Received: 29 May 2020 | Accepted: 3 August 2020
DOI: 10.1002/agj2.20419

Agronomy Journal

NOTE AND UNIQUE PHENOMENA

Intensification options of small holders' cassava production in South-west Nigeria

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Funding information
EC and IFAD, Grant/Award Number: COFIN - ECG - 57 – IITA (Achieving development impact and environmental sustainability through intensification of pro-poor cropping systems based on cassava, yam, and legume)

Abstract

Cassava (*Manihot esculenta* Crantz) is a staple food crop in Nigeria, but root yields hardly exceed 10 t ha^{-1}. Intensification of small holders' cassava production is key to improved food security and income generation. We tested, in two demonstration trials and 20 on-farm trials, different intensification options: cassava growth type (erect and branching), fertilizer application (with and without), and cassava – legume arrangement (0.5 by 2 m/1 by 1 m spacing of cassava) in demonstration trials. In on-farm trials, farmers tested a subset of these treatments. The demonstration trials had median cassava yields of about 20 (Akindele village) and 15 (Osunwoyin village) t ha^{-1}. Fertilizer application increased the yield of the erect cassava variety. Cassava intercropped with cowpea [*Vigna unguiculata* (L.) Walp.], reduced yield and the branching cassava variety produced lower yield than the erect variety. Median cowpea yields were about 1 and 1.5 t ha^{-1} pod yield. Median yields in the on-farm trials were about 10 t ha^{-1}. Intercropping with cowpea reduced cassava root yields (on average by 2.4 t ha^{-1}), again, cowpea pod yields of 1–1.5 t ha^{-1} were attainable. In summary, this study confirmed that intensification measures need to be site and user or farmer specific.

1 | INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a staple food crop in Nigeria (Otekunrin & Sawicka, 2019) and widely grown by small holder farmers, is emerging as a cash crop for many farmers who sell their harvest to processors (FAO & IFAD, 2005). However, in Nigeria, cassava root yields tend to be low with less than 10 t ha^{-1} fresh root mass from 2012 to 2018 (FAOSTAT, 2020). Cassava is often grown in "slash-and-burn" or "slash-and-pack" systems following a few years of fallow in areas where there is still sufficient bush and forest cover. Cassava is often intercropped with a range of crops: white yam (*Dioscorea rotundata* Poir.), water yam (*D. alata* L.), tomato (*Lycopersicon esculentum* Mill.), egusi melon (*Cucumeropsis mannii* Naudin, *Cucurbitaceae*), maize (*Zea mays* L.), etc.; with maize being the most common intercrop and pulses or legumes being of little importance (Fawole & Oladele, 2007). Cassava is usually viewed as more important than its associated crops (Mutsaers, Ezumah, & Osiru, 1993). However, cassava root yield losses and generally lower fresh root yields are observed when intercropped with groundnut (Arachis hypogaea L.), cowpea [*Vigna unguiculata* (L.) Walp.], or

Abbreviations: BLUP, best linear unbiased predictor; CMD, cassava mosaic disease; LGA, local government area; WAP, weeks afternonbreakingspaceplanting.

chickpea (*Cicer arietinum* L.) (Ogola et al., 2013). Nevertheless, the systems attained land equivalent ratios greater than 1 and thus had an overall advantage over sole cassava (Ogola et al., 2013). In Ghana, intercropping cassava with maize and soybean [*Glycine max* (L.) Merr.], followed by a second intercrop of cowpea reduced root yields by 22–51%, depending on the cassava variety and the density of the legume (Dapaah, Ennin, & Asafu-Agyei, 2004). Thus, cassava variety and legume species and density modify the root yield response. In Nigeria, a range of cassava varieties differing in plant architectures are grown. Among the most popular varieties are TMS 30572, a profusely early branching type and TME 419, an erect growing and rarely branching type, known for its high root dry matter yields (Wossen et al., 2017). Generally, intercropping of root crops with legumes is poorly documented, as reported by Raseduzzama and Jensen (2017), who conducted a meta-analysis of the yield stability in intercropping and found only one root crop–legume intercrop paper.

