Asian Journal of Research in Crop Science

Volume 8, Issue 1, Page 51-58, 2023; Article no.AJRCS.95175
ISSN: 2581-7167

Integrated Soil Fertility Management: A Promising Pathway for Sustainable Intensification of Smallholder Cotton Farming Systems in Côte d'Ivoire

Jean-Baptiste Gnélié Gnahoua [a*], Marie Luce Mâ Semba Ouattara [a], Zonlehoua Coulibali [a], Loua Barthélémy Diomandé [a] and Yadé Réné Soro [b]

[a] Laboratory of Earth, Water and Environment Sciences, Institute of Agriculture and Pasture Management, Péléforo Gon Coulibaly University, Côte d'Ivoire.
[b] Department of Biochemistry, Faculty of Biosciences, Laboratory of Biotechnologies, Félix Houphouet-Boigny University, Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. Author JBGG designed the experiment and wrote the main text of the manuscript. Authors MLMSO, ZC, LBD and YRS analyzed the data. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJRCS/2023/v8i1157

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/95175

Original Research Article

Received: 27/10/2022
Accepted: 29/12/2022
Published: 27/01/2023

ABSTRACT

Aims: This study was aimed to increase the sustainability of smallholder cotton cultivation in Côte d'Ivoire, through the implementation of Integrated Soil Fertility Management, combining the use of moderate amounts of mineral fertilizer and fortified organic manure.
Study Design: The experiment was set up in a Fisher block design, with four treatments and three replications.

**Corresponding author: E-mail: baptistegnelie@yahoo.fr;*

Place and Duration of Study: The trials were conducted in four locations across two largest cotton growing areas (Odienne and Minignan) in the northern agro-ecological zone, between March and September 2021.

Methodology: The technical options included: 1) mineral fertilizer (25 kg NPK ha^{-1} + 12.5 kg urea ha^{-1}) + 0 kg manure ha^{-1} (control), 2) mineral fertilizer + 50 kg manure ha^{-1}, 3) mineral fertilizer + 75 kg manure ha^{-1} and 4) local practice (200 kg NPK ha^{-1} + 50 kg urea ha^{-1} + 0 kg manure ha^{-1}).

Results: The results showed an increase in seed cotton yield for the manure treatments compared to the control treatment. Non-significant yield difference was found between the manure treatments and local practice. The average yields obtained in Odienne were 5.73 ± 0.70 t ha^{-1} for 75 kg manure ha^{-1} and 5.13 ± 0.96 for 50 kg manure ha^{-1}, versus 2.58 ± 0.76 t ha^{-1} for the control treatment. In Minignan, the average yields obtained were 6.86 ± 1.76 t ha^{-1} for 75 kg manure ha^{-1} and 5.73 ± 0.70 t ha^{-1} for 50 kg manure ha^{-1}, versus 2.58 ± 0.76 t ha^{-1} for the control. The Agronomic Efficiency of applied manure varied from 37.00 ± 13.07 to 73.41 ± 16.89 kg cotton kg^{-1} and from 44.34 ± 15.05 to ^{1} for the two agro-ecological zones.

Conclusion: The Integrated Soil Fertility Management system was proven to be a promising pathway for achieving sustainable intensification of smallholder cotton cultivation systems.

Keywords: Cotton cultivation; integrated soil fertility management; fortified organic manure; agronomic efficiency; productivity; Côte d'Ivoire.

