture indicators on smallholder farms. Furthermore, the best models for estimating EWT, FMC and SLA were derived from the random forest regression (RFR) algorithm with rRMSE of 3.13%, 1% and 3.48 %, respectively. The findings are critical towards developing a robust and spatially explicit monitoring framework of maize water status and serve as a proxy of crop health and overall productivity of smallholder maize farms.

Keywords: maize moisture stress, unmanned aerial vehicle, machine learning, precision agriculture.

INTRODUCTION

Crop moisture stress is one of the most drastic limiting factors of maize crop production (Avetisyan and Cvetanova, 2019). Maize (*Zea mays L.*) is an important grain crop that is mostly grown under rain-fed conditions and consumed by the majority of Southern Africa as a staple food (Ngoune Tandzi and Mutengwa, 2020). Considering that maize growth is sensitive to water stress (Daryanto *et al.*, 2016), it is imperative to develop optimal methods to quantify maize moisture stress, as it is a key pathway towards effectively monitoring drought impacts and deriving useful information that can be used to inform irrigation decisions.

A variety of physiological indicators have been developed to quantify crop moisture stress. These include equivalent water thickness (EWT), fuel moisture content (FMC) and specific leaf area (SLA) (Liu *et al.*, 2015; Zhang *et al.*, 2017; Zhou *et al.*, 2020). Although there have been various studies conducted in monitoring crop water status (Zhang *et al.*, 2019; Zhou *et al.*, 2020), there still is disagreement on the best-suited indicator for maize moisture content prediction at a leaf level in small fields.

In recent years, unmanned aerial vehicles (UAVs), commonly known as drones, have received widespread attention in precision agriculture (Maes *et al.*, 2018). Although UAV based proximal sensing has become a powerful tool for estimating physiochemical variations in vegetation, only a few studies have been conducted on identifying the best method as well as the best moisture indicators to evaluate maize crop moisture stress at a farm scale. Therefore, it is imperative that operational and robust regression algorithms are identified, tested and validated for their performance in predicting smallholder maize functional traits, such as moisture content. In this regard, this study sought to investigate the potential of UAV derived multispectral imagery and machine learning techniques in the remote estimation of smallholder maize moisture content. The objectives of this study were to: (1) evaluate the performance of five regression techniques in predicting maize moisture content, and (2) determine the most suitable indicator of smallholder maize moisture content. The anticipated results will help provide a technical approach for the quick and accurate monitoring of changes in either EWT, FMC or SLA, because of moisture variability, to inform irrigation decisions and planning of smallholder maize crops.

MATERIALS AND METHODS

Description of the study area

This study was conducted at Swayimane (29° 52’ S, 30° 69’ E), a communal area located within the uMshwathi Municipality, north-east of Pietermaritzburg, South Africa. Maize experimental plots were conducted in summer, which is the optimal maize growing season. The maize plot covered a spatial extent of 250 m^2 and was primarily rain-fed. The maize crop was sown in mid-November 2021. At the time the project commenced, the crop was 86 days’ old, termed the reproductive phase of the growth cycle. Specifically, the maize seedlings were at an intermediate between the kernel blister stage (growth stage R2) and kernel milk stage (growth stage R3).

Field Sampling and water content measurements

Field data collection was conducted on the 11th of February 2021 at Swayimane. The first fully developed leaf (first leaf below whorl) was collected from the top of the maize canopy at each sample point to measure leaf moisture content indicators. A LI-3000C Portable Area Meter combined with a LI-3050C Transparent Belt Conveyer Accessory with a one mm^2 resolution was used to measure the leaf area (A) of sampled maize leaves (Li-Cor, USA). The fresh weight (FW) of sampled maize leaves were obtained using a calibrated scale. Field measurements were conducted between 12:00 noon and 14:00 as this is the most optimal period of the day for crop photosynthetic activity (Sade *et al.*, 2015). The sampled maize leaves were then dried in an oven at 70° C until a constant dry weight (DW) was reached (approximately 48 hours). The A, FW and DW were then used as input variables to compute maize leaf moisture indicators using the following equations:

$$EWT_{leaf} = (FW - DW) / A \qquad \text{units: } gm^{-2} \ (1)$$
$$FMC_{leaf} = (FW - DW) / DW \times 100\ \% \qquad \text{units: } \% \ (2)$$
$$SLA_{leaf} = A / DW \qquad \text{units: } g^{-1}\, m^2 \ (3)$$

The computed data for each crop moisture indicator was integrated with the GPS location and converted into a point map that was overlaid with the UAV multispectral images of the study area.

The UAV platform, image acquisition and processing

The DJI Matrice 300 series (M300) and the MicaSense Altum imaging sensor were used to acquire images covering the maize field considered in this study. The Altum camera integrates a radiometrically calibrated thermal sensor with five spectral channels that measure reflectance in the visible to the non-visible light spectrum (i.e., blue, green, red, red-edge, NIR and thermal) at a ground sampling distance of 9.6 cm per pixel. The imagery derived from the imaging platform were orthomoisaced and pre-processed to enhance image features in Pix4D Fields photogrammetry software.

Model development and statistical analysis

The reflectance data obtained from the Altum multispectral and thermal bands were used to derive VIs. The sampled data were randomly split into training (70%) and validation data (30 %). The former was used in the model development and the latter in assessing the accuracy of predictive models. A comparative analysis was conducted between the support vector regression, random forest regression, decision trees regression, artificial neural network regression and the partial least squares regression algorithms in predicting leaf moisture content indicators (i.e. EWT, FMC and SLA). Lastly, the coefficient of determination (R2), the root mean square error (RMSE) was computed to evaluate performance of regression models in predicting leaf moisture content indicators.

RESULTS

Evaluation of maize moisture indicators and optimized regression models

Table 4 illustrates the model accuracies obtained in predicting leaf EWT, FMC and SLA based on the RFR, DTR, ANNR, PLSR and SVR regression techniques. The accuracies of the prediction models illustrated that the RFR was the most optimal technique for predicting crop moisture indicators. The results revealed that the optimal indicators of maize moisture content based on the RFR models were FMC_{leaf} and EWT_{leaf}, followed by SLA_{leaf}. Additionally, the UAV multispectral bands and derived VIs were successful in predicting all maize moisture content indicators.

Table 1. Prediction accuracies of EWT_{leaf}, FMC_{leaf} and SLA_{leaf} derived using optimal models based on the RFR, DTR, ANNR, PLSR and SVR regression models.

Model	EWT_{leaf} (g m^{-2})			FMC_{leaf} (%)			SLA_{leaf} (m^2 g^{-1})		
	R^2	RMSE	RRMSE	R^2	RMSE	RRMSE	R^2	RMSE	RRMSE
RFR	0,89	10,28	3,13	0,76	0,45	1,00	0,73	0,0004	3,48
DTR	0,73	25,16	7,67	0,65	1,08	1,35	0,7	0,0009	8,16
ANNR	0,84	14,29	4,35	0,34	1,54	1,92	0,68	0,0007	6,60
PLSR	0,74	17,1	5,15	0,45	0,48	0,60	0,6	0,0008	19,33
SVR	0,78	15,05	4,76	0,69	0,70	0,89	0,71	0,0005	18,82

DISCUSSION

Estimating maize moisture content indicators

Results in this study indicate that when estimating maize equivalent water thickness, an optimal estimation accuracy (rRMSE =3.13 % and R^2 =0.89) can be obtained based on spectral variables derived from the NIR section of the electromagnetic spectrum (NDVI, NIR, NDWI, and NDRE). This can be explained by the fact that leaves which are characterised by high moisture status reflect highly in the NIR region due to multiple scattering within the leaf cell, which is primarily controlled by leaf cuticles, mesophyll thickness and intercellular air spaces and is directly linked to leaf moisture content (Romero-Trigueros *et al.*, 2017; Sibanda *et al.*, 2021). Fuel moisture content (FMC) was optimally predicted to a model accuracy of rRMSE of 1 % and R^2 = 0.76. The results of this study show that FMC is particularly sensitive to the red-edge waveband and associated derivatives of these spectral channels. Such sensitivity of the red-edge band in predicting FMC can be explained by its positive association with crop biomass as well as chlorophyll content, which is also positively correlated with FMC (Sibanda *et al.*, 2021). This was the case in studies by Bar-Massada and Sviri (2020) and Cao and Wang

(2017) that confirmed a variation in the reflectance of green leaves under water stressed conditions in the red-edge band, making this wavelength a significant predictor of FMC. Furthermore, NDWI, which is primarily derived from the NIR band, has a significant influence in the prediction of FMC. This VI is particularly important in predicting moisture content as it is sensitive to the variations of leaf reflectance induced by water molecules and dry matter content, hence, strongly correlates to plant water stress (Zhang and Zhou, 2015). Furthermore, results illustrate that all maize leaf moisture content indicators were optimally predicted using UAV-derived data. Accordingly, FMC and EWT yielded the highest predictive power of moisture content, while SLA was effectively estimated. In comparison, the FMC and EWT are the most ideal crop water indicators for monitoring moisture stress using field spectroscopy techniques (Yi *et al.*, 2014; Liu *et al.*, 2015).

