Effects of cropping practices and soil properties on yam (*Dioscorea spp*) yields in different agro-ecosystems in Burkina Faso and Côte d'Ivoire

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Abstract

Yam is a staple food for millions of people however, yam yields remain low due to its high variability. This study aims to characterize yam cropping practices and to identify yield variability determinants at farm level in four sites in Burkina Faso and Côte d'Ivoire. A survey was done on 130 yam farmers. Yam germination rate, density of the plantation and yields were measured. Soil samples, taken at 0 – 30 cm, were analyzed for soil chemical properties. Individual interviews with farmers were done on seedlings, soil fertility management. Results showed yam cropping was characterized by the use of mineral fertilizers (93 %) in Leo and by fallow practices (90 %) in Midebdo. In Liliyo, yam cropping is characterized by the use of smaller seeds and higher density of plantation (187.7 ± 1.0 g, 10221.0 ± 268 plants ha^{-1}). Leo presented highest average yield for *Dioscorea rotundata* (9.0 ± 5.1 t ha^{-1}). Density of plantation and pH_{water} significantly determined yam yield variability for *D. alata* while for *D. rotundata*, yields were affected by total P for the four sites. These results highlight the need to better understand the underling yam yield determinants before attempting to improve yam production in West Africa.

Keywords: Yam, yield, determinant, Burkina Faso, Côte d'Ivoire

Effets des pratiques culturales et des propriétés du sol sur les rendements de l'igname (Dioscorea spp) dans différents agroécosystèmes au Burkina Faso et en Côte d'Ivoire

Résumé

L'igname est une culture vivrière pour des millions de personnes, cependant les rendements de l'igname restent faibles dû à sa grande variabilité. Une étude a été faite dans différents agroécosystèmes au Burkina Faso et en Côte d'Ivoire afin de comprendre la variabilité des rendements de l'igname. Cette étude a

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concerné 130 producteurs d'igname dans quatre sites. Les taux de germination, les densités de plantation et les rendements ont été mesurés. Des échantillons de sol, prélevé à 0 – 30 cm, ont été analysés. Des entretiens individuels ont été réalisés auprès des producteurs sur les semences et la gestion de la fertilité. Les résultats ont montré que la culture de l'igname était caractérisée par l'utilisation des engrais minéraux (93 %) à Leo, par la pratique de la jachère (90 %) à Midebdo et par l'utilisation de petites semences (187.7 ± 1.0 g) et de forte densité (10221.0 ± 268 plants ha^{-1}) à Liliyo. Leo a présenté les rendements d'igname les plus élevés (9.0 ± 5.1 t ha^{-1}) comparé aux autres sites. Dans les quatre sites, la densité de plantation et le pH_{eau} du sol ont affecté les rendements de *Dioscorea alata* et P total du sol a affecté les rendements de *Dioscorea rotundata*.

Mots – Clés : Igname, rendements, déterminants, Burkina Faso, Côte d'Ivoire

Introduction

Yam (*Dioscorea spp*) has an important nutritional value as it contains in carbohydrates, protein, vitamin C, magnesium, potassium, manganese, copper and fiber (Frossard *et al.*, 2000). It is the staple food for more than 300 million people (Asiedu and Sartie, 2010; Alabi *et al.*, 2019) and worldwide annual consumption of yams was 18 million tons in 2021 (Wumbei *et al.*, 2022). Yams are not only a nutritious food but also a rich source of chemical compounds with various medicinal properties. Saponin, diosgenin, and steroids are some of the chemicals found in yam that are used to create natural and pharmaceutical remedies (Guchhait *et al.*, 2022). In addition to these components, yam also contains bioactive compounds that provide health benefits. For instance, diosgenin and dioscorin, which are isolated from yam, have shown promise in preventing and treating degenerative diseases (Obidiegwu *et al.*, 2020). Moreover, yam is a source of income for many smallholders and employment to a lot of people in many areas where it is cultivated (Wumbei *et al.*, 2022). Yam is cultivated in Caribbean, Asia, South America and in Africa. West Africa produces over 90% of world yam production with Nigeria, the largest producer followed by Ghana and Côte d'Ivoire (FAOSTAT, 2023). Despite yam importance, its cropping encounters many constraints which leading to lower yields. The most important significant constraints were rainfall, labor scarcity, lack of financial resources, pest damage and decline of soil fertility (Kouakou et *al.*, 2019). Yield gap contributor also includes the scarcity and the high cost of quality yam seeds, losses incurred during harvest and post-harvest, lack of robust varieties adapted to agro-ecological environments of the savannah under climatic constraints, low potential of yam markets yam seed, limited opportunities for smallholders, particularly women, in terms of yam production and marketing (Verter and Becvarova, 2014; Idumah and Owombo, 2019). The contribution of these factors to yam yields vary according to the area (Cornet, 2015). Besides, yam remains an orphan crop compared to other crops such as casava and maize (Frossard *et al.*, 2017) and most of the studies were done on yam in Nigeria and Ghana.