1. INTRODUCTION

In Côte d'Ivoire, as in many other tropical regions, the implementation of sound agronomic practices has become a critical issue to sustain agricultural production such as cashew and cotton cultivations. Cotton is the third largest agricultural export after cocoa and coffee, with an annual production of 580,000 tones [1]. It contributes about 1.7% of the Gross Domestic Product (GDP), and provides livelihoods and more than 50% of cash-income to rural population [2,3]. This crop is widespread in the northern regions, where it represents a main source of income generation and employment along with cashew cultivation [4]. Cotton is produced by strong private companies and smallholder farmers, with low resource endowments [5]. The cotton producing area covers the northern half of the country (7°5N to 12°N: 3°W to 8.5°W) [6], which include the regions of Savannah (64.24%), Worodougou (19.13%) and Denguele (7.46%). In local practices, smallholder cotton cultivation systems are characterized by the use of improved (disease resistant or high yielding) varieties released by the National Agronomic Research Centre and common applications of chemical pesticides and fertilizers provided by the farmers' organizations. Despite the use of high-performing plant material and the broad application of mineral fertilizers, agricultural production has remained low, with an average yield of 1.5 tones ha^{-1} [7]. This low productivity of the cotton cultivation is a result of continuous cropping and synergistic effect of biophysical constraints, including micronutrients deficiency (Zn, Cu and B) and low soil organic matter [8]. Some continuously farmed lands, where standard fertilizers are applied, may fall into the category of so-called non-responsive soils [9]. This category refers to soils showing little or no response to standard fertilizer inputs [10]. The non-responsiveness of soils is due to other constraints such as soil acidification, low organic matter content, micronutrients deficiency and soil born pests and diseases, which cannot be alleviated by applied fertilizers [10,11].

The Integrated Soil Fertility Management (ISFM) was hypothesized to be a holistic alternative for sustainable intensification of agricultural productions [12]. This concept is defined as a set of practices that necessarily include the use of mineral fertilizer, organic inputs and improved crop varieties, combined with local adaptation and aiming at optimizing agronomic use efficiency of the applied nutrients [12]. This research was aimed to improve the sustainability of smallholder cotton cultivation systems through the combined use of moderate amounts of mineral fertilizer and fortified organic manure and an improved cotton variety.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Study area

The experiment was conducted in two largest cotton growing regions (Odienne and Minignan), which are located in the northern Côte d'Ivoire.

The demonstration trials were carried out in four locations. The selected locations were Dioulatchedougou and Tanhanso for Odienne, and Somontou and Tienny for Minignan agro-ecological zone. The selection of these locations was based on the significance of cotton farming and their geographical position to take into account the side-specific variation of ecological conditions. Both regions are covered by a tropical climate, with similar temperature and rainfall patterns. The annual rainfall ranges from 1000 to 1750 mm and the mean temperature from 24 to 27◦C, with an average humidity of 60–70%. These agro-ecological zones are also characterized by a natural vegetation that is mainly composed of shrubby and herbaceous savannah, and ferralitic and ferruginous soils [13].

2.1.2 Plant and inputs material

The planting material was consisted of an improved cotton variety (Gouassou F1) that was released by the National Agronomic Research Centre. It is one of the most widely grown cotton varieties by local farmers. The selection of this variety was motivated by its high yield potential and disease resistant traits and by the quality of the fibre. The soil amendment was consisted of mineral fertilizer that includes NPK (15-15-15 + 6S + 1B) and Urea (46% N), and a fortified organic manure (Fertinova). The chemical composition of the fortified manure was 2.0% total nitrogen (0.2% N-nitric, 1.8% N-organic), 3.0% available phosphorus (P2O5), 2.0% potassium (K2O), 70.0% dry matter (DM) and 24% organic matter (OM).

2.2 Methods

2.2.1 Experimental setup

The experiment was set up in a Fisher block design, with three treatments and three replications. The experimental design was consisted of three blocks. Each block was composed of three individual plots, to which three treatments were randomly assigned. The spacing between the individual plots was 5 m within the block and the inter-block distance was 4 m. The size of the individual plot was 4 x 5 m, and that of the experiment was 20 x 25 m, with a total area of 500 m^2. The individual plot was consisted of 5 rows, each with 17 cotton seedlings. The spacing between seedlings was 30 cm within the row and the rows were 80 cm distant. Each seedling comprised two plants, for a total of 170 plants per individual plot.

2.2.2 Treatment application

The NPK fertilizer and fortified organic manure (Fertinova) were both applied as a bottom dressing at the time of planting the crop to the seed rows and then re-bedded to avoid nutrient leaching. Urea was applied at the flowering stage of the crop (40 days after sowing) to the planting rows as described above. The mineral fertilizer was applied at moderate rates of 25 kg NPK ha^{-1} and 12.5 kg urea ha^{-1}, compared to the standard application of 200 kg NPK ha^{-1} + 50 kg urea ha^{-1}, as recommended by the extension organizations. This application of mineral fertilizer was combined with three increasing doses of 0, 50, 75 kg organic manure ha^{-1} and the resulting treatments were as follows:

- 25 kg NPK ha^{-1} + 12.5 kg urea ha^{-1} + 0 kg manure ha^{-1};
- 25 kg NPK ha^{-1} + 12.5 kg urea ha^{-1}+ 50 kg manure ha^{-1};
- 25 kg NPK ha^{-1} + 12.5 kg urea ha^{-1}+ 75 kg manure ha^{-1}.