The performance of machine learning algorithms in predicting maize moisture content indicators

Results in this study show that the RFR approach is the most suitable explorative tool to predict all maize moisture content indicators. For instance, RFR optimally predicted FMC, EWT and SLA, producing the highest prediction accuracy (rRMSE = 1%, 3.13 % and 3.48 %). The RFR algorithm can effectively establish the relationship between leaf reflectance and maize moisture at a farm scale. The strength of RFR could be explained by the fact that the algorithm is not highly affected by noise in the data, hence there is a reduced risk of producing overfitting models (Abdel-Rahman *et al.*, 2013; Zhu *et al.*, 2017). In a similar study, Sibanda *et al.* (2021) confirmed the robustness of the RFR model in modeling moisture content elements, particularly FMC by achieving optimal R^2s as high as 1 and an RMSE of 16.4 %.

The SVR approach was also optimal in predicting maize leaf EWT, FMC and SLA. The strength of the SVR lies in its ability to circumvent outliers and exhibiting a high generalization capacity to handle unseen patterns (Liang *et al.*, 2018). The results in this study reveal that the SVR is similar to the RFR in predictive power. This could be explained by the fact that the SVR and RFR ensembles optimally operate with a relatively small number of training samples, which is often the case for data acquired at a field scale after avoiding spatial autocorrelation (Wang *et al.*, 2016; Zhu *et al.*, 2017) .Therefore, the results of this study demonstrate that the model properties of RFR and SVR are well suited for the estimation of smallholder maize moisture content.

CONCLUSION

The present study tested the utility of UAV-based multispectral data in a comparative approach of estimating moisture content using RFR, SVR, DTR, ANNR and PLSR machine learning techniques and EWT, FMC and SLA of maize crops in smallholder farms. This study demonstrates that UAV-derived multispectral data can predict maize moisture variations of smallholder farms with exceptional accuracy, hence can complement and inform farms drought-related water stress. However, there are research gaps that demand further inquiry, particularly on smallholder maize farms. Future studies should aim to evaluate the utility of UAV derived data and the optimal moisture indicators in characterising the variation of maize moisture content across different phenological stages. Additional studies are necessary to evaluate whether UAV sensors that measure spectral reflectance along the SWIR section of the electromagnetic spectrum improve the prediction of smallholder maize moisture content. Finally, this study was site and crop-specific, therefore, studies conducted across various climates, different smallholder crops and at a multi-temporal scale should be assessed to draw broad conclusions in characterising crop moisture stress.

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ROBOTICS, AUTOMATION, AND SMALL FARM MECHANIZATION

SELF-DEVELOPED SMALL ROBOT FOR TOMATO PLANTS DETECTION #9413

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ABSTRACT

A mobile (robot) measuring station for tomato plant detection has been developed, equipped with different sensors and a self-developed hardware and software background. The development aims are the applications in precision crop production: artificial intelligence-based detection, imaging, data collection, automation, and remote sensing. The robot is fault-free in field conditions and is therefore a key development tool for precision farming and digital agriculture. The measurement system developed is modular. It consists of three main components: the power supply, the data processing and storage unit, and the physical quantity measuring units (sensors).

INTRODUCTION

Recently, several studies have drawn attention to the need for a paradigm shift again, the current adverse effects of agriculture on the biosphere cannot be reduced with the knowledge provided by research based on traditional experiments (1). Global food security is threatened by several sources, such as population growth, meat consumption trends, and the effects of climate change (2). In addition, increasing pest, disease and weed tolerance is putting increasing pressure on both conventional and precision technologies (3). To alleviate the burden of these challenges, it provides the opportunity to automate and robotize certain aspects of the farming process.

The definition of a robot

A robot is any entity that perceives, interprets, and intervenes in a dynamically changing environment in an adaptive manner. Another important feature is the communication and the collaboration. An autonomous system needs information to make the right decisions before acting. If the autonomous system has incorrect information, it will make incorrect decisions and perform incorrect actions.

Agricultural robots

The type of agricultural robots is the following: data collectors, weed killers, plant protectors, harvesters, and appropriate combinations of these, as well as robots in animal husbandry (milking, feeding, monitoring robots for the health of herds). The mechanical operation of agricultural robot systems requires real-time correction. The GPS coordinates must be determined from point to point as soon as possible with high accuracy (5). The so-called real-time differential correction (RTK) can greatly increase the accuracy of GPS data (6). In the last decade, RTK technology has undergone great development (+/-1 inch).

Small smart robots

The "Internet of Things" (IoT) technology has spread in agriculture as well, thus providing a "big data" for the data source and intervention of precision methods (7,8). As IoT technology has evolved, intelligent agricultural robots need both flexibility and adaptability to move and act in field environments (9). Robots must work with these technologies and above-mentioned conditions. Their design must adapt not only according to predetermined parameters, but also adapt to changes in environmental factors. Nowadays, many options are available that facilitate the processing of information from large databases. Artificial neural networks have been incorporated into agriculture in many applications because of their advantages over traditional systems. The main advantage of neural networks is their ability to make predictions based on information. Neural networks can be designed instead of actual programming. In the case of robots used in agriculture, not only is the changing environment a big challenge, but also the fact that the equipment often must handle living, vulnerable materials. Applied artificial intelligence also integrates the opportunities offered by machine learning.

MATERIAL AND METHOD

Robot structure, concept

When planning and choosing the methods used, we tried to take advantage of the opportunities provided by the methodical planning used in engineering sciences. In addition (10), we also used a now widespread method, the "From Toy to Tool" process. The equipment has a compact, modular structure, both hardware and software. Hardware contains three parts: the power supply, the control system, and the intervention devices (Fig. 1).

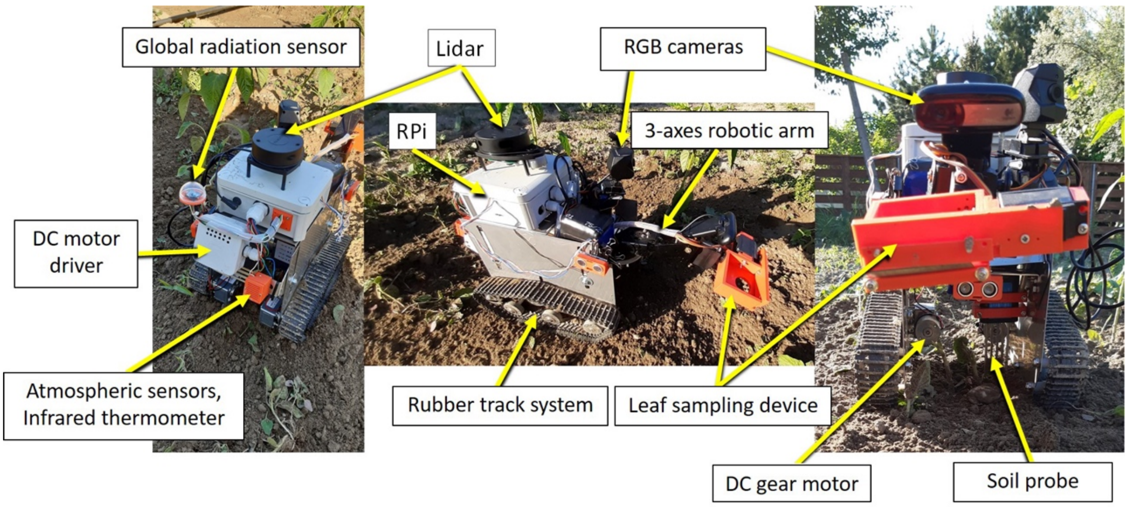

Fig. 1. Build by the robot (Source: own figure).

The robot is based on a metal frame structure. The height barrier of the robot can be easily adjusted to the specific plant culture, which helps with the positioning of the sensors and sampling equipment. The running gear is a rubber belt for proper traction on the ground, and due to this design, the control of the robot can also be easily realized. The robot is powered by two direct current gear motors (DC). The speed of these motors can be regulated, and thanks to their high torque, they are suitable for moving the robot. The maximum speed of the equipment is 20 cm/s, which is sufficient for data collection and detection. An H-bridge motor control circuit is responsible for the operation of the motors, which can directly control the two motors simultaneously. Its power supply is ensured by a LiPo battery pack via a control unit, a battery management system (BMS). The batteries have a 3S3P design and produce a direct voltage of approximately 12V, which supplies energy directly to the drive and, on the other hand, to the other lower voltage systems with the help of voltage regulation electronics (DC-DC converter). Approximately 4 hours of operating time are available under operating conditions. The central unit of the device is a Raspberry Pi 4 microcomputer, which is complemented by a "Shield" panel specially developed for this robot, on which the other additional electronic components and connectors are located. Half of this "Shield" is for easy fitting of other electronic components to the central unit. It is also equipped with an RGB camera that can be positioned along two axes with servo motors. For orientation, the equipment has three ultrasonic distance sensors as well as Lidar and GPS, so it can move autonomously between the rows of cultivated plants. It also collects information from the environment, e.g.: global radiation, air temperature, humidity; and soil properties: soil surface infrared thermometer, temperature, moisture content, EC, pH, and NPK. The soil properties sensing probe is driven into the ground by a stepper motor through a gear-rack transmission, and with the help of an H-bridge motor control circuit. The robot is equipped with a three-axis servo motor-based arm, at the end of this arm there is a leaf sampling device. This structural element can be modeled like a pair of scissors, the positioning of which is performed manually by the robot operator. The robot was programmed in the Python programming language to control the mobile unit. Full control and optimization of the machine is available to the user. Both wired (LAN) and wireless (Wifi, Bluetooth) connections are available on the robot platform. The robot is controlled by a specially designed application via a PC, smartphone, or tablet.