The present study aims to understand yield variability and its determinants in West Africa. The specific objectives of this study were to i) Describe current yam cropping practices and soil chemistry properties in yam production areas of Burkina Faso and Côte d'Ivoire ii) determine current yam yields variability from farmers' fields in both countries, iii) identify and analyse yam yields determinants in Burkina Faso and Côte d'Ivoire. This research endeavours to provide valuable insights that can be used to enhance yam production and increase yields in the West Africa region.

I. Material and methods

I.1. Study area

We conducted our study in Burkina Faso and Côte d'Ivoire in West Africa (figure 1). Two main yam production areas were selected in each country, Midebdo and Leo in Burkina Faso, Liliyo and Tiéningboué in Côte d'Ivoire.

Leo and Midebdo are in the western centre and western south of Burkina Faso and characterized by sudano-sahelian and sudanese climate, respectively (Kambiré *et al.*, 2015). Tiéningboué, a forest-savannah transition area, is in the sudanese climatic zone (Kouassi *et al.*, 2010) and located at in the centre of Côte d'Ivoire. Liliyo is in the guinean climatic zone (Kouassi *et al.*, 2010) located in the South-West Côte d'Ivoire. The average annual total rainfall in 2017 – 2018 was estimated to 1052.6 ± 128.6 mm in Leo, 1067.5 ± 131.2 mm in Midebdo, 1241.3 ± 145.7 mm in Tiéningboué and 1568.3 ± 242.4 mm in Liliyo (NASA/ TRM, 2021). During the same period, the mean annual temperature estimated from the Moderate-Resolution Spectroradiometer at 5.6 km resolution (NASA/MODIS, 2021) was 34.3 ± 4.1 °C in Leo, 33.0 ± 3.8 °C in Midebdo, 29.3 ± 1.8 °C in Tiéningboué and 28.0 ± 2.3 °C in Liliyo (NASA/ TRM, 2021).

The soils in Leo derived from non-differentiated migmatites and granitic rocks (Hottin and Ouedraogo, 1976) and were mainly Lixisols and rarely Gleysols under clay-sandy material deeply (Kaloga, 1973). The soils in Midebdo derived from nondifferentiated migmatites and granitic rocks (Hottin and Ouedraogo, 1976) and were mainly Lixisols and Nitisols but Gleysols, Leptosols, Cambisols could also be observed (Moreau *et al.*, 1969, WRB, 2014). The soils in Tiéningboué, derived from granitic and granito-gneiss rocks (Camara, 1983, Diatta, 1996) leading mainly to Plinthosols and Nitisols but also Luvisols and Lixisols (Jones *et al.*, 2013). The soils in Liliyo were mostly Ferralsols (WRB, 2015) and derived from granitic rocks and schists (Perraud and De la Souchère, 1970, Dabin *et al.*, 1960). Kaolinite, a low-activity clay minerals are dominant in these soils, but illite and smectite can also be found (Dabin *et al.*, 1960, ORSTOM, 1969). These soils are also characterized by the presence of goethite and hematite, are acidic (pHwater of 4 - 6) with low available nutrients content (Dabin *et al.*, 1960, ORSTOM, 1969).

These four sites are yam growing areas which start from May to January every year.