The demonstration experiment included two reference plots from individual farmers in the study area, to which the standard dose of mineral fertilizer (200 kg NPK ha^{-1} + 50 kg urea ha^{-1}) was applied for the assessment of the yield differences.

2.2.3 Crop monitoring and harvesting

During the cotton cropping cycle, a set of field operations (weeding, plant re-bedding, pesticides application) were performed according to the recommendations of the technical structures. The chemical pesticides applied to the unit and reference plots were consisted of Belt Expert 480 EC and Fortiss 37 EC that are commonly used in cotton cultivation for pests control. The cotton bolls were harvested in the individual plots at full maturity that is four months after planting.

2.2.4 Observations and measurements

The observations were focused on boll number and average weight per plant and fibre yield. At full maturity (four months after planting), nine plants were randomly selected from three central rows for the individual plots, excluding border plants. For each selected plant, the total number of bolls was determined by counting. Then, three bolls were harvested and dried using a solar dryer for yield assessment. The dried bolls and extracted fibre were weighed and the yield was calculated by the following formula:

Yield (t ha^{-1}) = Average boll weight per plant x Planting density

The Agronomic Efficiency (incremental yield per unit applied inputs) of fortified manure was calculated according to the formula described by [14]:

AE = Yield of fertilized plot - Yield of control plot / Amount of applied fertilizer

Where: AE = kg kg^{-1}

2.2.5 Data analysis

Data on crop yield and Agronomic Efficiency of fortified organic manure were analyzed using SPSS (Statistical Package for Social Sciences, version 20.0) software. The effect of the treatments for the different parameters was determined by an analysis of variance at the α = 0.05 significance level. The means of treatments were compared with the Newman-Keul test whenever significant differences found.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Effect of treatments on cotton yield in Odienne agro-ecological zone

Crop yields for the different treatments in the agro-ecological zone of Odienne are presented in (Table 1). The Analysis of variance showed highly significant differences (*P* = .00) in the effect of fortified organic manure on cotton yield in both locations (Dioulatchedougou and Tanhanso). The comparison of means showed higher yields for both fertilizer rates compared to the control treatment without manure addition. The yields of the two manure treatments were statistically similar. The yield values obtained in Dioulatchedougou were 5.64 ± 0.70 t ha^{-1} for the 50 kg manure ha^{-1} and 5.80 ± 0.87 t ha^{-1} for the 75 kg manure ha^{-1}, compared to 3.00 ± 0.54 t ha^{-1} for the control treatment. Yield values in Tanhanso were 4.61 ± 1.01 and 5.67 ± 0.69 t ha^{-1} for 50 kg and 75 kg manure ha^{-1} respectively, compared to 2.16 ± 0.76 t ha^{-1} for the control treatment.

3.1.2 Effect of treatments on cotton yield in Minignan agro-ecological zone

Crop yields for the different treatments in the agro-ecological zone of Minignan are presented in (Table 2). The Analysis of variance showed highly significant differences (p < .01) in the effect of fortified organic manure on cotton yield in both locations (Somontou and Tienny). The comparison of means showed higher yields for both manure doses compared to the control treatment without manure addition. The yields of the two manure doses were not statistically different at Somontou, but varied at Tienny. The yield values in Somontou were 5.32 ± 0.37 t ha^{-1} for 50 kg manure ha^{-1} and 5.80 ± 0.87 t ha^{-1} for 75 kg manure ha^{-1}, compared to 3.27 ± 0.25 t ha^{-1} for the control treatment. The 75 kg ha^{-1} manure application dose gave a higher yield value in Tienny. The yield values in Tienny were 5.80 ± 0.37 and 8.40 ± 0.76 t ha^{-1} for 50 kg manure ha^{-1} and 75 kg manure ha^{-1} respectively, compared to 2.82 ± 0.71 t ha^{-1} for the control treatment.

