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Effect of Integrated Soil Fertility Management on Disease Severity and Cassava Quality in Southern Côte d'Ivoire

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Abstract: ***Cassava production in southern Côte d'Ivoire is constrained by the lack of sustainable farming technologies, such as scarcity of drought and disease resistant cassava varieties, fertilizer and pesticides inputs. This study aims to evaluate the effects of integrated soil fertility management (ISFM) systems on severity of cassava mosaic and anthracnose diseases and on cassava quality parameters (dry matter, starch and hydrogen cyanide contents). To this end, field experiments were carried out at two locations (Dabou and Bingerville) during the 2012-2013 cropping season, as a split-split-plot design with three factors in three replications: cassava genotype (improved varieties Yavo, Bocou 1 and local variety Yace), cassava spacing (2 x 0.5 m and 1 x 1 m), and nutrient management (manure at 5 t ha-1 or mineral NPK fertilizer at 50 kg ha^{-1}, and legume intercropping with cowpea or groundnut). Overall, nutrient management did not affect the severity of both cassava diseases. Cassava mosaic disease (CMD) was less prominent for improved varieties Yavo and Bocou 1 (average scores of 1.1 and 1.2, respectively), compared to the local variety Yace which scored 2.8 on a 1-5 scale. In general, the ISFM treatments did not significantly affect cassava tuber quality. HCN content of tubers was decreased when more K was added through manure recommended dose application. Dry matter content was ca. 10% lower in Bingerville (lower fertility site) for both varieties Yace and Bocou 1 in treatment with cowpea and without fertilizer addition. The ISFM system that provided resilience to CMD and sustained quality cassava production appears as a suitable strategy for achieving sustainable intensification of cassava cultivation. Adoption of this technology depends on the ability of smallholder farmers to own or purchase nutrients resources and improved cassava genotypes.***

Keywords: Diseases control, Integrated Soil Fertility Management, *Manihot esculenta*, Productivity, Tuber quality

1. Introduction

Cassava (*Manihot esculenta* Crantz) is one of the major food crops widely grown in tropical and sub-tropical countries primarily for its tuberous roots, used for human consumption and animal feeds [1]. As in many parts of Africa also the cassava leaves are widely consumed in Côte d'Ivoire [2]. Beyond this traditional role of cassava for large scale food insecurity alleviation, it has become an income generating crop, increasingly used as raw material for food, bio-fuel, starch and adhesive materials industries [3].

Despite this critical importance of cassava for human wellbeing, its cultivation is afflicted with many constraints as a result of application of weak technologies, poor adapted varieties and the use of marginal to depleted soils. Cassava production is affected by various pests and diseases [4], which, in addition to soil nutrients depletion, result in large yield gaps. The major disease threats of cassava in Africa include cassava mosaic disease (CMD) transmitted by a whitefly (*Bemisia tabaci*) and cassava anthracnose disease (CAD) caused by *Colletotrichum gloeosporioides* [5]. CMD is estimated to lead to a production loss of 25-50% in Africa. Yield reduction due to cassava mosaic virus could reach 50 to 75%, especially in regions where susceptible varieties are grown and inefficient agronomic practices are applied [6].

Attempts to control cassava diseases in many tropical agro-ecological zones have been much focused on the introduction of more tolerant varieties and the application of crop protection products [7]. Unfortunately, in southern Côte d'Ivoire, smallholder farmers have no access to resistant/tolerant cassava varieties [8], and without application of fertilizer and crop protection products due to unaffordable cost and availability. Furthermore, the application of fertilizer in subsistence farming is further hampered by the elusive perception of farmers that fertilizer can deteriorate the quality of products. Therefore, biological control methods by using tolerant varieties in combination with good agronomic practices would be necessary to obtain resilience to pests and diseases for achieving sustainable intensification of cassava production [7]. In line with the above, Integrated Soil Fertility Management (ISFM) approach that combines: 1) use of improved varieties, 2) modest mineral fertilizer rates, 3) organic matter management and 4) adaptation to local conditions, could offer such options [9]-[10]. However, the extent to which full ISFM systems affect cassava disease severity and tuber quality has not received much attention.

We hypothesized that the integration of ISFM components can mitigate cassava (mosaic and anthracnose) diseases intensity and improve the tuber quality (dry matter, starch, hydrogen cyanides contents) in poor soils.

2. Material and Methods

2.1 Material

The improved cassava genotypes Yavo and Bocou 1 and the widespread local variety Yace were selected for the experiments. Cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogea*) were selected as legume intercrops. Composted chicken manure and mineral fertilizer NPK (15-15-15) were used as inputs for cassava due to their availability in the area. The nutrient content of the manure was 14.9 g N kg-1, 5.6 gP kg-1 and 4.3 g K kg-1 (dry matter). Two experiments were set up on-farm, at Dabou (05°21' N; 04°21' W; 39 m asl) and Bingerville (05°18' N; 03°49' W; 20 m asl) in southern Côte d'Ivoire. Both sites are the two largest cassava-growing and -consuming areas of Côte d'Ivoire. This area has inherently low soil fertility and bimodal rainfall patterns, with two rainy periods corresponding to the cassava cropping season. Soils are acidic, sandy Ferralsol (USS Working Group WRB, 2014) low in organic matter and CEC (cation exchange capacity).