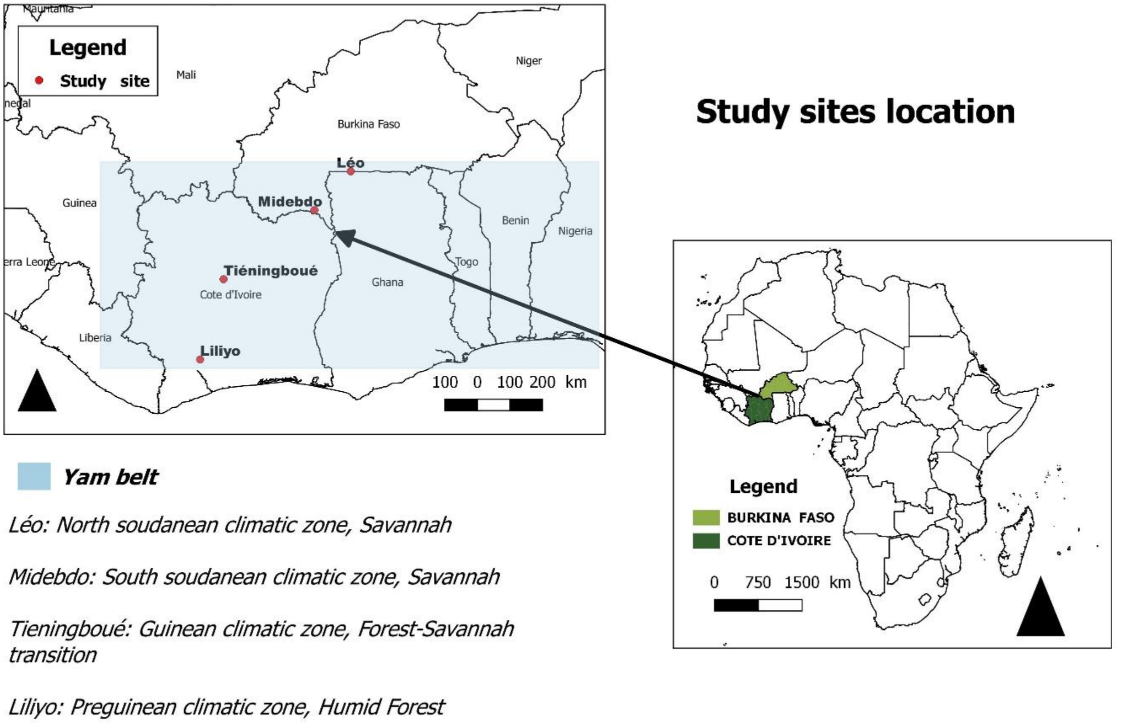


Figure 1: Study sites location in Africa

I.2. Field data collection

We collected data in the four sites from Mai 2017 to April 2018. For this study, we selected volunteer farmers according to stratified sampling (Gumuchian and Marois, 2000). In total, 30 yam farmers from 6 villages in Leo, 29 yam farmers from 5 villages in Midebdo, 33 yam farmers from 11 villages in Tiéningboué, and 38 yam farmers from 14 villages in Liliyo. Yam germination rate, density of plantation and yields were measured by conducting field observations and taking measurements of the relevant parameters. We interviewed farmers on their cropping practices such as seedling, soil fertility management such as fallow, weeding, staking and associated crops in yam production.

I.3. Soil and yam tubers samples analysis

Soil samples were taken at 0 – 30 cm soil depth in 3 locations according to the diagonal in each farm. Composite soil samples were then made for each farm and a total 130 soil samples was obtained for the four study sites. Soil samples were air - dried and sieved at 2 mm. About 20 g of each air – dried soil samples were oven-dried and milled at ~ 10 µm with MM 200 Retsch. Soil samples at 2 mm were used for pH measurements, available P analyses, DTPA and $BaCl_2$ extractions. Samples milled at 10 µm were used for XRF spectroscopy and C, N elemental analysis. Soil samples pH were measured with Benchtop pH meter (model 720A, Orion Research Inc., USA) while available P was extracted using an anion exchange resin membrane (Kouno *et al.*, 1995). As for exchangeable cations (Ca^{2+}, Mg^{2+} and K^{+}) they were analysed by the BaCl2 method (Hendershot and Duquette, 1986). Total element (K, Ca, P) concentration in the soil was determined by energy dispersive X-ray fluorescence spectrometry (ed-xrf) measurements on a spectro xephos instrument (spectro Analytical Instruments GmbH, Germany). Soil samples C and N were measured by combustion of 60 mg milled samples weighed into tin foil capsules (Vario PYRO cube, Elementar Analyse systeme GmBH (https://www.elementar.de/en.html accessed date)).

I.4. Path analysis on yam yields determinants

We used the path analysis method to identify the factors that control yam yield variability. Empirical knowledge and assumptions were used to construct a conceptual model. Total N and available nutrients such as available P, K, Ca and Mg were assumed to have direct effects on yam yields. Soil C and CEC were assumed to affect the available nutrients while pH would affect CEC and available nutrients (Hagedorn *et al.*, 2018). Soil organic carbon affect CEC, pH_{water} and available nutrients (Hagedorn *et al.*, 2018). Soil clay content affects CEC thus available nutrients. Seed weight would affect soil organic carbon, germination rate. Fertilizer inputs could affect soil organic carbon. Data of measured variables were used to evaluate the model.

I.5. Statistical analysis

We used the R software version 3.4 for the statistical analysis. The means, the standard deviation and the standard error were calculated using the analysis of variance function. Means were compared using Tukey test in lsmeans'package (Lenth, 2016) in R software. Path standardized coefficients and their significance levels were calculated by the confirmatory factor analysis (CFA) approach. Only the significant relations ($p < 0.05$) were kept and the goodness of fit of the path model was also tested using chi square, comparative fit index (CFI) and root mean square error of approximation (RMSEA). CFI tends to range from zero to one, with large values suggesting a good fit.