Considering the low yields, the current state of cassava production calls for intensification measures following the principles of integrated soil fertility management (ISFM) with the use of improved germplasm and fertilizer application (Vanlauwe et al., 2010). Fertilizer is usually not applied in the Southwest of Nigeria. Wossen et al. (2017) reported that only 12% of their surveyed farmers applied fertilizer to their cassava fields. Combined with fertilizer use and optimized spatial arrangements, intensification of cassava systems through diversification with a legume intercrop may create the following advantages: (a) make additional use of already cleared land during the slow initial growth phase of cassava, (b) improve food security and reduce risk, and (c) increase nutritional quality when the legume is consumed with cassava and/or increase growers' income through sales of the legume grains (Fawole & Oladele, 2007; Kuyper & Adijei-Nsiah, 2017; Mutsaers et al., 1993). In Sud-Kivu, the Democratic Republic of Congo, cassava intensification, was implemented in a step-wise approach starting by planting in rows with constant distances between plants and rows in flat soil, followed by varied spacing of the rows to better accommodate an intercrop without reducing the cassava plant density and/or to allow a second short-term intercrop after the first. As a sequential or parallel step, fertilizer was applied to a sole cassava crop or to cassava and its associated crop (Pypers, Sanginga, Kasereka, Walangululu, & Vanlauwe, 2011).

The introduction of new or modified technologies requires demonstrating that these technologies bring about positive change in crop production, but they need to as well satisfy farmers' needs that may not be directly connected to a technology and they may not compromise other activities considered essential in farming households. Therefore the objectives were to understand what are acceptable options of intensification in cassava-based systems in central demonstration trials; and specifically, to test the best three options of intensification: (a) intercropping cassava and legume; (b) fertilizer application; and (c) modifying the planting pattern of cassava and the associated legume.

Core Ideas

- The success of sustainable intensification in smallholders' farms is not guaranteed.
- The effect of intercropping cassava with cowpea depends on the growth habit of cassava.
- A second intercrop may be prone to failure in 2 m cassava spacing.

2 | MATERIALS AND METHODS

2.1 | Description of the experimental sites

We implemented this project in four villages in Southwest Nigeria: Akindele (Ido Local Government Area [LGA]) and Lagbedu (Ogo-Oluwa LGA) in Oyo state, and Osunwoyin (Ayedire LGA) and Iwara (Atakunmosa East LGA) in Osun state (Figure 1). These villages follow a transect of environments and farming systems in Southwest Nigeria. This transect comprised tree crops and arable crop-dominated systems (Ido LGA, Oyo state), mixed farming of arable crops, trees, and livestock in the transition zone from forest to savannah (Ogo-Oluwa LGA, Oyo state), tree crops and livestock rearing (Ayedire LGA, Osun state), and tree crop systems with oil palm (*Elaeis guineensis* Jacq.) and cocoa (*Theobroma cacao* L.) (Atakunmosa East LGA, Osun state). All areas are characterized by high poverty levels and poor market access (IITA internal report, Humidtropics Nigeria Action Site stakeholder workshop Osogbo Osun state, 6 and 7 Feb. 2014). The majority (about 80%) of farms in these areas were smaller than 5 ha, on which overall at least 18 different crops were grown mainly in a form of intercropping (95% in Osun and almost 20% in Oyo). Cassava was cultivated on 25% of these farms, while cowpea or bean (*Phaseolus vulgaris* L.) were grown on less than 1%. Fallow periods were longer in Osun (3–6 yr) than in Oyo (0–3 yr). Only 40% of the farmers in Ayedire and Atakunmosa East LGAs felt that their yields were declining. Slightly more than 50% of the farmers in Ido LGA and all farmers in Ogo-Oluwa LGA also felt their yield were declining (IITA internal report, Baseline Report