RESULTS AND DISCUSSION

Artificial vision is used to identify syndromes of plant diseases, pests, and pathogens by considering several visual characteristics that fall into three general categories: biological (morphology), spectral reflectance characteristics, and visual structure. The robot can automatically collect information from the environment at predetermined intervals, including global radiation, humidity, temperature, atmospheric pressure, soil moisture and temperature, and soil properties (EC, pH, NPK). With the help of these data, it is possible to archive an information base for crop production systems. It means an agricultural monitoring system to support the predictions. By analyzing images from the RGB camera, artificial intelligence based on neural networks can recognize changes in plant parts and inform the robot operator. This method used a neural network model created through the Edges Impulse platform. With this artificial intelligence-based model, the robot can detect part of unhealthy leaves. This makes it possible to take samples for expert (machine or human) determination of the cause of the actual change (nutrient deficiency, infection, etc.).

Using another model based on a neural network, the robot can detect ripe tomatoes and store photos. Using these images, with the distance between the tomato berries and the camera (measured by Lidar) can be used to estimate the tomato yield, using the OpenCV post-analysis method. During the process, the mass of the tomato berries is extracted from the completed images through post-processing. A color-segmented mask was used by transforming the images with the appropriate algorithm to determine the surface of the ripe berries. Based on the calculated surface and Lidar distance data, the volume of the berries can be determined by 3D modeling (Fig. 2). The mass of ripe tomato berries can be calculated by introducing the average density characteristic of tomato varieties.

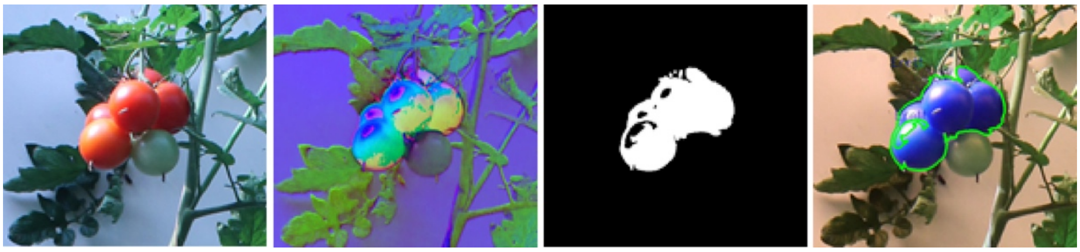

Fig. 2. Steps of image processing for tomato yield estimation (Source: own drawing).

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POTENTIALS OF UNMANNED AERIAL VEHICLES (UAVs) IN THE NIGERIAN AGRICULTURE
#9468

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ABSTRACT

The continuous development of technology is driving the invention of new machineries such as the Unmanned Aerial Vehicles (UAVs), also known as “drones”. The UAVs have become much more popular within the last decade for its significant roles in agriculture, among other industries, yet their applications in Nigeria are yet to be appreciated. Therefore, the present study reviewed the characteristics and multiple uses of UAVs in agriculture and their potentials for the Nigerian agriculture. Major applications of the agricultural UAVs for the Nigerian agriculture were identified to be soil analysis, crop disease detection and identification, pesticide application, yield and biomass predictions for large-scale farming, weed management including weed detection, weed monitoring and individual weed treatments. In terms of precision agriculture, crop stress assessment, irrigation scheduling, improved water-use efficiency for both surface and subsurface irrigation systems, and spatial variability assessments are inclusive. Further potentials include monitoring of plant growths based on its nutrient status, spatial variability in the nutrient’s distribution across the fields and plant health monitoring. Agricultural UAVs were identified to have potentials in not only agriculture but also national security, in terms of nomads-farmers dispute resolution, through livestock monitoring and management. Challenges that may hinder the future use of the UAVs in the country as well as appropriate recommendations were also suggested for the effective use of agricultural UAVs in Nigeria.

Keywords: Agricultural UAVs; Agricultural Robotics; Precision Agriculture; Agricultural Mechanization; Agricultural Remote Sensing, Smart farming in Nigeria

INTRODUCTION

Specially designed machineries such as the Unmanned Aerial Vehicles (UAVs) also known as “Drones” are in place to foster for the 70% increase of Agricultural Food Production by the year 2050 projected by the FAO (McGill, 2009). UAVs were in use solely for military applications until lately. In 1921, the United States of America converted the abandoned military vehicles used for the World War I, technically categorized as Manned Aerial Vehicles (MAVs), for pesticide applications. It was until 1985 that the first UAV for pesticide spray and crop monitoring was developed by Yamaha, named “Rmax” (Chen et al., 2021; Giles & Billing, 2015; Lan & Chen, 2018). Yamaha was in continuous technological development, until 2007 when its UAVs production was stopped to protect its technology. UAVs net worth and value in agriculture is now predicted as the second to infrastructure (Mazur et al., 2016). According to the Association for Unmanned Vehicle Systems International (AUVSI) predicted the consumption of most (80%) civilian used UAVs by the agricultural sector in the near future (Lan & Chen, 2018). Agricultural UAVs have shown the competencies of being vigorous to weather conditions (Dandois et al., 2015). Their contribution to the smallholders is said to bring climate-smart agriculture (CSA) and precision agriculture closer. Unfortunately, developing countries are yet to appreciate the use of such UAVs in the agricultural domain. Hence, this paper is an attempt to explore the major applications of these UAVs in Agriculture, its potentials, and the challenges to be faced for the Nigerian Agriculture.

APPLICATIONS OF UAVs IN AGRICULTURE

According to the literature surveyed from reliable internet resources, the use of agricultural UAVs varies significantly, with crop protection and plant growth and monitoring supposed as the major applications (Fig. 7). Crop protection also have four distinct branches, as in Fig. 8 below, with weed detection and management possessing the major use (40%).

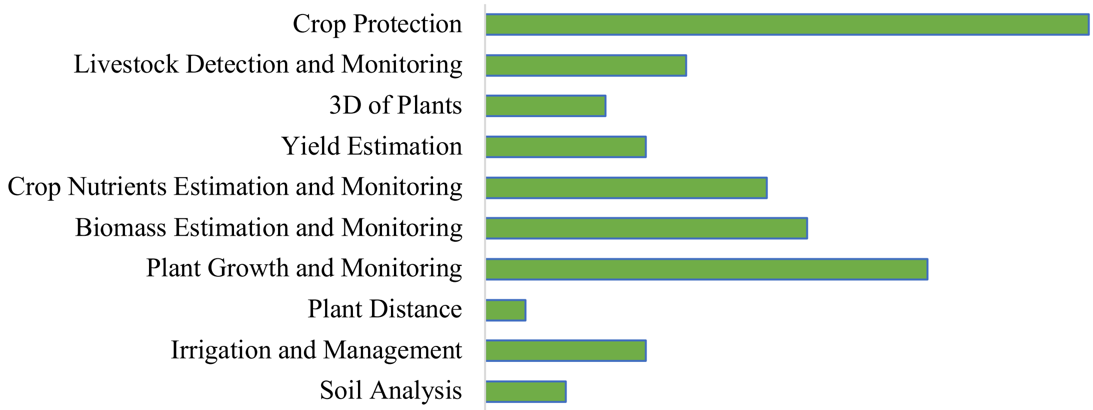

Fig. 7. Agricultural UAV Applications According to Literature Survey (2016-2021).

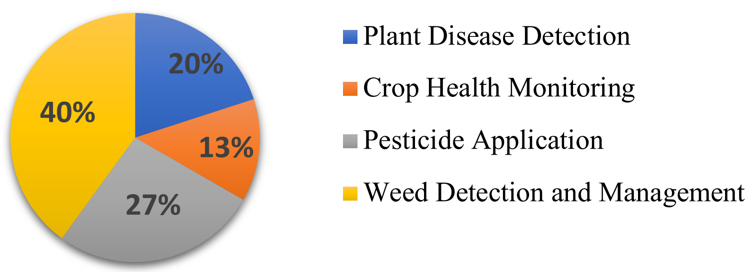

Fig. 8. UAV Applications in Crop Protection (2016-2021).

KEY REQUIREMENTS AND CHALLENGES

Regulation of usage

For the success of UAV adaptability and efficient use, its regulation is globally required. The Nigerian Civil Aviation Authority (NCAA) is the body responsible for UAVs regulation in the country for civilian use, agriculture inclusive. It permitted the use of UAVs in agriculture with concerns relevant for national security, user certification and authorization, user safety, public safety, and privacy. Despite the appreciable guidelines set by the body (NCAA, 2019), UAV regulations are still in its infancy stage, as it is the case for Africa in general (African Union & New Partnership for Africa's Development (NEPAD), 2018). Systematic review, update and enforcement of such regulations are critical for the sustainability of UAV applications in the country specifically and Africa in general (Ayamga et al., 2021).

Network availability

Configuring the UAV to acquire suitable images from the field, collecting the images, and most importantly, processing the images requires tremendous amount of data and viable internet connection. The widest available network in Nigeria is 3G, while 4G LTE is significantly spreading (Tugbiyele, 2019). Preparations for migration into 5G are yet to arrive. With such developments, the major challenge still in place include the costs (Osuagwu et al., 2013) and reliability on the network stability due to the problems associated with local internet service providers. Farmlands are usually in remote locations; therefore, the quality of internet services needs to be strengthened enough until a successful data acquisition and processing can be accomplished with the optimum efficiency and in the shortest possible time.