RMSEA varies from zero to one, the smallest value indicating better model fit. Significant p-value of chi square indicates better fit of the model (Hu and Bentler, 1999).

II. Results and discussion

II.1. Yam cropping practices

II.1.1. Yam seed weight

Yam seed weight varied within site and between sites. In Leo, yam farmers in Outoulou and Onliassan villages used bigger yam seed (500 ± 01 g). In Midebdo, yam farmers in Midebdo village used the biggest yam seed (300 ± 00 g) but no significance difference was observed between villages. In Tiéningboué for *Dioscorea rotundata* Poir., Bagao farmers used bigger yam seed (400 ± 10 g) while Menementou farmers used smaller yam seed (200 ± 04 g). As for *Dioscorea alata* L., Tiéfindougou's and Moussatogoda's farmers in Tiéningboué used yam seed of 266.7 ± 49.4 g and 275.0 ± 25.0 g. In Liliyo, Koziayo 2 yam farmers used bigger yam seed (221.2 ± 27.8 g) while Gnagboyo's farmers used smaller yam seed (138.9 ± 18.2 g). Comparison between sites (table I) showed that Leo farmers used the biggest yam seed (482 ± 0.3 g) while Liliyo farmers used the smallest yam seed (187.7 ± 1.0 g).

II.1.2. Yam germination rate, density of plantation

The germination rate of yams did not show significant variation within or between sites however, the plantation density of yams varied significantly both within and between sites. In Leo, yam (*Dioscorea rotundata* Poir.) farmers in Outoulou had higher density of plantation (6187.5 ± 277.2 plants ha^{-1}) while yam farmers in Onliassan had lower density of plantation (5461.1 ± 218.1 plants ha^{-1}). In Midebdo, Pkamhela yam (*D. rotundata*) farmers had higher density of plantation (5275.340 ± 277.2 plants ha^{-1}) but no significance difference was observed between villages. In Tiéningboué for *D. rotundata*, Lamakamagaté farmers had higher density of plantation (7588.9 ± 447.3 plants ha^{-1}) while Niatibo farmers had lower density of plantation (5366.7 ± 100 plants ha^{-1}). As for *Dioscorea alata* L., Moussatogoda farmers in Tiéningboué had higher density of plantation (7706.3 ± 468.7 plants ha^{-1}) while Tiéfindougou farmers had lower density of plantation (5400 ± 866.7 plants ha^{-1}). In Liliyo for *D. alata*, Koziayo1 farmers had higher density of plantation (10893.3 ± 400.9 plants ha^{-1}) but no significance difference was observed between villages. Comparison between sites showed that Liliyo yam farmers had higher density of plantation (10221.0 ± 268 plants ha^{-1}) while Midebdo yam farmers had lower density of plantation (5000.0 ± 142 plants ha^{-1}).

II.1.3. Fertilization management

In yam cropping, farmers in Midebdo, Tiéningboué and Liliyo did not use fertilizers while farmers in Leo used mineral fertilizers. More than 93 % of yam farmers in Leo used NPK (14-23-14) for the first application and 70 % of these farmers used urea (46 % N) or urea + NPK for the second application. As for the mode of application, 44 % of yam farmers in Leo applied NPK on soil surface while 56 % of yam farmers in Leo applied NPK inside each mound. Urea or urea + NPK were applied on soil surface by 38 % yam farmers and urea and urea + NPK were applied inside each mound by 58 % of yam farmers in Leo. The average quantity of NPK was 357.4 ± 54.5 kg ha^{-1} and the average quantity of urea was 232.3 ± 60.0 kg ha^{-1}. No significant difference was observed between villages for fertilizers input in Leo.

Few farmers (2 %) in Leo practiced fallow for yam cropping while the majority (90 %) of farmers practiced fallow in Midebdo. In Midebdo, 75 % to 100 % of yam farmers in the different villages practiced fallow. In Tiéningboué, only 33 % of yam farmers in Menemenetou practiced fallow while more than 50 % yam farmers in other villages practiced fallow. In Liliyo, more than 50 % of Lessiri, Koffikro and Gnogboyo practiced fallow while only 14 % of Koziayo practiced fallow.

The number of manual weeding did not vary within site except in Tiéningboué where farmers in Bagao and Menemetou weeded 04 times per year their yam fields while farmers in Tiéfindougou weeded 02 times their yam fields. In general, Midebdo presented higher number of weeding (2.9 ± 0.7) compared to Liliyo that presented lower number of weeding (2.2 ± 1.0).

The number of associated crops only varied within site in Leo and Liliyo (table I). In Leo, Nadion farmers associated 02 crops to yam while the other village used 03 crops (millet, maize and sweet potatoes) to yam. In Liliyo, Petit Bouaké farmers associated 06 crops (cassava, maize, pepper, eggplant, okra, tomato) to yam while Koziayo and Gnogboyo farmers associated 02 crops to yam.