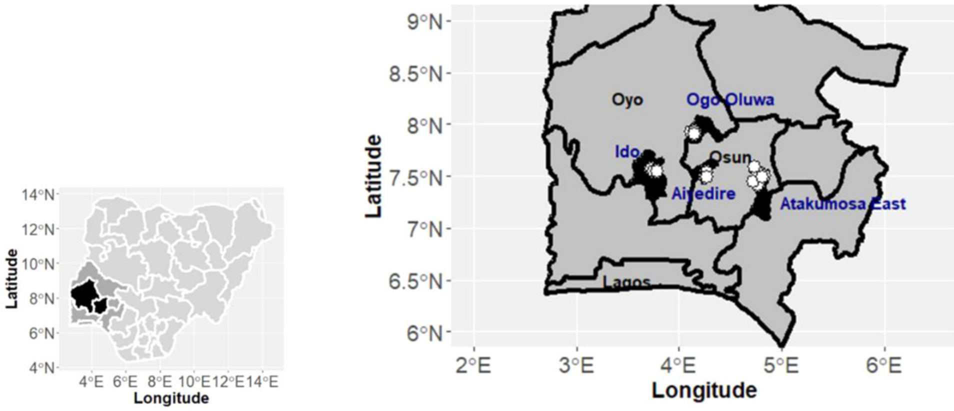

FIGURE 1 Map of Nigeria with an excerpt showing a selection of Southwest states of Nigeria. The study was conducted in Ido and Ogo-Olowa local governments (LGAs) in Oyo state and Ayedire and Atakunmosa-East LGAs in Osun state; dots indicate trial locations

of the Humidtropics Program for Nigeria and Cameroon, 2015). Farmers commonly agreed that cocoa was their most important crop followed by cassava, yam, oil palm, and maize (not ranked) at all locations. Plantain/banana (*Musa* X *paradisiaca* L.)was another important crop in Ido and Atakunmosa East LGAs; coco yam (*Xanthosoma sagittifolium* (L.) Schott, Araceae) in Ayedire LGA and cashew (*Anacardium occidentale* L.) in Ogo-Oluwa LGA, which is already bordering the derived savanna environment.

2.2 | Demonstration trials

In September 2014, we implemented demonstration trials at Akindele (Ido LGA in Oyo state) and Osunwoyin (Ayedire LGA in Osun state) after we had agreed in group meetings at each village on a set of factors that was of mutual interest to be tested. The fields had been slashed for land clearing after 2 and 3 yr of fallow at Ido and Ayedire, respectively. Most of the slashed biomass had initially been left on the ground but were moved to the borders of the field (slash and pack) prior to soil tillage. At the Ido and the Ayedire sites, signs of partial burning could be observed, much more pronounced at Ayedire. At both sites, stumps of bushes and smaller trees were still in the soil, most of which were retained. All fields were left flat after manual soil tillage by hand hoe. The trials were planted by a team of research technicians and then maintained by the farmers. Fertilizer application, planting of a second legume, as well as all harvests were also conducted by technicians. Cassava planting stakes were about 20 cm long and planted slanting at an angle of about 45 °. The legume was sown in the intercropped plots in two rows between two cassava rows of 1 m distance (six beds of legume per plot) or in four rows between cassava rows of 2 m distance (three beds of legumes per plot; Table 1). Treatments 1, 2, 3, 4, 7, 8, 10, and 11 received a herbicide application after planting {Propaben 400 EC [at 5 L ha^{-1}, active ingredients: metolachlor [(*RS*)-2-Chloro-*N*-(2-ethyl-6-methyl-phenyl)-*N*-(1-methoxypropan-2-yl)acetamide] and prometryn [6-methylsulfanyl-2-*N*,4-*N*-di(propan-2-yl)-1,3,5-triazine-2,4-diamine]} and Round-up [at 4.5 L ha^{-1}, active ingredient: glyphosate, *N*-(phosphonomethyl)glycine]) to control weeds during early stand establishment. Treatments 5, 6, and 9 were expected to allow farmers to observe the difference of herbicide application vs. manual weed control only. However, we were not able to assess farmers observations on this or collect related data. Non-sprouted cassava stakes were replaced at 4 weeks after planting (WAP). A second stake was planted next to cassava plants that appeared severely damaged by the herbicide application. The original stake was maintained. The second legume {soya bean [*Glycine max* (L.) Merr.]} was planted at the beginning of the wet season in May 2015 in two rows between cassava rows of 2 m distance in Treatments 2 and 4.