2.2 Methods

2.1 Experimental set up

The experiment was set up in each location. The technical components included: 1) cassava genotypes (improved varieties Yavo and Bocou 1, vs. a local variety Yace), 2) legume intercropping using cowpea and groundnut, 3) cassava spacing (1 x 1 m – traditional practice, vs. 2 x 0.5 m – modified spacing), and 4) moderate application rates of chicken manure (5 t ha^{-1}) and mineral fertilizer (50 kg NPK 15-15-15 ha^{-1}). Varieties Bocou 1 and Yavo are currently released to farmers in Côte d'Ivoire and were selected for their high production potential sustained by their drought and cassava mosaic disease resistant trait. The experiment was carried out as a split-split-plot design and three randomized blocks were used as repetitions. Blocks were composed of three sub-blocks. Each sub-block contained one cassava variety grown at both spacings and included eight treatments (hereafter referred to as T0 – T7). The treatments were: T0: control (no inputs), T1: chicken manure applied at recommended dose (10 t ha^{-1}) hereafter referred to as 'reference dose', T2: cowpea intercrop, T3: groundnut intercrop, T4: cowpea intercrop + NPK (50 kg ha^{-1}), T5: groundnut intercrop + NPK (50 kg ha^{-1}),T6: cowpea intercrop + half manure reference dose (5 t ha^{-1}), T7: groundnut intercrop + half manure reference dose (5 t ha^{-1}).

2.2 Data Collection

a) Assessment of diseases symptoms

The individual plots were inspected for disease symptoms at 6 months after planting (MAP), and the disease scores were recorded for each cassava stand, by rating plants on a 1 to 5 scale, as described by Hahn *et al.* [11]. For cassava mosaic disease (CMD) these ratings were: 1 = no symptoms, apparently healthy plant, 2 = light mosaic, slight chlorotic aspect of the leaves, slight deformation, 3 = medium mosaic, shrinkage and deformation of the lower third of the leaf, 4 = strong mosaic, shrinkage and deformation of the lower half of the leaf, stunting of the plant, 5 = severe mosaic, deformation of the leaf on at least four fifth, pronounced stunting of the plant. For cassava anthracnose disease (CAD) these ratings were: 1 = no symptoms, apparently healthy plant, 2 = few superficial cankers on stems, leaf yellowing and defoliation, 3 = many deep cankers on stems, leaf yellowing and defoliation, 4 = deep canker lesions, leaf yellowing, stems deformation, 5 = severe anthracnose, severe canker lesions, defoliation, and necrosis of plant tip. The total of 35 and 36 cassava plants for S1 and S2, respectively, was inspected for symptoms of both diseases, and the scores were recorded for the individual plots. The average cassava disease scores of the individual plots were used to compare the effect of treatments and effect of the cassava varieties.

b) Tuber quality analysis

The most important traits of cassava tubers quality for consumption and processing include dry matter, starch and hydrogen cyanides contents. Therefore, cassava was harvested 9 months after planting in accordance with the local practices, and abovementioned quality parameters were determined on composite samples for the individual plots.

Dry matter was determined via the AOAC method [13] (AOAC, 1990). The starch was extracted from cassava fresh tuberous roots following method described by Delpeuch *et al.* [14]. The hydrogen cyanide (HCN) content of cassava tuber was determined by the alkaline titration method [15].

2.3 Statistical analysis

A general linear model (GLM) was used to analyze disease and quality data with SPSS (Statistical Package for Social Science, version 21) software. The effect of factors was assessed at $P < 0.05$ and for significant effects, post-hoc analyses were performed using Tukey's test.

3. Results

3.1 Treatment effects on disease severity

3.1.1 Mosaic disease severity

The disease scores of cassava mosaic disease (CMD) for the different ISFM treatments are shown in Table 1. There were no significant differences ($P > .05$) for treatments and spacing on the severity of CMD for the individual cassava varieties at both locations. No statistically significant ($P >$ .05) interaction effects were found for both locations. However, cassava variety had a highly significant ($P < .01$) effect on CMD disease severity for both spacings at both locations. In Dabou, the average disease score of CMD for both spacings ranged from 1.1 to 1.6, 1.0 to 1.1 and 2.5 to 3.1 for the improved cassava varieties Bocou 1, Yavo and the local variety Yace, respectively. In Bingerville, the average disease score of CMD ranged from 1.1 to 1.3, 1.0 to 1.2 and 2.5 to 2.8, respectively, depending on treatments.

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3.1.2 Anthracnose disease severity

The disease scores of cassava anthracnose disease (CAD) for the ISFM treatments are shown in Table 2. There were no significant differences ($P > .05$) for treatment, spacing and cassava variety on severity of CAD at both locations. No statistically significant ($P > .05$) effects of interactions were found for both locations. The disease scores of CAD ranged from 1.6 to 2.0 for the different cassava varieties for both spacings in Dabou and Bingerville, depending on treatments.