Table I: Yam cropping practices in different zones of Burkina Faso and Côte d'Ivoire (averages and standard errors calculated from II to V)

Variables	Leo *(n=30)*	Midebdo *(n=29)*	Tiéningboué *(n=33)*	Liliyo *(n=38)*
Plantation density	5734.8 ± 152 b	5000.0 ± 142 b	6187.0 ± 277 b	10221.0 ± 268 a
Germination rate	90.4 ± 3.1 a	90.1 ± 2.9 a	82.7 ± 2.0 a	85.7 ± 1.7 ab
Seed weight	483.3 ± 0.3 a	248.3 ± 0.7 a	255.2 ± 1.4 a	187.7 ± 1.0 b
Number of weeding	2.7 ± 0.3 a	2.9 ± 0.7 a	2.6 ± 1.4 a	2.2 ± 1.0 b
Number of associated crops	2.0 ± 0.1 b	2.6 ± 0.3 a	3.0 ± 0.2 a	2.4 ± 0.3 b

Means ± standard error with same letter are not significantly different with Tukey test at confidence level of 95%. Means comparison was done between site. "*n*" means number of farmers interviewed per sites.

II.2. Yam yield variability

Figure 2 presents yam (*Dioscorea rotundata* Poir. and *Dioscorea alata* L.) yields variability within and between sites. In Leo (figure 2A), the highest *D. rotundata* yield was obtained in Hélé village (14.8 ± 2.7 t ha^{-1}) whereas Benaverou and Nadion villages showed the lowest *D. rotundata* yields (6.7 ± 1.4 t ha^{-1} and 7.1 ± 4.3 t ha^{-1}). In Midebdo (figure 2B), Kalambiro village recorded the highest *D. rotundata* yield (8.8 ± 2.3 t ha^{-1}) while Midebdo village recorded the lowest *D. rotundata* yields (2.9 ± 1.0 t ha^{-1}). No significant difference was observed between yam yields within Tiéningboué and Liliyo.

Yam yields also varied between the studied sites (figure 3). Leo presented higher average yield for *D. rotundata* (9.0 ± 5.1 t ha^{-1}) compared to Tiéningboué (4.2 ± 4.2 t ha^{-1}). No significant difference was observed for average yield for *D. alata* between Tiéningboué (7.0 ± 5.2 t ha^{-1}) and Liliyo (6.0 ± 2.6 t ha^{-1}).

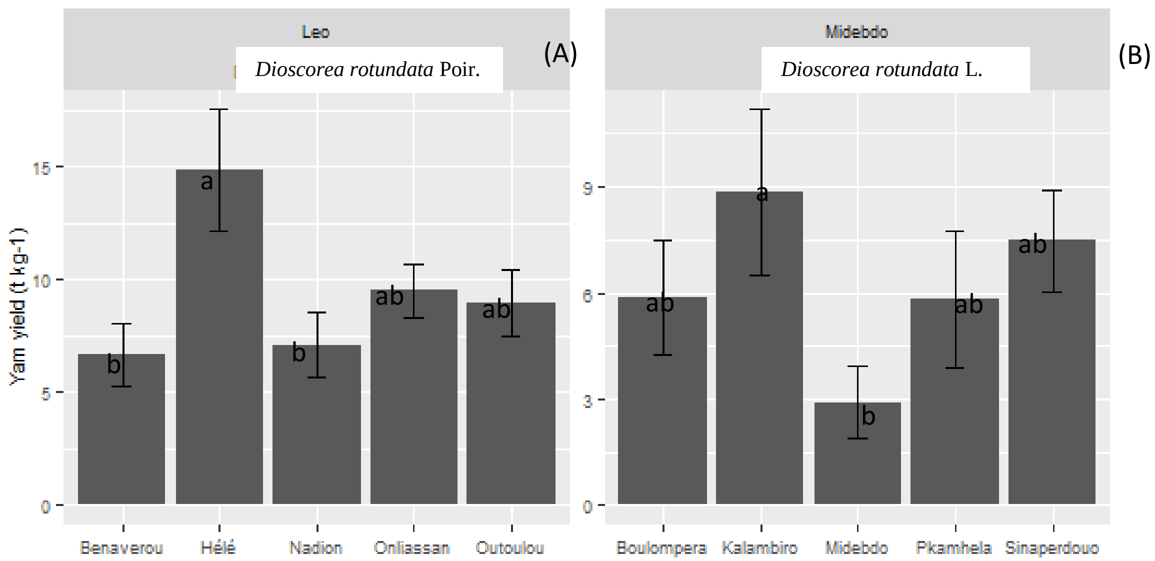


Figure 2: Yam variability within Leo site (A) and Midebdo site (B) in Burkina Faso