2.2.1 | Treatments

For the comparison of different intensification options and/or factors we chose sole cassava (erect variety TME 419) at a spacing of 1 by 1 m as basic treatment. We then tested options on cassava growth type (late branching with an erect habitus (referred to as erect in the following), and early and profusely branching (referred to as branching in the following) and variety (erect = TME 419; branching = TMS 30572; and a local variety by each site), fertilizer application (with or without), cassava – legume arrangement (0.5 by 2 m spacing of cassava with four rows of legume, 1 by 1 m spacing of cassava with two rows of legume), legume species (cowpea, soya bean, peanut [Arachis hypogaea L.]) and some of their interactions

TABLE 1 Treatments of the demonstration trials that were planted in September 2014 in Osunwoyin (Ayedire LGA) and Akindele (Ido LGA)

Treatment	Rep	Cassava Variety	Cassava Spacing	Legume Species	Legume Plant density	Legume Distance to cassava	Legume Distances intra row	Distances inter row	Nutrient N	Nutrient P	Nutrient K
			m		plants m^{-2}	m	m	m	kg ha^{-1}		
T1	2	TME	1.0 by 1.0	na	na	na	na	na	0	0	0
T2	2	TME	0.5 by 2.0[a]	cowpea	10	0.625	0.2	0.25	0	0	0
T3	2	TME	1.0 by 1.0	na	na	na	na	na	68	20	74
T4	2	TME	0.5 by 2.0[a]	cowpea	10	0.625	0.2	0,25	68	20	74
T5	1	Local	1.0 by 1.0	na	na	na	na	na	0	0	0
T6	1	30572	1.0 by 1.0	na	na	na	na	na	0	0	0
T7	1	TME	1.0 by 1.0[b]	cowpea[c]	10	0.4	0.2	0.2	68	20	74
T8	1	30572	1.0 by 1.0[b]	cowpea[c]	10	0.4	0.2	0.2	68	20	74
T9	1	30572	0.5 by 2.0[a]	cowpea[c]	10	0.625	0.2	0.25	68	20	74
T10	1	TME	0.5 by 2.0[a]	soybean[d]	10	0.625	0.2	0.25	68	20	74
T11	1	TME	0.5 by 2.0[a]	peanut[e]	10	0.625	0.2	0.25	68	20	74

[a] Spacing of cassava at 0.5 by 2 m: four lines of cowpea between two rows of cassava.
[b] Spacing of cassava at 1.0 by 1.0 m: two lines of cowpea between two rows of cassava.
[c] Cowpea variety: IT97k-568-18, early maturing (70–79 d), erect (in the trial the growth was more semi-erect or creeping; some cowpea varieties may climb when under any kind of shade (C. Fatokun, personal communication, 2017).
[d] Soya bean variety: TGx 1835-10E (NGGM-08-16), early maturing (90–100 d).
[e] Peanut variety: Samnut 24, about 80 d to maturity.