3.2 Treatment effects on tuber yields

There was no significant ($P > .05$) effect of cassava spacing on tuber yields for both sites. Highly significant differences in fresh tuber yield were observed between treatments for the individual cassava varieties at both locations ($P < .001$). There were also significant differences in tuber yields between the three cassava varieties at both locations. The improved variety Yavo performed better than Bocou 1 and Yacé in nearly all treatments, but gave similar yields to the other varieties for the treatments including cowpea with or without fertilizer amendments. The local variety Yace gave similar or higher yields compared to the improved variety Bocou 1 depending on treatments. Cassava tuber yield was increased for groundnut plus manure or mineral NPK fertilizer in Dabou and Bingerville, respectively.

Table 1: Disease scores of cassava mosaic disease (CMD) for ISFM treatments and three cassava varieties in Dabou and Bingerville

ISFM Treatments	Higher fertility site: Dabou			Lower fertility site: Bingerville		
	Yace Local	Bocou 1 Improved	Yavo Improved	Yace Local	Bocou 1 Improved	Yavo Improved
Spacing (1 m x 1 m)	1.7 (0.5)a	1.8 (0.4)a	2.0 (0.0)a	1.9 (0.2)a	2.0 (0.0)a	2.0 (0.0)a
Groundnut	1.9 (0.1)a	1.7 (0.4)a	2.0 (0.0)a	1.9 (0.1)a	2.0 (0.0)a	2.0 (0.0)a
Groundnut + low NPK	1.7 (0.5)a	1.8 (0.3)a	2.0 (0.0)a	1.9 (0.1)a	1.7 (0.6)a	2.0 (0.0)a
Groundnut + half manure	1.7 (0.5)a	1.7 (0.4)a	2.0 (0.0)a	1.8 (0.3)a	1.7 (0.6)a	2.0 (0.1)a
Cowpea	1.7 (0.5)a	1.6 (0.4)a	1.9 (0.1)a	2.0 (0.0)a	2.0 (0.0)a	2.0 (0.0)a
Cowpea + low NPK	1.7 (0.6)a	1.6 (0.5)a	2.0 (0.0)a	1.8 (0.3)a	2.0 (0.0)a	2.0 (0.0)a
Cowpea + half manure	1.7 (0.4)a	1.8 (0.2)a	2.0 (0.0)a	1.9 (0.2)a	2.0 (0.0)a	2.0 (0.3)a
Manure reference dose	1.7 (0.4)a	1.9 (0.2)a	2.0 (0.0)a	2.0 (0.0)a	1.7 (0.5)a	2.0 (0.0)a
Control	1.7 (0.4)A	1.7 (0.3)A	2.0 (0.0)A	1.9 (0.2)A	1.9 (0.3)A	2.0 (0.0)A
Mean						
Significance levels	0.99	0.97	0.40	0.86	0.66	0.54
CV*	5.0	6.0	1.4	4.0	8.7	3.5
Spacing (2 m x 0.5 m)						
Groundnut	1.7 (0.4)a	1.6 (0.4)a	2.0 (0.0)a	1.8 (0.4)a	2.0 (0.0)a	2.0 (0.0)a
Groundnut + low NPK	1.8 (0.3)a	1.7 (0.4)a	2.0 (0.0)a	2.0 (0.0)a	2.0 (0.0)a	2.0 (0.0)a
Groundnut + half manure	1.8 (0.5)a	1.8 (0.2)a	2.0 (0.0)a	1.8 (0.3)a	1.8 (0.3)a	1.9 (0.2)a
Cowpea	1.7 (0.6)a	1.6 (0.5)a	2.0 (0.0)a	1.8 (0.3)a	1.8 (0.4)a	2.0 (0.0)a
Cowpea + low NPK	1.7 (0.5)a	1.7 (0.3)a	2.0 (0.1)a	1.9 (0.2)a	2.0 (0.0)a	2.0 (0.0)a
Cowpea + half manure	1.7 (0.6)a	1.9 (0.3)a	2.0 (0.0)a	1.9 (0.1)a	1.8 (0.3)a	1.9 (0.2)a
Manure reference dose	1.8 (0.4)a	1.9 (0.1)a	2.0 (0.0)a	1.9 (0.1)a	2.1 (0.1)a	2.0 (0.0)a
Control	1.7 (0.5)a	1.9 (0.1)a	2.0 (0.0)a	1.9 (0.1)a	1.8 (0.3)a	2.0 (0.0)a
Mean	1.8 (0.4)A	1.8 (0.3)A	2.0 (0.0)A	1.9 (0.2)A	1.9 (0.2)A	1.9 (0.1)A
Significance levels	1.00	0.83	0.63	0.97	0.67	0.69
CV*	2.8	7.3	0.6	3.5	5.8	2.8

Different small letters per column indicate significant difference for treatments; different capital letters for means indicate significant difference for varieties at $P < .05$; values between brackets are standard deviations; *CV = coefficient of variation

Legumes without fertilizer addition did not give higher cassava tuber yields or even reduced yields for all cassava varieties in both locations compared to the control (no inputs) treatment (Table 3).