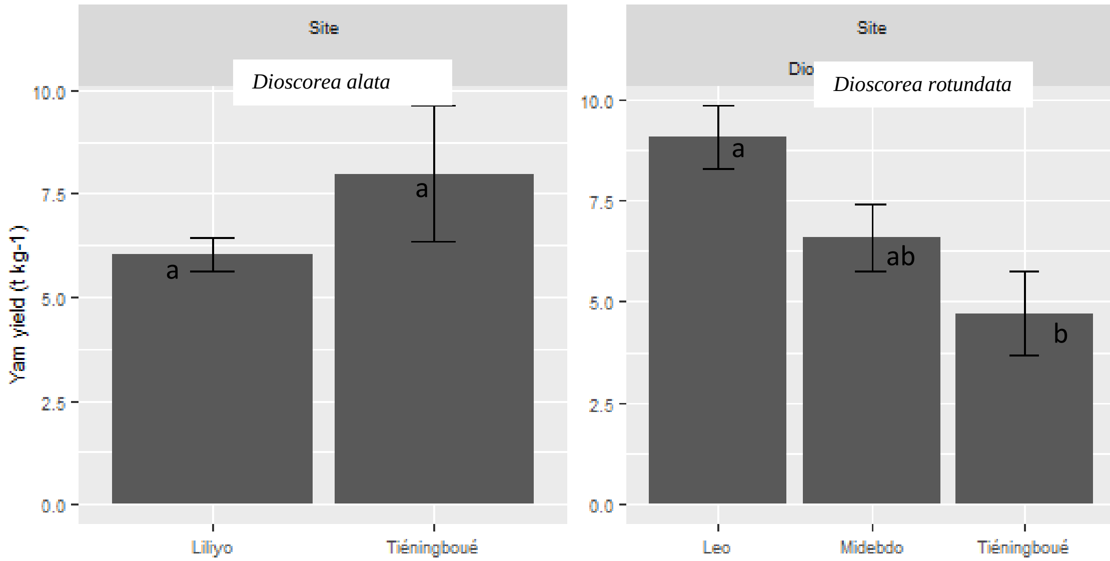


Figure 3: Yam variability between sites for *Dioscorea alata* Poir. (A) and *Dioscorea rotundata* L. (B) in Burkina Faso and Côte d'Ivoire.

II.3. Soil chemical characteristics of the four study sites

The soils at the four study sites were all acidic (table II). The lowest pH_{water} was observed in Leo and Liliyo soil (5.2 ± 0.1) while the highest pH was observed in Midebdo soil (6.4 ± 0.1). Leo soil presented the lowest CEC (2.5 ± 0.2 cmol kg^{-1}) and Tiéningboué soil presented the highest CEC (7.6 ± 0.7 cmol kg^{-1}). Total carbon content in Leo (4.7 ± 0.3 g kg^{-1}) and Midebdo (6.7 ± 0.7 g kg^{-1}) soils were lower but was higher in Tiéningboué soil (19.3 ± 1.4 g kg^{-1}). Soil C and N contents followed similar trend. Midebdo soil presented the lowest total P (0.2 ± 0.0 g kg^{-1}) and Tiéningboué soil presented the highest total and available P (0.6 ± 0.1 mg kg^{-1}, 15.8 ± 3.1 mg kg^{-1}). Leo (13.7 ± 1.6 g kg^{-1}) and Liliyo (14.0 ± 2.0 g kg^{-1}) soils presented the highest total K (13.7 ± 1.6 g kg^{-1}, 14.0 ± 2.0 g kg^{-1}) while Leo and Midebdo soils presented the highest K_{av} (51.6 ± 3.9 mg kg^{-1}, 56.9 ± 7.7 mg kg^{-1}). The highest Ca_{av} and Mg_{av} content were observed in Tiéningboué soil and the lowest was observed in Leo soil. Leo soils presented the lowest Cu_{av} (0.03 ± 0.01 mg kg^{-1}), Fe_{av} (8.31 ± 1.10 mg kg^{-1}) and Zn_{av} (0.15 ± 0.02 mg kg^{-1}) compared to Liliyo soils that presented the highest Cu_{av} (0.71 ± 0.08 mg kg^{-1}), Fe_{av} (41.95 ± 5.83 mg kg^{-1}) and Zn_{av} content (2.74 ± 0.30 mg kg^{-1}). In terms of soil texture, the silt content was highest in Midebdo soils presented higher silt content (417.42 ± 7.30 g kg^{-1}) compared to the other sites.