3.1.3 Variability of the cotton yield response across agro-ecological zones

The side-specific variation in cotton yields for the different agro-ecological zones is presented in (Table 3). The analysis of variance showed non-significant differences (*P* > .05) in the effect of locality on crop yield for the different organic manure treatments, except for the 75 kg manure ha^{-1} dose, which induced variable yields in the Minignan agro-ecological zone (*P* = .00). The average yields values were 5.73 ± 0.70, 5.13 ± 0.96 and 2.58 ± 0.76 t ha^{-1}, respectively for the 75 kg manure ha^{-1}, 50 kg manure ha^{-1} and the control treatment in the agro-ecological zone of Odienne. For the Minignan agro-ecological zone, the average yields were 6.86 ± 1.76, 5.73 ± 0.70 and 2.57 ± 0.74 t ha^{-1} respectively. The yield values of the two reference fields were 5.57 ± 0.35 and 6.23 ± 0.46 t ha^{-1}, which were not statistically different (P-value > .05) from those of the demonstration plots combining the moderate doses of mineral fertilizer and fortified organic manure.

3.1.4 Agronomic Efficiency of fortified organic manure

The Agronomic Efficiency (AE) of applied organic manure rates for the different locations is presented in (Table 4). Analysis of variance showed non-significant differences in Agronomic Efficiency of organic manure rates for the different locations (*P* >.05). The average values of AE in the agro-ecological zone of Odienne were 40.33 ± 16.87 and 37.00 ± 13.07 kg cotton kg^{-1} manure for Dioulatchedougou and Tanhanso, respectively. In the Minignan agro-ecological zone, average values of AE were 44.34 ± 15.05 and 73.41 ± 16.89 t ha^{-1} for Somontou and Tienny, respectively.

Table 1. Cotton yields (t ha^{-1}) for different application rates of fortified organic manure in Odienne agro-ecological zone

Traitements	Locations	
	Dioulatchedougou	Tanhanso
Mineral fertilizer + 0 kg manure ha^{-1}	3.00 (0.54) ^{b}	2.16 (0.76) ^{b}
Mineral fertilizer + 50 kg manure ha^{-1}	5.64 (0.70) ^{a}	4.61 (1.01) ^{a}
Mineral fertilizer + 75 kg manure ha^{-1}	5.80 (0.87) ^{a}	5.67 (0.69) ^{a}
Means	4.90 (1.35)	4.37 (1.43)
P-value	.00	.01
Signification	HS	HS

Different letters per column indicate significant difference for treatments at p < .05; values between brackets are standard deviations; HS: Highly significant; Mineral fertilizer = 25 kg NPK ha^{-1} + 12.5 kg urea ha^{-1}.

Table 2. Cotton yields (t ha^{-1}) for different application rates of fortified organic manure in Minignan agro-ecological zone

Traitements	Locations	
	Somontou	Tienny
Mineral fertilizer + 0 kg manure ha^{-1}	3.27 (0.25) ^{b}	2.82 (0.71) ^{c}
Mineral fertilizer + 50 kg manure ha^{-1}	5.32 (0.37) ^{a}	5.80 (0.37) ^{b}
Mineral fertilizer + 75 kg manure ha^{-1}	5.80 (0.87) ^{a}	8.40 (0.76) ^{a}
Means	4,51 (1.18)	5.53 (0.18)
P-value	.00	,00
Signification	HS	HS

Different letters per column indicate significant difference for treatments at P < .05; values between brackets are standard deviations; HS: Highly significant; Mineral fertilizer = 25 kg NPK ha^{-1} + 12.5 kg urea ha^{-1}.