3.3 Treatment effects on tuber quality

3.3.1- Dry matter content

The dry matter contents of cassava tuber for the different ISFM treatments are shown in Table 4. There were no significant differences in average dry matter contents ($P > .05$) between cassava varieties or crop spacing at both locations. There were no significant ($P > .05$) differences for treatment for variety Yavo at both locations. Significant differences for treatment were observed for varieties Bocou 1 and Yace in Bingerville, where the dry matter content of tuber decreased when cowpea was intercropped without fertilizer addition. However, cowpea with fertilizer addition to cassava did not affect tuber dry matter content for the same cassava varieties. The average dry matter contents of tuber for the different cassava varieties ranged from 39 to 43% in Dabou and Bingerville, depending on cassava varieties.

3.3.2 Starch content

There were no significant differences ($P > .05$) between cassava varieties or crop spacings in starch contents of tuber at both locations. There were no significant differences ($P > .05$) for treatment for the different cassava varieties at both locations. The average starch contents of tuber for the different cassava varieties ranged from 20.6 to 26.7% in Dabou and Bingerville, depending on cassava varieties (Table 5).

3.3.3 Hydrogen cyanide content

There were no significant ($P > .05$) differences in cyanide contents between cassava varieties or spacings at both locations (Table 6). There were no significant differences ($P < .05$) for treatment for cassava variety Yavo at both locations. In Dabou, significant differences ($P < .05$) were observed for varieties Yace and Bocou 1, especially for spacing S2. The cyanides content was decreased for manure reference dose for variety Bocou 1 and Yace, e.i. 5.0 and 4.0 mg kg^{-1}, respectively. The other ISFM treatments did not affect tuber cyanide contents which ranged from 6.0 to 8.0 mg kg^{-1}. In Bingerville, significant ($P < .05$) differences for treatment were observed for variety Bocou 1 for both spacings. For variety Bocou 1, the hydrogen cyanide content of tuber was decreased for manure reference dose, i.e. 4.0 mg kg^{-1} for both spacings. The cyanide contents of the other ISFM treatments ranged from 6.0 to 9.0 mg kg^{-1} and 5.0 to 8.0 mg kg^{-1} for spacing S1 and S2, respectively, for the same cassava variety. On average, the hydrogen cyanide contents ranged from 5.0 to 7.0 mg kg^{-1} for both locations, depending on cassava varieties.

Table 2: Disease scores of cassava anthracnose disease (CAD) for ISFM treatments and three cassava varieties in Dabou and Bingerville

ISFM Treatments	Higher fertility site: Dabou			Lower fertility site: Bingerville		
	Yace Local	Bocou 1 Improved	Yavo Improved	Yace Local	Bocou 1 Improved	Yavo Improved
Spacing (1 m x 1 m)						
Groundnut	2.7 (0.7)a	1.1 (0.0)a	1.1 (0.0)a	1.9 (1.1)a	1.1 (0.0)a	1.1 (0.0)a
Groundnut + low NPK	2.6 (0.7)a	1.2 (0.0)a	1.1 (0.1)a	1.5 (0.5)a	1.2 (0.3)a	1.1 (0.1)a
Groundnut + half manure	2.7 (0.7)a	1.4 (0.4)a	1.1 (0.0)a	2.0 (0.8)a	1.1 (0.2)a	1.1 (0.0)a
Cowpea	3.1 (0.4)a	1.3 (0.2)a	1.1 (0.0)a	2.0 (0.8)a	1.1 (0.1)a	1.1 (0.0)a
Cowpea + low NPK	3.1 (0.8)a	1.5 (0.5)a	1.1 (0.1)a	1.8 (0.6)a	1.0 (0.0)a	1.1 (0.1)a
Cowpea + half manure	2.9 (0.9)a	1.2 (0.1)a	1.1 (0.1)a	1.5 (0.7)a	1.3 (0.5)a	1.1 (0.1)a
Manure reference dose	2.5 (0.4)a	1.2 (0.0)a	1.1 (0.1)a	2.5 (0.8)a	1.0 (0.0)a	1.1 (0.1)a
Control	2.7 (0.4)a	1.3 (0.1)a	1.2 (0.3)a	1.5 (0.3)a	1.0 (0.0)a	1.2 (0.3)a
Mean	2.8 (0.6)A	1.2 (0.2)B	1.1 (0.1)B	1.9 (0.7)A	1.2 (0.2)B	1.1 (0.0)B
Significance levels	0.92	0.62	0.93	0.66	0.72	0.46
CV*	8.0	10.0	4.2	19.1	9.1	0.7
Spacing (2 m x 0.5 m)						
Groundnut	2.7 (0.6)a	1.3 (0.2)a	1.0 (0.1)a	1.8 (0.5)a	1.0 (0.1)a	1.3 (0.6)a
Groundnut + low NPK	2.9 (0.1)a	1.5 (0.4)a	1.1 (0.0)a	1.6 (0.2)a	1.0 (0.0)a	1.0 (0.0)a
Groundnut + half manure	2.7 (0.3)a	1.6 (0.5)a	1.1 (0.1)a	2.2 (0.6)a	1.0 (0.0)a	1.0 (0.0)a
Cowpea	3.1 (0.4)a	1.3 (0.3)a	1.0 (0.1)a	2.0 (0.7)a	1.0 (0.0)a	1.0 (0.0)a
Cowpea + low NPK	2.7 (0.5)a	1.2 (0.2)a	1.1 (0.2)a	1.9 (0.6)a	1.0 (0.1)a	1.0 (0.0)a
Cowpea + half manure	2.7 (0.5)a	1.3 (0.3)a	1.1 (0.1)a	2.1 (0.8)a	1.0 (0.0)a	1.0 (0.0)a
Manure reference dose	2.7 (0.3)a	1.3 (0.2)a	1.2 (0.0)a	1.9 (0.6)a	1.0 (0.0)a	1.0 (0.0)a
Control	2.7 (0.1)a	1.3 (0.4)a	1.1 (0.1)a	2.1 (0.6)a	1.0 (0.0)a	1.0 (0.0)a
Mean	2.8 (0.3)A	1.3 (0.3)B	1.1 (0.1)B	2.0 (0.5)A	1.0 (0.0)B	1.0 (0.1)B
Significance levels	0.91	0.77	0.77	0.95	0.56	0.47
CV*	5.0	10.0	4.0	10.0	1.6	11.3