Import regulations for quality standardization

Nigeria is a developing country situated in the tropics. Most technological products are manufactured elsewhere and exported to the country. It is well known that designs and manufacturing of technological gadgets are affected by environmental conditions. Temperature, for e.g., was known to influence the chemical reactions in batteries in accordance with “Arrhenius equation” (Laidler, 1984) and the ionic conductivities of its electrons, thus generating heat and consequently tempering with the battery’s quality. This implies a serious need for import standards of the UAV itself and its components, to suit the local conditions in terms of quality and reliability for data collection, processing, and results.

Intensive research and training

Nigerian agriculture is majorly a smallholder-based system. Thus, the incorporation of advanced agricultural mechanization technologies as well as the UAVs is a great task. For the UAV, specifically, researches proved its potential for use in smallholder agriculture (Kumi et al., 2021; Wahab et al., 2018) but with much more sophistication in the tech. Therefore, the modern agricultural sector if not provided with intensive training and research opportunities in Nigeria, the success of UAV applications might be daunting especially in the hands of the public sector.

RECOMMENDATIONS

Agricultural UAVs have been proved to be of optimum benefit to the Nigerian Agriculture. This is more specific to on-farm operations (from planting to harvest) and livestock production.

Recommendations for future dimensions are given as follows:

1. Improved agricultural technologies was set the topmost priority for the agricultural sector as part of the government’s diversification plan (FGN, 2019). The stakeholders in the Nigerian agriculture should put up suitable policies for the success of UAVs use in agriculture. This should therefore include the UAVs and suitable policies in its regards should be made.
2. Agricultural UAVs are an advancement in agricultural mechanization technologies. Despite their versatility in terms of applications and qualitative results, their associated costs will be a huge setback for their success in Nigeria. Therefore, easy accessibility and lower costs could be achieved through government or custom hiring services. Government hiring services for agricultural mechanization, tractor in essence, have failed already (Kabir et al., 2019). An investigation into the future and success of UAV custom hiring services is therefore recommended.

3. Nigeria is a country situated in the tropics. Designs of UAVs could have potentialities in terms of using solar energy as power source. Thus, the potentialities and practicality of agricultural UAVs designed locally, and sustainability is highly recommended. Agricultural Engineers and students are recommended to apply the basic concepts for to achieve the optimum level of UAV utilization in the country.
4. Farmsteads are usually based in remote locations where viable internet connection may be difficult to obtain. It is recommended that portable and suitable internet connection facilities and network boosting tools should be developed. Research in this regard could be available; hence, their suitability for use in the Nigerian soil for its diversity should be ascertained.

CONCLUSION

UAVs or drones have been proved to have versatile applications in the agricultural industry. Nigeria, with its vast population and smallholder-dominated agriculture has the potentials of employing the UAVs for the future upgrade of the agricultural sector. In this regards, multiple literatures were reviewed to see the possible applications of UAVs in the Nigerian agriculture. Challenges to be encountered and possible solutions were recommended.

DECLARATION OF INTERESTS

The authors declare no conflict of interest.

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DETECTING THE IMPACT OF HAIL DAMAGE ON MAIZE CROPS IN SMALLHOLDER FARMS USING UNMANNED AERIAL VEHICLES DERIVED MULTISPECTRAL DATA #9731

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ABSTRACT

Natural disasters such as hailstorms are now frequent and negatively impact smallholder farmers' livelihoods. In these events, there is a need for robust and innovative techniques for monitoring the extent of their damage in smallholder croplands to optimise production. In this regard, this study sought to evaluate the utility of drone-derived multispectral data in estimating crop health elements (i.e., equivalent water thickness (EWT), chlorophyll content, and leaf area index (LAI) of maize crops in smallholder croplands using the random forest regression algorithm. A hailstorm occurred in the study area during the reproductive stage 2 -3 and 3 to 4. EWT, Chlorophyll content and LAI were measured before and after the storm. Results of this study showed that there could be optimally estimated Equivalent water thickness, Chlorophyll content, and leaf area index based on the red edge and its spectral derivatives. Specifically, EWT was estimated to a RMSEs of 5.31gm^{-2} and 27.35 gm^{-2}, R^2 of 0.88 and 0.77, while Chlorophyll exhibited RMSEs of 87.4 and 76.2, and R2 of 0.89 and 0.80 and LAI yielded a RMSEs of 0.6 m^2 m^{-2} and 0.19 m^2 m^{-2}, before and after the hail damage, respectively. The findings of this study illustrate the prospects of utilizing UAVs in proximal sensing of crop productivity.

INTRODUCTION

The frequency of destructive weather events associated with climate change, such as thunderstorms, lightning and hailstorms, has increased, and with it, negative impacts of various magnitudes which are detrimental to the survival of humans (Raihan, Onitsuka et al. 2020). Developing countries, particularly the poor and marginalized rural communities, are the most susceptible to these events because they lack the resources and knowledge to implement robust adaptation and mitigation strategies. In sub-Saharan Africa, smallholder croplands dominate the agricultural sector, and these contributes to addressing hunger, malnutrition, and poverty and fostering food and nutrition security (Blair, Shackleton et al. 2018). Maize is one of the major crops grown in smallholder farms and contributes towards GDP, food, and nutrition security (Mashaba-Munghemezulu, Chirima et al. 2021), yet it is often exposed to natural disasters such as hailstorms storms. Early assessment of the impacts of hail on maize production could help determine the adaption strategy to minimize the risk associated with crop failure.

In smallholder systems, there are limited accurate and objective approaches that can be used to assess the spatial extent and magnitude of hail damage on crops. The approaches currently utilised in assessing the extent and magnitude of hail damage are limited to point-based laborious and time-consuming field surveys, that are lacking spatial representativeness (Singh, Saxena et al. 2017). Hence there is a need for objective approaches that can estimate the spatial extent and magnitude of damage to assist in the on-farm decision-making processes (Singh, Saxena et al. 2017). Remote sensing has emerged as the most robust, accurate and spatially explicit technique for assessing hail damage on the crop (Singh, Saxena et al. 2017).

Previous remote sensing-based research efforts were generally conducted in developed countries in commercial croplands based on sensors such as Landsat and Moderate-resolution imaging spectroradiometer (MODIS) and Sentinel 2 MSI data, amongst others (Prabhakar, Gopinath et al. 2019). Despite considerable successes associated with these studies, the generated conclusions and models were more applicable to commercial farms covering large areas, not smallholder croplands in developing countries which fragmented and are >2 ha. Meanwhile, crop attributes such as leaf equivalent water thickness (EWT), chlorophyll, and leaf Area Index (LAI) are related to the health and productivity of crops and have been successfully characterized using remotely sensed data in smallholder croplands. In this regard, EWT, chlorophyll content and LAI can be used as proxies for understanding the impact of hail damage on maize crops in smallholder croplands.

Unmanned aerial vehicles (UAVs) have presented better prospects of characterizing the spatial crop attributes in smallholder croplands than satellite-borne data. In this regard, UAVs offer ultra-high spatial resolution near real-time data on crop health and product attributes. To the best of our knowledge, very limited studies have been conducted based on UVA remotely sensed data in mapping the effect of hail damage in smallholder crops such as maize. This study sought to evaluate the utility of drone-derived multispectral data in detecting the changes in crop health and productivity elements (Equivalent water thickness (EWT), Chlorophyll content, and leaf area index (LAI)) of maize in smallholder croplands before and after a hailstorm based on the random forest regression ensemble.

MATERIALS AND METHODS

This study was conducted in Swayimane, a communal rural area within the uMshwathi local municipality in the KwaZulu Natal, South Africa (29°31'24' 'S; 30°41'37" E). Swayimani receives a mean annual rainfall between 600 mm and 1200 mm as well as an average annual temperature of 24 ºC. Most of the precipitation in Swayimane occurs in summer, and of late, there has been an increase in thunderstorms and hail events. Maize was planted in 3 plots measuring approximately 15m x 50m on the 8th of February 2021 and harvested on the 26th of May 2021 across a growth cycle of 108 days (Brewer, Clulow et al. 2022). The phenological growth stage of maize crops considered in the study was between the day of the year 41 to DOY 147. In this regard, a hail storm occurred on DOY 144 between the early (DOY 102) and mid-reproductive stages (118) of maize (Ndlovu, Sibanda et al. 2022).

Field sampling: A polygon was digitized around the experimental plot and saved as a keyhole markup language file (*.kml*). The *.kml* file was then used in ArcMap 10.5 to generate random sampling points where crop data was to be measured. It was also used to generate the flight plan to acquire the images. A total of 63 sampling locations were generated in a GIS.