Table 3. Yields variation (t ha^{-1}) across locations for different fortified organic manure application rates

Locations	Treatments		
	Mineral fertilizer + 0 kg manure ha^{-1}	Mineral fertilizer + 50 kg manure ha^{-1}	Mineral fertilizer + 75 kg manure ha^{-1}
Zone: Odienne			
Dioulatchedougou	3.00 (0.54) ^{bA}	5.64 (0.70) ^{aA}	5.80 (0.87) ^{aA}
Tanhanso	2.16 (0.76) ^{bA}	4.61 (1.01) ^{aA}	5.67 (0.69) ^{aA}
Means	2.58 (0.76)	5.13 (0.96)	5.73 (0.70)
P-value	.19	.22	.85
Signification	NS	NS	NS
Zone: Minignan			
Somontou	3.27 (0.25) ^{bA}	5.32 (0.37) ^{aA}	5.67 (0.69) ^{aB}
Tienny	2.82 (0.71) ^{cA}	5.80 (0.87) ^{bA}	8.40 (0.76) ^{aA}
Means	2.58 (0.76)	5.73 (0.70)	6.86 (1.76)
P-value	.19	.84	.00
Signification	NS	NS	HS

** Different small letters per row indicate significant difference for treatments; different capital letters per column indicate significant difference for locations at p < .05; values between brackets are standard deviations*

Table 4. Agronomic efficiency (in kg cotton kg^{-1} inputs) of manure application rates in different locations

Treatments	Locations			
	Dioulatchedougou	Tanhanso	Somontou	Tienny
50 kg Manure ha^{-1}	33.67 (14.41) ^{a}	35.97 (10.42) ^{a}	30.99 (10.91) ^{a}	63.78 (10.12) ^{a}
75 kg Manure ha^{-1}	47.39 (19.06) ^{a}	38.03 (17.76) ^{a}	44.34 (15.05) ^{a}	83.05 (18.23) ^{a}
Means	40.33 (16.87)	37.00 (13.07)	37.67 (13.84)	73.41 (16.89)
P-value	.37	.87	.28	.18
Signification	NS	NS	NS	NS

Different letters per column indicate significant difference for treatments at P < .05; values between brackets are standard deviations; NS: Non significant.

3.2 Discussion

The experimental results showed a highly beneficial effect of the combined application of moderate amounts of mineral fertilizer (25 kg NPK ha^{-1} + 12.5 kg urea ha^{-1}) and fortified organic manure on cotton yields for the different locations. Higher cotton yields were obtained for the 75 kg manure ha^{-1} dose (Dioulatchedougou: 4.51 ± 1.18 t ha^{-1}, Tanhanso: 5.30 ± 2.75 t ha^{-1}, Somontou: 5.32 ± 0.37 t ha^{-1}, Tienny: 8.40 ± 0.76 t ha^{-1}), compared to the control treatment without manure addition, which gave values from 2.16 ± 0.76 to 3.27 ± 0.25 t ha^{-1}. The agronomic performance of the both organic manure application rates (50 and 75 kg ha^{-1}) over the control treatment could be related to a low soil organic matter and micronutrients contents that was alleviated by the addition of manure [15]. The organic amendments (animal manure, crop residues, and bio-char), in addition to providing nutrients, contributes to the reduction of soil acidity, enhances the water holding capacity, microbial activity, and that improve crops resilience and yields [16].

Standard fertilizers are often composed of macronutrients (N, P, and/or K), and their application without addition of micronutrients (Zn, Cu and B) has the disadvantage of not sustaining agricultural productions [12]. Furthermore, the efficiency of mineral fertilizers in tropical soils is often impaired by inherent acidity. Strong soil acidity (pH < 5), more than affecting most of the biological processes (e.g. nitrification) and reducing CEC and nutrient availability, increases the level of exchangeable aluminum (Al) leading to problem of toxicity [17]. Under acidic soil conditions, phosphorus and other minerals bind to metal ions (Al, Fe and Zn), forming metal-oxides that become not available for crop uptake [18,19]. This inherent soil acidification is exacerbated by continuous cultivation stemming from a land pressure, and the standard application of mineral fertilizers and pesticides [20]. Some of the croplands under continuous cultivation, with standard fertilizer application, may have fallen into the category of non-responsive soils, due to low soil organic matter content, acidification and micronutrients deficiency [9].