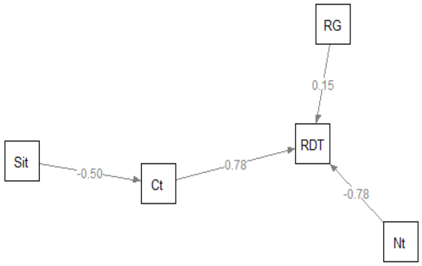
Table II: Soil chemical characteristics in yam farm in the four study sites

Variables	Leo *(n=30)*	Midebdo *(n=29)*	Tiéningboué *(n=33)*	Liliyo *(n=38)*
pH_{water}	5.2 ± 0.1 c	6.4 ± 0.1 a	5.9 ± 0.1 b	5.2 ± 0.1 c
CEC (cmol kg^{-1})	2.5 ± 0.2 c	4.0 ± 0.4 b	7.6 ± 0.7 a	4.5 ± 0.3 b
C (g kg^{-1})	4.7 ± 0.3 c	6.7 ± 0.7 c	19.3 ± 1.4 a	12.2 ± 1.0 b
N (g kg^{-1})	0.3 ± 0.0 c	0.4 ± 0.0 c	1.5 ± 0.1 a	1.0 ± 0.1 b
P_{tot} (g kg^{-1})	0.3 ± 0.0 b	0.2 ± 0.0 c	0.6 ± 0.1 a	0.3 ± 0.0 b
P_{av} (mg kg^{-1})	2.4 ± 0.5 b	2.1 ± 0.3 b	15.8 ± 3.1 a	3.2 ± 0.2 b
K_{tot} (g kg^{-1})	13.7 ± 1.6 a	4.9 ± 1.0 c	7.0 ± 0.7 b	14.0 ± 2.0 a
K_{av} (mg kg^{-1})	51.6 ± 3.9 a	56.9 ± 7.7 a	13.9 ± 1.5 b	7.2 ± 0.5 b
Ca_{av} (mg kg^{-1})	380.5 ± 38.7 c	610.7 ± 62.0 b	1225.1 ± 123.4 a	704.7 ± 57.6 b
Mg_{av} (mg kg^{-1})	50.5 ± 4.9 c	89.2 ± 12.8 bc	182.2 ± 16.7 a	114.4 ± 9.3 b

Means ± standard error with same letter are not significantly different with Tukey test at confidence level of 95 %. Means comparison was done between site. "av" means available et "tot" means total. "*n*" means number of soil samples per sites.

II.4. Determinants of yam yields

Determinant of yam yields variability varied between sites. In Leo (figure 4), yam yields were significantly determined mostly by Ct (0.78) and Nt (-0.78) followed by silt (-0.39) and germination rate (0.15). In Midebdo yam yields were significantly determined by total Ca (0.43) and available Fe (0.42). In Tieningboué, yam yields were significantly determined by density of plantation (0.77) for *Dioscorea rotundata* Poir. while for *Dioscorea alata* L. it was available Fe (0.79). In Liliyo (figure 5), yam yields were significantly determined by available Zn (-0.52), available Cu (0.45) and density of plantation (0.39). In the four studied sites, density of plantation (0.89) and pH_{water} (0.32) significantly determined yam yield variability (figure SM 2) for *D. alata* while for *D. rotundata*, yields were negatively affected by total P (-0.53), total Si (-0.41) and total Al (-0.37). Available Fe (0.25) affected positively and directly *D. rotundata* yields meanwhile total C (0.16) and total Ca (0.04) mostly affected the yields through available Fe and total P.



(A) (B)

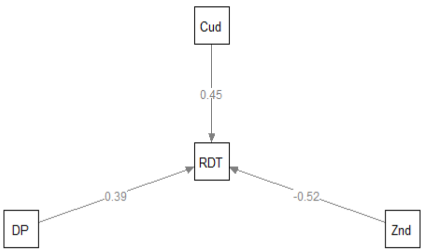


Figure 4: Yam yield determinants (A) in Leo and (B) in Liliyo (RDT = yam yield, Nt = total N, Ct = total C, Sit = silt, RG= germination rate, DP = Density of plantation, Znd = available Zn, Cud = available Cu)

II.5. Discussion

Yam cropping practices varied within and between sites. The variation within site may be explained by traditional custom in the different villages, ethnic group of farmers or different training programs received by the farmers.

Leo farmers used largest yam seeds for planting than Liliyo farmers. This may be due to yam seeds price and availability that were the main constraints for yam cropping in Liliyo (focus group). Similarly, Liliyo recorded higher plants density contrary to Midebdo and that could be explained by the scarcity of lands for annual cropping, 92 % of Liliyo site were occupied by perennial croplands (Ilboudo *et al*, 2022).