These points were then imported into a hand-held Trimble Global Positioning System (GPS) with sub-meter accuracy for locating them. The maize plants that coincided with the location of the sampling point were marked and considered in this experiment. Then leaf area index, chlorophyll content and equivalent water thickness were measured before and after the hail storm (Ndlovu, Odindi et al. 2021, Brewer, Clulow et al. 2022). A Konica Minolta soil plant analysis development (SPAD) 502 chlorophyll meter (Minolta corporation, Ltd., Osaka, Japan) was employed to measure chlorophyll content on the adaxial maize leaf surface. The SPAD unitless values were converted to chlorophyll content in micromoles per square meter (µmol m-2) following the universal model derived by Markwell, Osterman et al. (1995) 's with R2 = 0.94 detailed below:

$$Chl\ (\mu mol\ m^{-2}) = 10^{s0.0265}$$

The SPAD meter readings were conducted on one leaf per plant. Specifically, the newest fully expanded leaf with an exposed collar and a minimum width of > 7 cm was considered to measure chlorophyll. A hand-held Li-Cor LAI 2200 plant canopy analyzer measured leaf area index estimates. In measuring each LAI estimate, five readings were conducted above and below the canopy of the maize plants. Initially, a reading was conducted above the canopy, and then four other readings were conducted below the canopy. The first fully developed leaf (first leaf below whorl) was acquired from the plants at each sampling point to measure the canopy equivalent water thickness of maize crops. Then a portable LI-3000C area meter in conjunction with the LI-3050C (Li-Cor, USA) transparent belt Conveyer with a millimetre resolution were used to measure the leaf area (*A*). The leaf's fresh weight (*FW*) was then measured using a calibrated digital scale with a 0.5g measurement error. The samples were then stored in brown paper bags, labelled accordingly, and taken to the laboratory, where they were oven dried at 70ºC until a constant dry weight (*DW*) was attained. Subsequently, the *FW* and *DW* were then utilized to derive EWT using the following formula:

$$EWT_{leaf}\ (gm^{-2}) = (FW - DW)\ /\ A.$$

All field measurements were conducted between 1200 and 1400 Hrs to coincide with the image acquisition time. All data we combined in an excel spreadsheet and converted into a point map in ArcGIS.

Remotely sensed data

In this study, a MicaSense Altum multispectral sensor mounted on a DJI Matrice 300 remotely sensed maize crops. The Altum multispectral sensor acquires remotely sensed data in the blue (475 nm), green (560 nm), red (668 nm), red-edge (717 nm), NIR (840 nm) and thermal (8000-14000 nm). To acquire the image, the generated *.kml* file of the field boundary was imported into the drone controller and used to generate an automated flight path. The acquired images had a resolution of 2064 × 1544 at 120 m (3.2 megapixels per multispectral band) and a ground sample distance (GSD) of 5.2 cm for the multispectral bands and 81 cm per pixel for the Thermal infrared at a height of 120 m. Before and after the flights, a MicaSense Altum calibrated reflectance panel (CRP) was utilized to calibrate the sensor. These images were then radiometrically corrected based on the CRP images using Pix4Dfields 1.8.0 (Pix4d Inc., San Francisco, CA, USA). The CRP reflectance is used by the Pix4Dfields software in radiometrically correcting the image. The reflectance data were then used to compute vegetation indices for estimating the impact of the hailstorm on maize crop parameters (Table 1). These vegetation indices were selected based on their performance in the literature. The point data were overlaid with the images to extract spectral signatures, which were then used for the Random Forest regression analysis.

Statistical analysis

Random Forest was used to predict maize crop EWT, LAI and chlorophyll content before and after the hailstorm. RF was hyper-tuned by identifying the optimal estimation number of trees (*Ntree*), and predictor variables tested for the best split when growing trees (*Mtry*). To identify the *Ntree* and *Mtry* values that can best predict maize that best estimated EWT, LAI and chlorophyll content before and after the hailstorm, the Ntree (the default value is 500 trees) values were tested from 500 to 9500, while Mtry was tested from 1 to 25 using a single interval (Adam, Mutanga et al. 2012, Mutanga, Adam et al. 2012).

Accuracy assessment

To assess the EWT, LAI and chlorophyll model accuracies, the data were split into two datasets at a ratio of 70/30% for the training and testing datasets, respectively. The root mean squared error (RMSE), relative root mean squared error (RRMSE %), and the coefficient of determination (R^2) were computed and used to evaluate the magnitude of agreement between the predicted and field-measured data derived from each model.

RESULTS AND DISCUSSION

Before the hailstorm, EWT was estimated to a RMSE of 5.31 (rRMSE = 0.272 %) and R^2 of 0.88 based on the NDVI, NIR NDWI, ClGreen, NDVIrededge, in order of importance. A considerable decline in the estimation accuracies of maize EWT was observed after the hailstorm. Specifically, EWT was then estimated to an RMSE of 27.35 (rRMSE = 59.16) and R^2 of 0.65 based on NDRE, NIR, NDWI, Clrededge, NDVI red edge and red edge in order of importance (Fig. 1). Chlorophyll, on the other hand, was optimally estimated before and after the hailstorm. Chlorophyll was estimated to have a RMSE of 76.2 (rRMSE = 28%) and an R2 of 0.75 based on the NDVI, NIR, Red edge, CLred edge, and CCCI, respectively NDRE in order of importance and amongst other variables. An optimal estimation was attained again after the hailstorm with a RMSE of 31.3 and a R^2 of 0.78 (rRMSE =25%) with the Red edge, NIR, MCARI, OSAVI, ENDVI, CTVI being the most influential spectral features, in order of importance (Fig. 1). LAI was also optimally estimated before and after the hailstorm. Before the storm, LAI was estimated to a RMSE of 0.19 (rRMSE = 11%) and R^2 of 0.89 based on the modified nNDVI (NIR/Thermal), nNDVI (R/T), EVI2, GLI, nNDVI(R/Thermal), BNDIV as the most influential estimation spectral features, in order of importance. After the storm, a RMSE of 0.32 (rRMSE = 15 %) and R^2 of 0.91 was obtained based on the nNDVI (NIR/B), nNDVI (G/NIR), nNDVI(Thermal/NIR/), RBNDVI as the most influential spectral variables, arranged in order of importance (Fig. 1). Fig. 2 shows the spatial distribution of EWT, chlorophyll and LAI.

The hailstorm generally tears the leaves in some instances plucking them off. The leaves often begin to wilt at the edges, losing moisture and discolour. This alters the plant moisture content, LAI and chlorophyll content, and in some instances, functionality Red-edge is closely related to leaf moisture content, chlorophyll concentration and leaf area index. Canopy spectral reflectance in the NIR region is a function of water transmissivity and leaf internal structure and is strongly related to leaf moisture content (Ndlovu, Odindi et al. 2021). Meanwhile, when the plant is healthy, its cells will be turgid and full of moisture, highly photosynthesizing and producing more chlorophyll content sensitive to Red, Red Edge and NIR Thermal bands. Based on the study's findings, it can be concluded that the impact of hail damage can be optimally characterized through mapping EWT, Chlorophyll content, and LAI of maize using Red-edge, NIR, and Red-derived spectral variables.

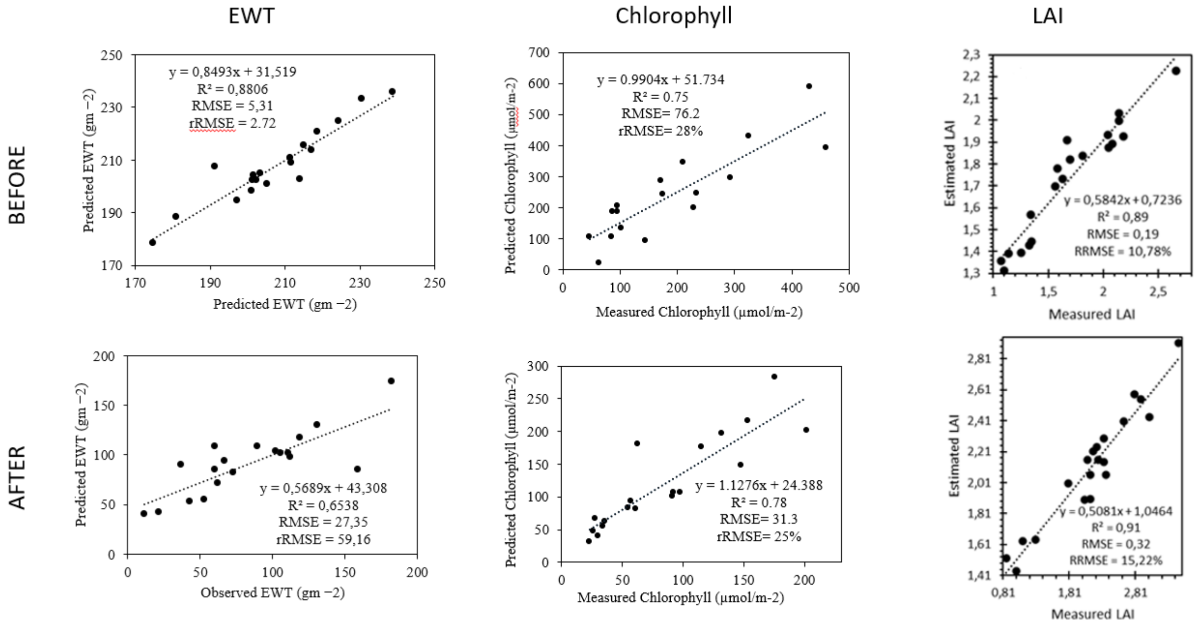

Fig. 1. One-to-one relation between predicted and measured EWT chlorophyll and LAI before and after the hailstorm.