Different small letters per column indicate significant difference for treatments; Different capital letters for means indicate significant difference for varieties at $P < .05$; values between brackets are standard deviations; *CV = coefficient of variation

Table 3: Average fresh cassava root yields (t ha^{-1}) combined for spacing S1 and S2, three cassava varieties and various ISFM components for the sites in Dabou and Bingerville

ISFM Component	Cassava variety		
	Yace (Improved)	Bocou 1 (Improved)	Yavo (Improved)
Higher soil fertility site : Dabou			
Groundnut	4.9 (2.5) cd,B	6.0 (2.7) b,B	9.2 (4.7) c,A
Groundnut + low NPK	8.1 (4.1) bc,B	6.6 (4.3) b,B	10.9 (1.8) c,A
Groundnut + half manure	9.6 (6.2) b,B	5.9 (3.4) b,C	15.5 (3.4) b,A
Cowpea	3.7 (2.1) d,B	2.8 (1.1) c,B	7.0 (1.3) cd,A
Cowpea + low NPK	5.7 (2.1) cd,A	4.9 (2.0) c,A	6.4 (2.3) d,A
Cowpea + half manure	6.1 (3.6) cd,A	6.3 (2.8) b,A	7.9 (3.9) cd,A
Manure reference dose	15.0 (3.3) a,B	13.2 (3.3) a,B	18.3 (4.5) a,A
Control	9.4 (1.5) b,A	8.2 (3.0) b,A	9.7 (2.2) c,A
Significant level (*P*)	0.000	0.000	0.000
CV*	46.1	45.2	39.7
Lower soil fertility site : Bingerville			
Groundnut	10.3 (5.9) ab,A	6.6 (3.2) b,B	10.3 (1.9) c,A
Groundnut + low NPK	9.0 (3.4) ab,B	8.7 (4.5) b,B	17.1 (7.2) a,A
Groundnut + half manure	8.4 (4.0) ab,B	7.7 (2.7) b,B	13.5 (5.6) bc,A
Cowpea	5.4 (2.9) b,B	6.6 (2.8) b,B	11.3 (6.0) bc,A
Cowpea + low NPK	9.3 (4.4) ab,A	7.6 (3.4) b,A	10.9 (2.4) bc,A
Cowpea + half manure	9.3 (4.0) ab,B	8.5 (0.7) b,B	15.1 (5.1) b,A
Manure reference dose	13.1 (2.7) a,B	14.8 (4.9) a,B	19.0 (5.3) a,A
Control	9.2 (4.1) ab,B	7.3 (4.2) b,B	14.3 (4.5) bc,A

Significant level (p)	0.036	0.003	0.047
CV*	22.8	31.4	22.2

Different small letters per column indicate significant difference for treatments; different capital letters per row indicate significant difference for varieties at *P* < .05 and values between brackets are standard deviations; *CV = coefficient of variation.

Table 4: Tuber dry matter content (%) of the local and improved cassava varieties for ISFM treatments and two cassava spacings

ISFM Treatments	Higher fertility site: Dabou			Lower fertility site: Bingerville		
	Yace Local	Bocou 1 Improved	Yavo Improved	Yace Local	Bocou 1 Improved	Yavo Improved
Spacing (1 m x 1 m)						
Cowpea	40.6 (3.3)a	39.0 (5.5)a	39.2 (6.7)a	34.4 (4.7)b	40.0(5.3)a	40.1(3.5)a
Cowpea + low NPK	42.8 (3.0)a	37.0 (1.5)a	43.0 (1.2)a	40.3 (4.7)ab	42.7 (0.2)a	40.4(1.6)a
Cowpea + half manure	44.5 (4.0)a	37.7 (6.8)a	44.2 (1.6)a	42.3 (1.4)ab	41.2 (5.3)a	44.1(5.6)a
Manure reference dose	48.0 (2.2)a	47.1 (4.0)a	42.0 (3.9)a	45.3 (0.5)a	45.3 (3.5)a	44.4(1.6)a
Control	43.4 (3.1)a	36.0 (4.0)a	42.7 (3.7)a	43.7 (2.8)a	42.7 (1.4)a	43.3(0.7)a
Mean	44.0 (3.7)A	39.3 (5.7)B	42.1 (3.8)A	41.2 (4.8)A	42.4 (3.7)A	42.4(3.3)A
Significance levels	0.13	0.09	0.61	0.02	0.54	0.34
CV*	6.2	11.4	4.5	10.3	4.6	4.8
Spacing (2 m x 0.5 m)						
Cowpea	40.0 (5.0)a	40.0 (4.3)a	41.6 (0.3)a	38.8 (3.2)a	36.7 (2.8)b	40.2 (3.5)a
Cowpea + low NPK	40.6 (4.5)a	38.7 (2.7)a	42.3 (4.8)a	44.0 (3.0)a	44.0 (1.8)a	41.0 (3.1)a
Cowpea + half manure	43.5 (1.3)a	43.2 (2.3)a	40.0 (3.0)a	43.4 (3.0)a	42.7 (2.7)ab	39.4 (1.2)a
Manure reference dose	40.5 (9.8)a	45.3 (3.2)a	43.5 (2.0)a	46.2 (2.4)a	46.0 (4.0)a	43.3 (2.1)a
Control	41.3 (3.0)a	39.3 (1.4)a	43.3 (5.6)a	44.5 (2.5)a	44.8 (0.3)a	42.5 (2.4)a
Mean	41.1 (4.9)A	41.3 (3.6)A	42.1 (3.4)A	43.4 (3.5)A	42.8 (4.0)A	41.3 (2.6)A
Significance levels	0.93	0.09	0.76	0.07	0.01	0.39
CV*	3.4	7.0	3.4	6.4	8.5	4.0