The results showed non-significant variations in crop response to the application of the two doses (50 and 75 kg ha^{-1}) of organic manure across locations. This invariability of crop response across locations could be explained by prevailing agricultural practices (continuous cropping and standard application of chemical pesticides and fertilizers), which potentially induces nearly similar levels of soil fertility. This could be certified by soil analysis that was unfortunately not performed due to the lack of a laboratory. This social constraint and the lack of a simplified diagnostic method, underpin the standard recommendation of mineral fertilizer implementation. The invariability of Agronomic Efficiency values for the two manure doses across locations could reflect yield improvements with increasing rates of manure and nearly similar economic returns for the farmers. The seed cotton yields obtained by the treatments with added manure were not significantly different to those of the reference plots from individual farmers. This non-significant yield differences reflect the ability of the integrated soil fertility management to sustain agricultural production. This result is in agreement with the finding of [21], who have reported a 19% increase in seed cotton yield following the application of oxen dung (3.88 t ha^{-1}) compared to 200 kg ha^{-1} of NPK fertilizer (3.25 t ha^{-1}), but with an increased amount of manure (3,000 kg ha^{-1}). The sustainability of Integrated Soil Fertility Management stems from the enhancement of soil microbial activity that is involved in nutrient cycling through the addition of organic manure, and the minimal use of mineral fertilizers, which reduces the negative externalities associated with standard applications. This sustainability can be enhanced by including grain or fodder legumes intercropping or rotation, minimum tillage, with side-specific adaptation of organic manure and fertilizer application rates.

4. CONCLUSION

The study provides insight into the potential of the Integrated Soil Fertility Management approach to sustain the smallholder cotton productions in northern Côte d'Ivoire. The implementation of the ISFM principle has resulted in seed cotton yield increases compared to the control treatment without manure addition. The ISFM treatments gave similar yields to the individual reference plots where standard fertilizer amount was applied. The invariability of crop response to the application of organic manure doses across locations and agro-ecological zones suggests a pattern of uniform soil conditions, as a consequence of continuous cropping and the standard application of chemical pesticides and fertilizers. The Integrated Soil Fertility Management can be sensed as a sound agronomic alternative for ecological and economic intensification of smallholder cotton cultivation. The sustainability of ISFM systems could be enhanced by including grain or forage legume intercropping or rotation and minimum tillage, with specific adaptation of applied inputs.