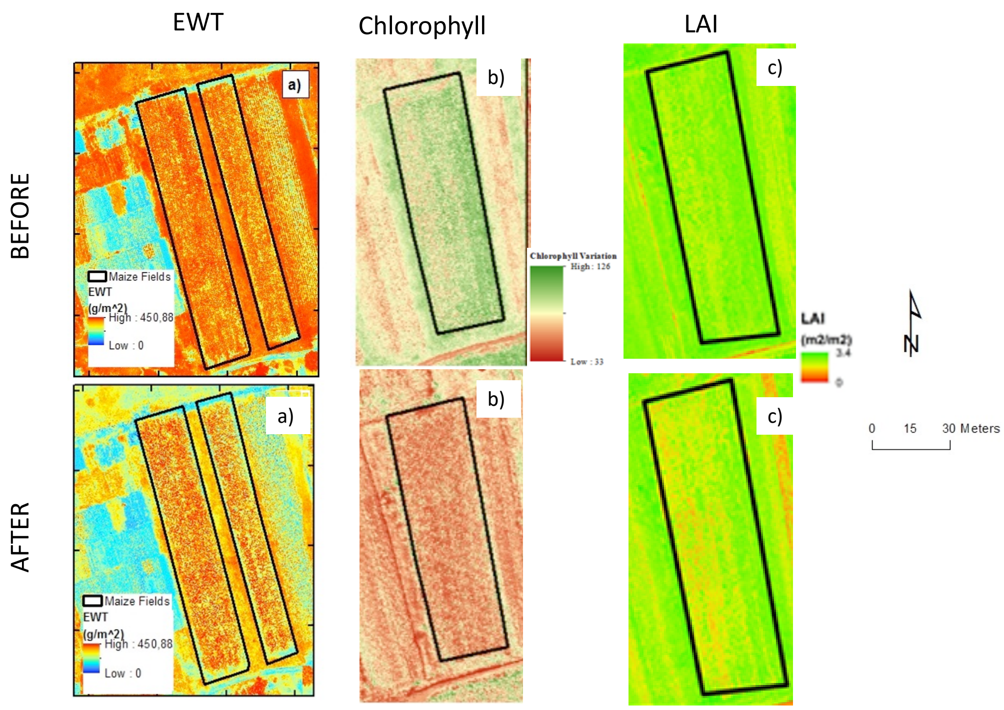

Fig. 2. The spatial distribution of EWT, chlorophyll and LAI before and after the hailstorm.

The implication of this Study's findings

There are high prospects of employing UAVs in crop condition assessment at the field scale. In interpreting the findings of this study there is a need to consider that this study was conducted based on data acquired after a hailstorm and in only one field. Subsequently, there is a need for further studies to investigate the contribution of site-specific factors in understanding the effect of natural disasters such as hailstorms on crops and the implications to yield.

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THE FUTURE OF FARMING: BRINGING BIOPHOTONICS AND MACHINE LEARNING TO REVOLUTIONIZE AGRICULTURE
#9734

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ABSTRACT

The future of farming is set to be revolutionized by biophotonics and machine learning. Biophotonics is the study of the interaction of light and living matter, and machine learning is a form of artificial intelligence that allows computers to learn from data. Together, these two technologies will allow for more precise and efficient farming, as well as greater yields and less wastage. Biophotonics will allow for more precise targeting of crops with pesticides and herbicides, as well as more efficient irrigation. Machine learning will enable farmers to predict weather patterns and forecast crop yields with greater precision. Together, these technologies will make farming more efficient and less dependent on guesswork. The future of agriculture is expected to be more efficient, more precise, and more productive. In this review, we discussed how biophotonics and machine learning will enable farmers to increase yields while reducing wastage. These technologies will revolutionize agriculture and make it more sustainable in the long term.

INTRODUCTION

The current state of agriculture faces several challenges, including an increasing global population, climate change, and diminishing resources. These challenges have led to the need for more sustainable, efficient, and precise farming methods. One of the key challenges facing the agriculture industry is the need for more precise and sustainable farming methods. Traditional farming practices can be imprecise, leading to overuse of resources and poor crop yields. Climate change is also a major challenge, as it leads to unpredictable weather patterns and an increased risk of crop failure (Thornton et al., 2014). The effects of climate change on agriculture include changes in temperature and precipitation, the increased frequency and intensity of extreme events, and the spread of new pests and diseases (Skendžić et al., 2021). In addition, the increasing global population is putting a strain on food production.

The United Nations predicts that the global population will reach 9.7 billion by 2050 and 11.2 billion by 2100 (Zheng, 2021; United Nations, n.d.). To feed this growing population, food production will need to increase by around 70% by 2050. To address these challenges, experts believe that biophotonics and machine learning can play a significant role in revolutionizing the future of farming (Marcu et al., 2017). Biophotonics is the study of light-matter interactions in biological systems and has potential applications in areas such as crop monitoring and disease detection. Machine learning, on the other hand, can be used to analyze data and make predictions, which can help optimize crop yields and improve the efficiency of farming operations.

One of the most promising applications of biophotonics in agriculture is precision farming. Precision farming is a concept of agriculture management that uses technology to optimize crop yields and reduce resource use. Biophotonics can be used to monitor crop growth and health, as well as detect pests and diseases (Martinelli et al., 2014). Machine learning, on the other hand, can be used to analyze data and make predictions, which can help optimize crop yields and improve the efficiency of farming operations. Machine learning algorithms can be used to analyze sensor data, weather forecasts, and other sources to predict crop yields and optimize planting and harvesting schedules. For example, machine learning can be used to identify the ideal planting and harvest dates for a particular crop based on weather forecasts, soil moisture, and other factors (Priya et al., 2018). Together, biophotonics and machine learning have the potential to enable precision farming, which can lead to increased crop yields, reduced resource use, and better management of crop diseases. By improving the efficiency and sustainability of agriculture, these technologies have the potential to help feed the growing global population and mitigate the effects of climate change. It is worth noting that the implementation of these technologies is not without challenges, from economic to societal. For example, precision farming requires a significant investment in technology, which can be a barrier for small farmers. Data privacy and security concerns may also arise when using machine learning in agriculture. Furthermore, the implementation of precision farming may lead to job loss in some areas of the agricultural sector.

LITERATURE REVIEW

The use of biophotonics and machine learning in agriculture is a rapidly growing field with a wide range of applications. Biophotonics is the study of light-matter interactions in biological systems. It has potential applications in areas such as crop monitoring, disease detection, and precision farming (Skolik et al., 2018). Machine learning, on the other hand, is used to analyze data and make predictions, which can help optimize crop yields and improve the efficiency of farming operations. One of the most significant applications of biophotonics in agriculture is precision farming. Precision farming is a farming management concept that uses technology to optimize crop yields and reduce resource use. Biophotonics can be used to monitor crop growth and health, as well as detect pests and diseases (Mitra, 2020). For example, hyperspectral imaging can be used to identify the specific spectral signature of a particular pest or disease, allowing for early detection and treatment (Che'Ya et al., 2022). This can lead to increased crop yields and reduced resource use. Another application of biophotonics in agriculture is crop monitoring.

Biophotonics (see Fig. 1) techniques such as fluorescence imaging and reflectance spectroscopy can be used to monitor crop growth and health, as well as to detect stress factors such as water deficiency and disease (Martinelli et al., 2014; Balasundram et al., 2020). For example, fluorescence imaging can be used to monitor the chlorophyll content of crops, which can indicate the health and growth of the crop (Su et al., 2019). Reflectance spectroscopy can be used to measure the canopy structure and chlorophyll content of crops, which can be used to estimate crop yields. In addition, machine learning is being used in agriculture to analyze data and make predictions, which can help optimize crop yields and improve the efficiency of farming operations. Machine learning algorithms can be used to analyze data from sensors, weather forecasts, and other sources to predict crop yields and optimize planting and harvesting schedules. For example, machine learning can be used to identify the ideal planting and harvesting dates for a particular crop based on weather forecasts, soil moisture, and other factors (Abbas et al., 2020).

Machine learning can also be used for crop disease detection. By analyzing images of crops, machine learning algorithms can identify the presence of pests and diseases and predict their spread. This can allow for early detection and treatment, which can lead to reduced crop losses and increased yields. Machine learning can also be used to predict crop yields based on a variety of factors, such as weather forecasts, soil moisture, and other factors. This can help farmers optimize planting and harvesting schedules, which can lead to higher crop yields. In general, current research on the use of biophotonics and machine learning in agriculture is showing promising results. These technologies have the potential to revolutionize the way we farm, by enabling precision farming, crop monitoring, and disease detection. However, it is important to note that the implementation of these technologies is not without challenges, and further research is needed to address these challenges and optimize their use in agriculture.