Different small letters per column indicate significant difference for treatments; different capital letters for means indicate significant difference for varieties at *P* < .05; values between brackets are standard deviations; *CV = coefficient of variation.

Table 5: Tuber starch content (%) of the local and improved cassava varieties for ISFM treatments and two cassava spacings

ISFM Treatments	Higher fertility site: Dabou			Lower fertility site: Bingerville		
	Yace Local	Bocou 1 Improved	Yavo Improved	Yace Local	Bocou 1 Improved	Yavo Improved
Spacing (1 m x 1 m)						
Cowpea	20.0 (1.1)a	20.1 (4.0)a	23.3 (3.4)a	20.4 (5.2)a	25.7 (3.5)a	20.4 (5.6)a
Cowpea + low NPK	27.4 (5.2)a	20.7 (6.0)a	20.0 (5.8)a	24.6 (4.2)a	24.5 (3.7)a	24.1 (3.4)a
Cowpea + half manure	24.5 (3.6)a	21.3 (5.5)a	25.5 (5.5)a	27.5 (2.0)a	23.8 (4.8)a	24.0 (1.0)a
Manure reference dose	21.2 (9.8)a	19.8 (4.7)a	21.3 (3.7)a	23.4 (2.0)a	25.2 (3.0)a	25.0 (0.8)a
Control	24.2 (5.3)a	24.4 (5.1)a	20.6 (6.3)a	26.0 (3.1)a	26.0 (8.1)a	23.4 (3.5)a
Mean	23.4 (5.7)A	20.6 (5.0)A	22.1 (4.8)A	24.3 (4.0)A	25.0 (4.3)A	23.4 (3.3)A
Significance levels	0.57	0.52	0.66	0.21	0.98	0.54
CV*	12.6	13.1	10.2	11.1	3.6	7.6
Spacing (2 m x 0.5 m)						
Cowpea	27.3 (5.6)a	18.7 (1.6)a	21.0 (4.7)a	22.4 (2.2)a	24.1 (7.0)a	23.4 (2.8)a
Cowpea + low NPK	27.6 (3.8)a	25.7 (5.1)a	20.5 (3.2)a	24.1 (4.6)a	29.5 (9.8)a	27.0 (1.8)a
Cowpea + half manure	27.0 (3.2)a	26.8 (3.1)a	24.6 (2.4)a	34.0 (9.4)a	24.6 (1.8)a	24.6 (2.1)a
Manure reference dose	22.0 (5.6)a	21.1 (4.0)a	20.5 (0.2)a	26.0 (1.1)a	27.5 (7.0)a	35.0 (9.5)a
Control	28.1 (3.3)a	23.0 (2.4)a	23.8 (3.1)a	27.3 (1.4)a	24.0 (3.7)a	21.3 (2.0)a
Mean	26.4 (4.4)A	23.0 (4.2)A	22.1 (3.2)A	26.7 (6.8)A	26.0 (6.0)A	26.3 (7.0)A
Significance levels	0.47	0.08	0.35	0.31	0.78	0.12
CV*	9.4	14.4	9.0	16.4	9.5	20.2

Different small letters per column indicate significant difference for treatments; different capital letter for means indicate significant difference for varieties at *P* < .05; values between brackets are standard deviations; * CV = coefficient of variation

3.3.4 Disease effects on cassava yields

There were no significant (*P* > .05) correlations between the severity of cassava mosaic or anthracnose disease and fresh roots yields or quality parameters (dry matter, starch and cyanide contents) at both locations.