Only Leo’s farmers practiced mineral fertilization while Midebdo farmers practiced fallow. Soil low fertility may explain fertilizers use in Leo and availability of arable land (73%) in Midebdo may also explain fallow practices in this studied site. This result indicates that yam cropping system in Midebdo is still traditional based on fallow and slash-and-burn shifting cultivation as described by Doumbia (1998).

Farmers associated 02 to 04 crops in yam cropping in all studied sites. This result is similar to Kouakou *et al.* (2019) that found that yam was associated with cassava, maize and vegetable crops in Côte d'Ivoire.

Yam yields varied significantly within site in Leo and Midebdo. This fact may be explained by the diversity of yam cropping practices. According to Cornet (2015) and Adifon *et al.* (2020), yam cropping practices greatly affect its yields.

Yam yields in the studied sites varied between sites. *D. rotundata* yields were higher in Leo while lower in Tiéningboué. This may be due to the difference in yam seed sizes and fertilizers used in both sites. This result is comparable to those Iseki and Matsumoto (2020) that found that the use of larger yam seed lead to higher yields due to larger shoot growth rates during the early growth period.

Our results showed that some soil chemical characteristics varied between our studied sites while others soil characteristics are similar. Soils of the studied sites were acidic but soil total carbon and CEC value was higher in Tiéningboué compared to Leo. These results are similar to Saiz *et al.* (2012) that also found acidic soils in open savannah grassland and woodland in Burkina Faso. Soil total carbon was lower in Liliyo compared to Tiéningboué could be explained by higher temperature and soil labour that contribute to organic matter decomposition (Conant *et al.*, 2011). Higher available K in Leo and Midebdo maybe to the presence of kaolinite which is the dominant clay mineral in Burkina Faso (Bationo, 2006).

Yam yield determinants varied between sites. Yields in Leo were mostly determined by total carbon. The importance of organic matter in soil CEC may explained this fact (Kassi *et al.*, 2017). In Midebdo, yields were determined positively by total Ca, available Fe and negatively by total P. This result may indicate that increasing P availability will increase yam yields in Midebdo. Ca, in addition to its nutrient role, is a cation that contribute in soil nutrient retention / availability by its presence in the clay-humus complex (Hamdani, 2020).

D. rotundata yields in Tiéningboué were determined by density of plantation while for *D. alata*, Fe determined yam yields. This difference may be explained by the fact that *D. alata* is more sensible to soil fertility compared to *D. rotundata* according to Diby (2010) findings in the center of Côte d'Ivoire. In Liliyo, yam yields were affected by Zn, Cu and density of plantation. Zn and Cu are oligo-elements that are important in plant nutrition. Cornet (2015) also found that plant density played a major role in yam yields variability.

Our results for all sites showed that *D. alata* yields were mostly determined by soil pH_{water} and density of plantation while *D. rotundata* yields were determined by total P, total Al and total Si. These results are different from those of Ike and Inoni (2006) that found that labour and material inputs were the major factors that influence changes in yam output in Nigeria. This difference may be explained by farmer-specific variables, such as education, farming experience and access to credit that affected inefficiency among yam producers (Ike and Inoni, 2006).

Conclusion

Yam farmers were investigated in Leo and Midebdo in Burkina Faso and in Tiéningboué and Liliyo in Côte d'Ivoire. Our results showed some practices were similar for all studied sites while other practices varied between sites. Yam yields also varied within sites especially in Leo and Midebdo. For all sites, Leo registered higher yields whereas Tiéningboué registered lower yields. Determinants of yam yield varied between sites and between yam species. In the four studied sites, density of plantation and pH_{water} significantly determined yam yield variability for *Dioscorea alata* L. while for *Doscorea rotundata* Poir., yields were affected by total P, total Si, total Al and available Fe. These results indicate that improving these determinants especially planting density, soil pH could increase yam yields in Burkina Faso and Côte d'Ivoire.

Funding

This work was funded by the Swiss Program for Research on Global Issues for Development (SNF/SDC) through the YAMSYS project (SNF project number: 400540_152017 / 1). We also beneficiated a scholarship from swiss federal commission.

Acknowledgments

We thank the YAMSYS team and collaborators, the LDSF team at ICRAF Côte d'Ivoire, the plant nutrition group at ETHZ and the agro-ecosystem group at ETHZ and The group of soil chemistry at ETHZ where you did the XRF analysis. We are also grateful to all farmers and authorities at Liliyo, Tiéningboué, Midebdo and Leo.

Authors' contributions

T. L. Jeanne Ilboudo collected field data, did the laboratory analysis and wrote this paper. Bismark Hassan NACRO, Emmanuel FOSSARD, Johan SIX, Lucien DIBY and D. Innocent KIBA supervised field data collection, laboratory analysis and contributed in this paper writing.

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