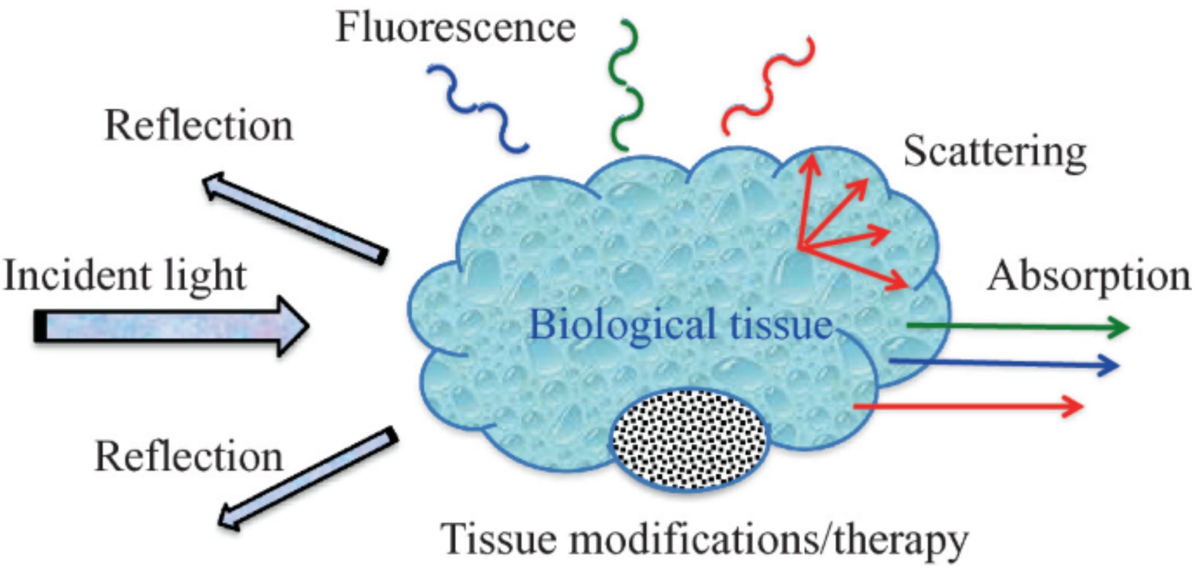

Fig. 9. Overview of biophotonics. Source: (https://link.springer.com/chapter/10.1007/978-981-19-3482-7_1).

CASE STUDIES

Case Study 1: Precision farming with hyperspectral imaging

Precision farming (see Fig. 2) is a farming management concept that uses technology to optimize crop yields and reduce resource use. One of the key technologies used in precision farming is hyperspectral imaging (see Fig. 3). In this case study, a farm in California has implemented a precision farming system using hyperspectral imaging to monitor their vineyards (Primicerio et al., 2012). The system captures hyperspectral images of the vineyards every day, which are then analyzed using machine learning algorithms to detect pests and diseases. The system has been able to detect pests and diseases that were not visible to the naked eye, leading to early detection and treatment. This has led to higher crop yields and reduced resource use. The farm has also been able to optimize planting and harvesting schedules using the data from the system, which has further increased crop yields. The benefits of using this technology in precision farming include increased crop yields, reduced resource use, and better management of crop diseases, which can ultimately lead to more efficient and sustainable agricultural practices. However, some challenges that come with this technology include high implementation costs, lack of skilled personnel, and data privacy and security concerns. Despite the challenges, the farm has found the system to be cost effective in the long run and has plans to expand the system to its other vineyards. The potential for further adoption of this technology in agriculture is high, if the implementation challenges can be addressed.

Fig. 10. An example of precision farming where drones are used for spectral imaging. Source: (https://cdnsciencepub.com/doi/full/10.1139/juvs-2019-0009?utm_campaign=RESR_MRKT_Researcher_inbound&af=R&utm_medium=referral&utm_source=researcher_app)

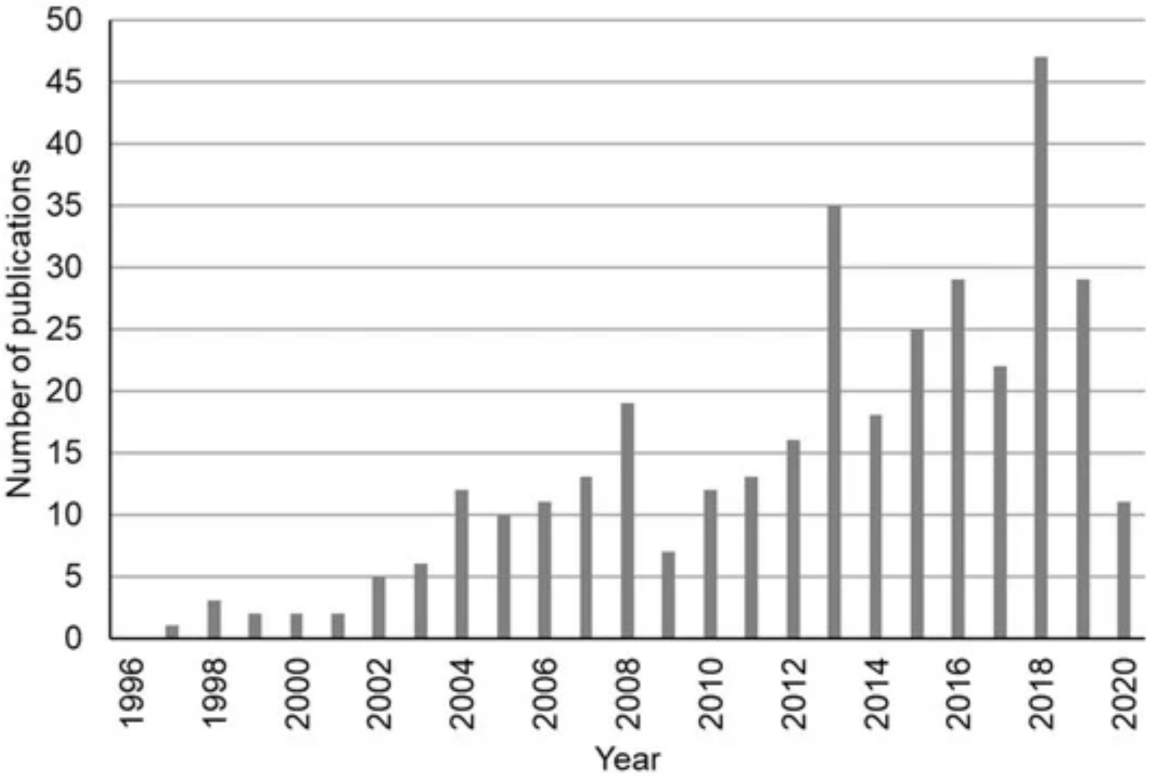

Fig. 11. Advances in hyperspectral imaging over the past years. Source: (https://www.mdpi.com/2072-4292/12/16/2659)

Case Study 2: Crop monitoring with fluorescence imaging and machine learning

Crop monitoring is the process of using technology to monitor crop growth and health, as well as detect stress factors (see Fig. 4) such as water deficiency and disease. In this case study, a farm in Iowa has implemented a crop monitoring system using fluorescence imaging and machine learning (Behmann et al., 2014). The system uses a fluorescence sensor mounted on a drone to capture images of crops. The images are then analyzed using machine learning algorithms to detect stress factors and predict crop yields. The system has been able to detect water deficiency and disease in crops that were not visible to the naked eye, leading to early detection and treatment. This has led to higher crop yields and reduced crop losses. The farm has also been able to optimize planting and harvesting schedules using the data from the system, which has further increased crop yields. Benefits of using this technology in crop monitoring include improved crop yields and reduced crop losses due to early detection of stress factors and pests. Challenges of using this technology include the need for skilled personnel to operate the equipment and analyze the data, as well as data privacy and security concerns. Despite the challenges, the farm has found the system to be cost effective in the long run and has plans to expand the system to their other fields. The potential for further adoption of this technology in agriculture is high if the implementation challenges can be addressed.

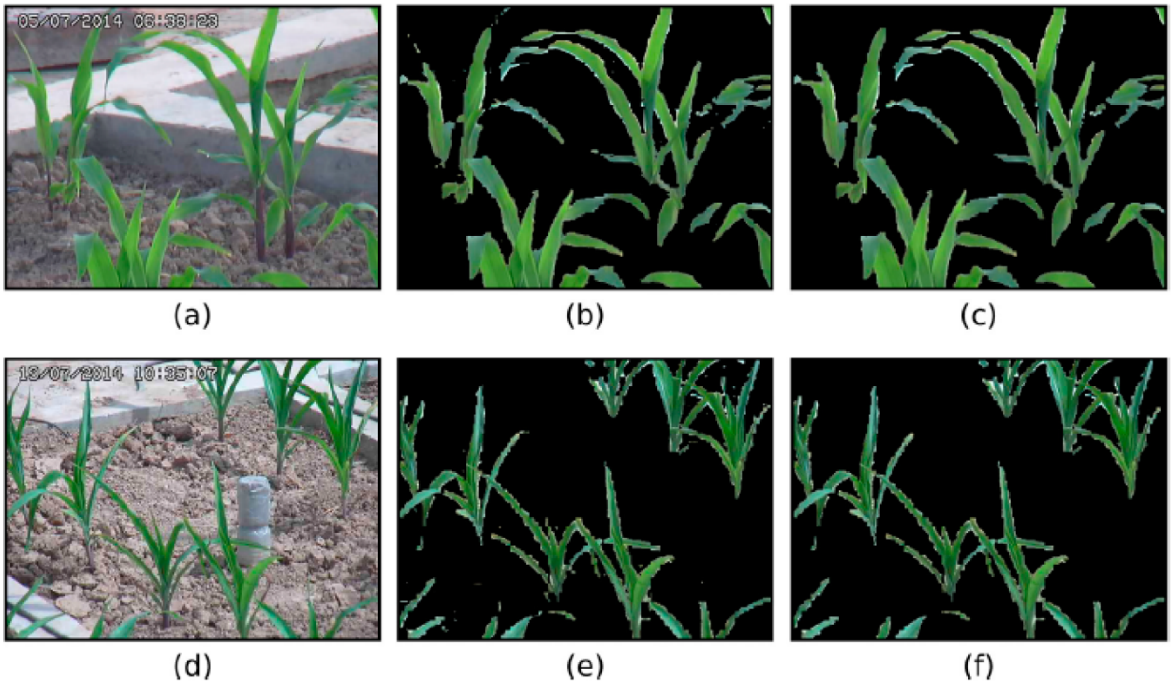

Fig. 12. Plant stress detection using optical sensors and machine learning. Source: (https://www.mdpi.com/2072-4292/14/12/2784/htm)