Table 6: Tuber HCN content (mg kg-1) of the local and improved cassava varieties for ISFM treatments and two cassava spacings

ISFM Treatments	Higher fertility site: Dabou			Lower fertility site: Bingerville		
	Yace Local	Bocou 1 Improved	Yavo Improved	Yace Local	Bocou 1 Improved	Yavo Improved
Spacing (1 m x 1 m)						
Cowpea	4.0 (3.0)a	8.0 (5.0)a	4.0 (1.0)a	6.0 (0.0)a	9.0 (2.0)a	8.0 (3.0)a
Cowpea + low NPK	6.0 (1.0)a	5.0 (1.0)a	4.0 (0.0)a	8.0 (3.0)a	6.0 (1.0)ab	4.0 (1.0)a

Cowpea + half manure	6.0 (1.0)a	5.0 (2.0)a	4.0 (1.0)a	6.0 (1.0)a	9.0 (2.0)a	6.0 (4.0)a
Manure reference dose	5.0 (2.0)a	6.0 (3.0)a	3.0 (1.0)a	5.0 (4.0)a	4.0 (1.0)b	5.0 (4.0)a
Control	5.0 (1.0)a	5.0 (1.0)a	4.0 (3.0)a	7.0 (2.0)a	8.0 (3.0)ab	5.0 (0.0)a
Mean	5.0 (2.0)A	6.0 (3.0)A	4.0 (1.0)A	7.0 (2.0)A	7.0 (2.0)A	6.0 (3.0)A
Significance levels	0.58	0.55	0.90	0.59	0.03	0.53
CV*	21.0	23.5	8.4	16.7	30.4	23.6
Spacing (2 m x 0.5 m)						
Cowpea	7.0 (1.0)ab	7.0 (2.0)ab	4.0 (2.0)a	7.0 (2.0)a	5.0 (1.0)ab	7.0 (3.0)a
Cowpea + low NPK	8.0 (0.0)a	6.0 (1.0)abc	5.0 (1.0)a	7.0 (1.0)a	5.0 (1.0)ab	5.0 (2.0)a
Cowpea + half manure	8.0 (1.0)a	8.0 (1.0)a	7.0 (2.0)a	8.0 (0.0)a	5.0 (1.0)ab	6.0 (4.0)a
Manure reference dose	5.0 (2.0)b	4.0 (1.0)c	4.0 (1.0)a	5.0 (1.0)a	4.0 (1.0)b	6.0 (3.0)a
Control	6.0 (1.0)ab	5.0 (1.0)bc	5.0 (1.0)a	6.0 (2.0)a	8.0 (2.0)a	5.0 (3.0)a
Mean	7.0 (2.0)A	6.0 (2.0)A	5.0 (3.0)A	7.0 (1.0)A	6.0 (2.0)A	6.0 (3.0)A
Significance levels	0.02	0.004	0.06	0.19	0.03	0.96
CV*	20.0	25.0	26.1	15.7	26.7	11.0

Different small letters per column indicate significant difference for treatments; different capital letters for means indicate significant difference for varieties at $P < .05$; values between brackets are standard deviations; * CV = coefficient of variation.

4. Discussion

4.1 Cassava diseases severity

While there is consensus about the effects of fertilizer amendment on crop yields (i.e. agronomic efficiency), there are contradicting reports in the literature on the effects on the severity of cassava diseases. Seruwagi *et al.* [15] did not observe significant effects of mineral fertilizer on severity of CMD in response to the application of 250 kg ha^{-1} NPK 46-19-60. However, Muengula-Manyi *et al.* [16] reported a significant increase of CMD severity for both improved and local cassava varieties following the application of mineral fertilizer 300 kg ha^{-1} NPK 17-17-17. Other findings have stressed a nutrient balance to control CMD [17]. Moreover, the control of cassava diseases, particularly CMD, has been focused on genotypic characteristics of the cassava rather than on nutrient management [18]. In this experiment, the improved cassava varieties showed less severe symptoms of CMD compared to the local variety. The difference between the cassava varieties clearly demonstrates the CMD tolerant traits of the improved varieties Bocou 1 and Yavo as opposed to the susceptibility of the local variety Yace. However, the effects of variety on severity of CAD were not significant, and both improved and local cassava varieties showed light severity of CAD at both locations. The low disease pressure for CMD as well as CAD observed for the different cassava varieties explain the non-significant effects on tuber yields and quality (dry matter, starch and cyanide contents). This indicates that disease incidence was not a severe problem for productivity of the cassava; hence the yield increases in ISFM treatments was an effect of legumes and manure or mineral fertilizer addition. Furthermore, varietal reaction to both cassava diseases did not differ significantly ($p > .05$) between the higher and lower fertility sites. This corroborates findings from Toualy *et al.* [5] from a survey carried out in the major cassava growing regions of Côte d'Ivoire, and who reported that the average disease score of CMD from 3.2 to 3.7 was independent of the agro-ecological zone. Significant and negative correlations between CMD incidence ($r=0.44$) or cassava bacterial blight (CBB) incidence ($r=0.45$) and cassava fresh root yields were observed by Fokunang and al. [18]. The low disease pressures for all the cassava varieties in the ISFM experiments can be related to the quality of the cuttings, which were taken from plants without apparent disease symptoms and to crop management. The composting of manure, land preparation by burning and timely weeding that potentially eliminate a great part of plant pathogens are among the reasons underlying this response of the cassava varieties. This indicates, for intensification, the necessity to integrate the agronomic control measures to address the problems of diseases and low yields that result [19].