ACKNOWLEDGEMENTS

The authors are thankful to the company Ivoire Coton (COIC) for the research initiative on fortified organic manure implementation and for funding. Special thanks are extended to the smallholder farmers and extension agents for their precious collaboration.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Coulibaly I, Coulibaly S, N'Goran KD, Yeo NA, Kouakou TH, Zouzou M. Evaluation of two phytoextracts for induction of phenolic markers indicative of the physiological status improvement of cotton grown in Côte d'Ivoire. IBSPR. 2022;10(3):39-50. doi: 10.15739/ibspr.22.007.
2. Koné I, Agyare WA, Gaiser T, Owusu-Prempeh N, Kouadio K-KH, Kouadio EN et al. Local cotton farmers' perceptions of climate change events and adaptations Strategies in cotton basin of Côte d'Ivoire. J Sustain Dev. 2022;15(3):108-24. DOI: 10.5539/jsd.v15n3p108.
3. Martin T, Ochou GO, Vaissayre M, Fournier D. Monitoring insecticide resistance in the bollworm *Helicoverpa armigera* (Hübner) from 1998 to 2002 in Côte d'Ivoire, West Africa. In: Proceedings of the world cotton research conference-3: Cotton production for the new millennium. Cape Town, South Africa; March 9-13, 2003.
4. Tillie P, Louhichi K. Gomez-Y-Paloma S. Impact of farming techniques for cotton production in Côte d'Ivoire: A farm-level modelling approach, Sixth International Conference, Sep 23-26, Abuja, Nigeria; 2019.
5. Gergely N. The cotton Sector of Côte D'Ivoire. Africa Region Working Paper Series. No. 130. (a) World B. Washington, DC; 2010.
6. Malanno K, Norbert BKK, Mamadou OB, Germain OO. New subdivision of cotton production area of Côte d'Ivoire based on the infestation of main arthropod pests. J Entomol Zool Stud. 2021;9(3):50-7. DOI: 10.22271/j.ento.2021.v9.i3a.8689.
7. Fonds Interprofessionnel pour la Recherche et le Conseil Agricole. Rapport Annu. 2018. French.
8. Kidron GJ, Zilberman A. Low cotton yield is associated with micronutrient deficiency in West Africa. Agron J. 2019;111(4):1977-84. DOI: 10.2134/agronj2018.07.0477.
9. Kurwakumire N, Chikowo R, Mtambanengwe F, Mapfumo P, Snapp S, Johnston A et al. Maize productivity and nutrient and water use efficiencies across soil fertility domains on smallholder farms in Zimbabwe. Field Crops Res. 2014;164:136-47. DOI: 10.1016/j.fcr.2014.05.013.
10. Kihara J, Nziguheba G, Zingore S, Coulibaly A, Esilaba A, Kabambe V et al. Understanding variability in crop response to fertilizer and amendments in sub Saharan Africa. Agric Ecosyst Environ. 2016;229:1-12. DOI: 10.1016/j.agee.2016.05.012, PMID 27489394.
11. Vanlauwe B, Descheemaeker K, Giller KE, Huising J, Merckx R, Nziguheba G et al. Integrated soil fertility management in sub-Saharan Africa: unravelling local adaptation. Soil. 2015;1(1):491-508. DOI: 10.5194/soil-1-491-2015.
12. Vanlauwe B, Coyne D, Gockowski J, Hauser S, Huising J, Masso C et al. Sustainable intensification and the African smallholder farmer. Curr Opin Environ Sustain. 2014;8:15-22. DOI: 10.1016/j.cosust.2014.06.001
13. Gnangui SLE, Fossou RK, Ebou A, Amon CER, Koua DK, Kouadjo CGZ et al. The rhizobial microbiome from the tropical savannah zones in northern Côte d'Ivoire. Microorganisms. 2021;9(9):1842. DOI: 10.3390/microorganisms9091842, PMID 34576737.
14. Liu C, Liu Y, Li Z, Zhang G, Chen F. A novel way to establish fertilization recommendations based on agronomic efficiency and a sustainable yield index for rice crops. Sci Rep. 2017;7(1):1001. DOI: 10.1038/s41598-017-01143-2, PMID 28439083.

15. Prescott CE, Rui Y, Cotrufo MF, Grayston SJ. Managing plant surplus carbon to generate soil organic matter in regenerative agriculture. J Soil Water Conserv. 2021;76(6):99A-104A.
DOI: 10.2489/jswc.2021.0920A.
16. Yadav V, Karak T, Singh S, Singh AK, Khare P. Benefits of biochar over other organic amendments: responses for plant productivity (*Pelargonium graveolens* L.) and nitrogen and phosphorus losses. Ind Crops Prod. 2019;131:96-105.
DOI: 10.1016/j.indcrop.2019.01.045.
17. Crawford TW, Singh U, Breman H. Solving agricultural problems related to soil acidity in Central Africa's Great Lakes region, Project report. AL: international fertilizer development center; 2008.
18. Zhang N, Wang Q, Zhan X, Wu Q, Huang S, Zhu P et al. Characteristics of inorganic phosphorus fractions and their correlations with soil properties in three non-acidic soils. J Integr Agric. 2022;21 (12):3626-36.
DOI: 10.1016/j.jia.2022.08.012.
19. Ettien DJB, Gnahoua GJ-B, Kouadio KKH, Koné B, N'Zué B, Kouao AAF et al. Soil fertility in land use for sustainable food crops production in the southern Côte d'Ivoire. Agric Biol J North Am. 2016;7:19-26.
DOI: 10.5251/abjna.2016.7.1.19.26.
20. Juo ASR, Dabiri A, Franzluebbers K. Acidification of a kaolinitic alfisol under continuous cropping with nitrogen fertilization in West Africa. Plant Soil. 1995; 171(2):245-53.
DOI: 10.1007/BF00010278.
21. N'guessan AN, Kouassi NJ, Kouame N, Kouadio YJ. Effect of fertilization and sowing method on the agronomic performance of a cotton variety (*Gossypium hirsutum* L.) grown in the Béré region of North Western Côte d'Ivoire. Int J Innov Appl Stud. 2022;36:806-12.

© 2023 Gnahoua et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/95175