Case Study 3: Disease detection in livestock using machine learning

Detection of diseases in livestock is an important aspect of animal husbandry and a major concern for farmers. In this case study, a farm in Australia has implemented a disease detection system in livestock using machine learning (García et al., 2020). The system uses cameras mounted in the livestock pens to capture images of the animals. The images are then analyzed using machine learning algorithms (see Fig. 5) to detect signs of disease such as lameness, lethargy, and weight loss. The system has been able to detect diseases in the early stages, allowing early treatment and reducing the spread of the disease. This has led to reduced animal losses and improved animal welfare. The farm has also been able to optimize its animal management strategies using data from the system, which has further increased animal health and productivity. Benefits of using this technology in the detection of diseases in livestock include the early detection and treatment of diseases, leading to reduced animal losses and improved animal welfare. The system also allows for a more efficient and targeted use of resources, such as medication and veterinary care. Additionally, the farm has been able to optimize its animal management strategies, which has led to increased animal health and productivity. However, the implementation of this technology also presents some challenges. One of the main challenges is the need for experienced personnel to operate the system and analyze the data. Additionally, data privacy and security concerns may also arise when using machine learning in livestock management. Furthermore, the cost of the system could be a barrier for some farmers, especially small farmers. Despite these challenges, the farm in this case study has found the system to be highly beneficial and has plans to expand the system to their other livestock pens. The potential for further adoption and scaling up of this technology in livestock management is high if the implementation challenges can be addressed.

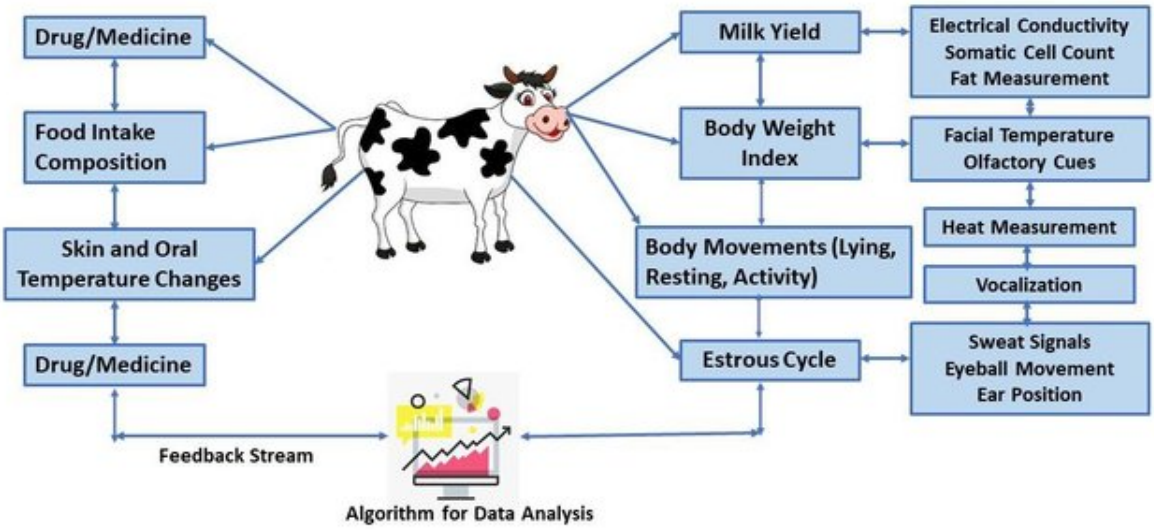

Fig. 13. An example of the use of machine learning algorithm in Livestock. Source: (https://www.sciencedirect.com/science/article/pii/S2214180420301343)

Case Study 4: Automated crop harvesting with machine learning

Automated crop harvesting (see Fig, 6) is a technology that uses robotics and machine learning to improve the efficiency and precision of crop harvesting. In this case study, a farm in Illinois has implemented an automated crop harvesting system using machine learning (Liakos et al., 2018). The system uses cameras and sensors mounted on a robotic harvester to capture images and data from the crops. The data are then analyzed using machine learning algorithms to identify ripe crops and optimize the harvesting process. The system has been able to increase the efficiency and precision of the crop harvesting process, leading to increased crop yields and reduced waste. The system also allows for a more efficient and targeted use of resources, such as labour and fuel. Additionally, the farm has been able to optimize its crop management strategies, which has led to increased crop yields and quality. However, the implementation of this technology also comes with some challenges. One of the main challenges is the high cost of the system, which can be a barrier for some farmers, especially small farmers. Additionally, maintaining and troubleshooting technology can be complex and requires skilled personnel. Another challenge is the limited compatibility of the technology with different types of crops and terrains, making it less suitable for some farms. Furthermore, there is also the concern of job displacement for farm workers as technology takes over their role. Despite these challenges, the farm in this case study has found the system to be highly beneficial and has plans to expand the system to other crops. The potential for further adoption and scaling up of this technology in crop harvesting is high as long as the cost of the system decreases, and the technology becomes more compatible with different types of crops and terrains. Additionally, there is a need to address the concerns of job displacement for farm workers.

Fig. 14. Automated crop harvesting using robots and machine learning. Source: (https://www.automate.org/industry-insights/agtech-automation-of-agriculture)

CHALLENGES AND OPPORTUNITIES

There are several technical, economic, and societal challenges facing the adoption of biophotonics and machine learning in agriculture. On the technical side, one of the main challenges is the high cost of implementing these technologies, which can be a barrier for some farmers, especially small farmers. Additionally, technology can be complex and difficult to maintain, requiring skilled personnel to operate and troubleshoot. Furthermore, there is limited compatibility of the technology with different types of crops and terrains, making it less suitable for some farms. On the economic side, there is concern about job displacement for farm workers as technology takes over their role. Additionally, farmers need to be able to see a return on their investment in these technologies for them to be adopted on a larger scale. On the social side, data privacy and security concerns may arise when using machine learning in agriculture. Furthermore, the use of these technologies can raise ethical concerns, such as their impact on the environment and the safety of the food produced (Parikh et al., 2022).

Considering these challenges there are key opportunities for future research and development in the field of biophotonics and machine learning in agriculture. One of the key opportunities is to develop more cost-effective and user-friendly technologies that are accessible to a wider range of farmers. Additionally, research is needed to optimize technology for different types of crops and terrains, as well as to improve compatibility with existing farm equipment and infrastructure. Another opportunity is to develop methods to address data privacy and security concerns, such as developing secure data storage and sharing methods. Another area of research is to develop methods to mitigate job displacement, for example, by developing new roles for farm workers to operate and maintain technology. Additionally, research can be done to understand the potential impact of these technologies on the environment and food safety and to develop strategies to minimize any negative impacts. Moreover, there is a need for research to improve the accuracy and reliability of the algorithms used in machine learning, and to develop methods to improve the interpretability of the results, so farmers can make better informed decisions. Additionally, research can be done to develop methods to integrate data from multiple sources, such as weather forecasts and soil moisture data, to improve the accuracy of predictions and recommendations. There are many challenges facing the adoption of biophotonics and machine learning in agriculture but also many opportunities for future research and development. Focusing on developing cost-effective, user-friendly, and compatible technologies, addressing data privacy and security concerns, mitigating job displacement, understanding the impact on the environment and food safety, improving the precision and interpretability of the results, and integrating data from multiple sources are crucial for the successful adoption and scaling up of these technologies in agriculture.

CONCLUSIONS

In conclusion, biophotonics and machine learning have the potential to revolutionize the future of agriculture by increasing crop yields, reducing resource use, improving animal welfare, and making the whole agricultural process more efficient, sustainable, and profitable. Investment in research and development to address challenges and improve the capabilities of these technologies is crucial for the successful adoption and scaling up of these technologies in agriculture. The review has highlighted the potential of biophotonics and machine learning to revolutionize the future of agriculture. The case studies presented in the review have shown that these technologies can be used in a variety of applications, such as precision agriculture, crop monitoring, and disease detection, and have led to increased crop yields, reduced resource use, and improved animal welfare. However, the review also highlighted several challenges facing the adoption of these technologies, such as high costs, lack of skilled personnel, data privacy and security concerns, job displacement, and environmental and food safety concerns. Despite these challenges, the potential for these technologies to revolutionize the future of agriculture is significant. Therefore, it is important to continue to invest in research and development to address the challenges and to further improve the capabilities of these technologies. In the future, research should focus on developing cost-effective, user-friendly, and compatible technologies, addressing data privacy and security concerns, mitigating job displacement, understanding the impact on the environment and food safety, improving the accuracy and interpretability of the results, and integrating data from multiple sources to make more accurate predictions and recommendations.

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