4.2 Cassava tuber quality

In general, ISFM treatments did not significantly affect cassava tuber dry matter contents. However, dry matter content decreased for varieties Bocou 1 and Yace when the cowpea was intercropped without fertilizer addition to cassava plants for the lower soil fertility site in Bingerville. Dry matter decreased by ca. 10 % for varieties Yace and Bocou 1, compared to the control (no inputs). This reduction of dry matter could be related to nutrients competition between cassava and cowpea in the lower fertility soil. The difference in tuber dry matter content between cassava varieties in treatment with cowpea and without fertilizer addition can be related to genotypic characteristics. The genotypic characteristics explain potential differences in synthesis and translocation of carbohydrates. Moreover, the genotypic differences can be related to nutrient use efficiency under low soil fertility, particularly K which is required for building up the storage roots.

There were no significant differences ($P > .05$) between cassava varieties as well as treatments with respect to effects on tuber starch contents. Furthermore, no significant correlations of cassava disease incidence and tuber starch content were observed for the different cassava varieties at both locations. The no significant effect of treatments on root starch contents can be related to poor soil fertility and pre-mature harvest. The non-significant effect of cassava variety that was observed indicates that treatments that improve root yield in the poor soil conditions result also in starch yield increases. This indicates that cassava root yield increment for ISFM treatment that resulted in starch yield increases was not affected by disease effects. Hence variety Yavo combined with groundnut intercropping and manure or mineral fertilizer addition can be advocated as suitable agronomic technology for starch production.

The cyanogenic glycosides are toxic compounds, the biosynthesis of which occurs naturally in plants and mainly in response to environmental stresses. The cyanogenic glycosides content of cassava has been reported to be affected by growing conditions and genetic characteristics of cultivars [20] - [21]. In this experiment, the application of the manure reference dose decreased the hydrogen cyanides (HCN) contents by 17 and 40% for varieties Yace and Bocou 1, respectively, in Dabou; and by 50% for Bocou 1 in Bingerville. The effects of treatment on tuber HCN content were not significant ($p > .05$) for variety Yavo despite a slight decrease observed with the manure reference dose application. This result is in line with Nur Faezah *et al.* [22] who reported for similar soil conditions (Sandy loam soil, pH 5.7) decreases in cyanides glycosides content of cassava from 5.1 to 4.0 mg kg^{-1}, with application of equivalent (180 kg K2O ha^{-1}) via organic manure. Cyanogenic glycosides of plants were shown to increase under sub-optimal growth conditions [23]. However, soils in the study area are inherently poor and acid, low in K content ($P < .05$ cmol kg-1), which is involved in synthesis and translocation of carbohydrates [24]. The genotypic differences of cassava varieties can be related to nutrient use efficiency under low soil fertility, particularly K which is required for building up the storage roots. The amount of potassium added with the recommended manure dose was 43 kg K ha^{-1}, which likely improved cassava nutrition and carbohydrates synthesis, and resulted in reduction of HCN production.

4.3 Suitability of the ISFM

The modest application rates of (manure or mineral) fertilizer in combination with legumes intercropping had no significant effects on the severity of both cassava diseases; whereas the advanced cassava varieties reduced the pressure of CMD significantly. Further, implementation of ISFM showed potential for increasing cassava yields. The implementation of ISFM did not affect cassava tuber quality (dry matter, starch and hydrogen cyanide contents), which was improved when more K was added via the manure reference dose in a sense that the HCN content decreased. This indicates the needs for increasing the application rate of K with the ISFM technology in order to improve the quality of the cassava; given that low HCN content is a desirable characteristic for cooking or processing of the cassava. The application rate of K can be increased by using available crop residues with high K content from fertilized oil-palm plantation and organic wastes from agro-industries.
The preservation of cassava tuber quality clearly contradicts the perception of farmers, recorded via group discussions from a technological innovation plate-form consisted of cassava producers, processors and local extension, and which associate fertilizer application to a deterioration of cassava tuber quality. The prospective cause underlying this elusive perception could be the lack of knowledge on appropriate use of fertilizer. This indicates a need to emphasize the implication of local extension for strengthening farmers' knowledge and capacity building on sustainable agricultural practices. Moreover, the adoption of the ISFM system could be hampered by availability of improved cassava germplasms and nutrient resources. Therefore, the effectiveness of the ISFM system depends on farmers' ability to own or purchase not only the nutrients, but the improved cassava genotypes. This stresses the prominent role of the research institutes and extension for releasing more (drought and disease) resistant or/and productive cassava genotypes to farmers in order to address the low productivity and limit the seasonal shortages of the cassava.

5. Conclusion

In summary, the implementation of ISFM system showed a potential to increase cassava yields and control the Cassava Mosaic Disease through the use of improved varieties. Furthermore, this technology did not affect the quality of cassava tuberous roots, which was improved when more K was added though manure recommended dose application and that decreased HCN contents. This suggests a need for increasing the application rate of K with ISFM technology in order to improve the quality of the cassava. Definitely, ISFM is a suitable alternative for addressing cassava disease and for preserving tuber quality that fits farmers' resource endowments. However, a key issue for achieving agricultural intensification is the improvement of farmer's knowledge on the implementation of ISFM approach and their ability to own or purchase the nutrients resources and improved cassava genotypes.

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