(Table 1). We considered T1–T4 as core treatments with a comparison of spacing and intercropping (2 m inter row spacing intercropped, 1 m inter row spacing, no intercrop) against fertilizer application (yes or no), which were repeated at each site to improve statistical analysis. Thus, each field consisted of two blocks, Treatments 1–9 were randomized in block 1 while Treatments 1–4 were repeated in an adjacent block 2 together with Treatments 10 and 11 that demonstrated the use of a different intercrop (same randomization at each site). Individual plot size was 42 m^2 (6 by 7 m). A basal application of NPK compound fertilizer 15:15:15 was applied after land preparation and superficially incorporated into the soil in treatments that were to receive fertilizer on the day of planting. The respective nutrient rates were 45 kg N ha^{-1}, 20 kg P ha^{-1}, and 37 kg K ha^{-1}. A second dressing was applied before seeding of the second legume (about 36 WAP, on 19 and 18 May 2015) at 22.5 kg N ha^{-1} applied as urea and 36 kg K ha^{-1} applied as KCl. Both fertilizers were applied in half-moon shaped shallow furrows to individual cassava plants. The fertilizer was covered with soil after application.

2.2.2 | Harvests of legume and cassava

Legume pods were harvested in December 2014 from an area of 16 m^2 (2 m cassava row spacing) or 12 m^2 (1 m cassava row spacing) from the center of the plots. The harvest area of the second legume was 8 m^2, from the central bed only. A subsample of the pods was oven dried to constant mass and dry pod yield per hectare calculated. Cassava storage roots were harvested in September 2015 from the central 20 m^2 (20 plants at full plant stand). The roots were separated into "marketable" healthy roots and non-marketable "poor" diseased/damaged roots and weighed. Of the heathy root fraction, a subsample was collected, oven dried to constant mass and dry storage root yield calculated.

2.3 | On-farm trials

On farm trials were planted with the start of the first rainy season in 2015. We designed three packages (A, B, C) to be tested on the farm (Table 2). Each package had four treatments (options) comparing sole cassava with and without fertilizer application with cassava intercropped with cowpea at cassava spacing of 1 by 1 m and 0.5 by 2 m. The packages differed in cassava variety (branching in A and B, erect in C) and the focus on fertilizer use (in A and C, all plots except for one sole cassava plot received fertilizer; in B, only one sole cassava plot received fertilizer). One farm received one test package. Fertilizer rate and application timing was the same as in the demonstration trials. Thus, we tested again Treatments 1, 3, 4, and 7 of the demonstration trials in package C and Treatments 6,

TABLE 2 Packages of treatment options (A, B, and C) with the varied factors (cropping system, cassava spacing, cassava growth type, and fertilizer application) in the on-farm trials that were planted in April to June 2015 in the local government area (LGA) of Ido, Ogo-Oluwa, Ayedire, and Atakunmosa East

Package	Cropping system	Cassava spacing	Growth type (cassava)	Fertilizer
A	Sole cassava	1 by 1 m	Branching	No
	Sole cassava	1 by 1 m	Branching	Yes
	Intercrop[a]	1 by 1 m	Branching	Yes
	Intercrop[a, b]	0.5 by 2 m	Branching	Yes
B	Sole cassava	1 by 1 m	Branching	No
	Sole cassava	1 by 1 m	Branching	Yes
	Intercrop[a]	1 by 1 m	Branching	No
	Intercrop[a,b]	0.5 by 2 m	Branching	No
C	Sole cassava	1 by 1 m	Erect	No
	Sole cassava	1 by 1 m	Erect	Yes
	Intercrop[a]	1 by 1 m	Erect	Yes
	Intercrop[a,b]	0.5 by 2 m	Erect	Yes

[a] Cowpea variety: IT99k-573-1-1 (Sampea 14), early maturing (70–79 d), erect (in the trial the growth was more semi-erect or creeping; some cowpea varieties may climb when under any kind of shade (C. Fatokun, personal communication, 2017).

[b] Soybean variety (planted in the intercropped plots with 0.5 by 2 m spacing after the harvest of cowpea): TGx 1988-5F (NCRISOY1), early maturing (90–100 d).

8, and 9 in package A. Individual plots of one test package were 10 by 7 m. Again, a second legume (soybean) was to be planted after the harvest of cowpea.

We started the on-farm trials with a workshop. Here we introduced the test packages to the farmers and the farmers identified a total of 40 volunteers across all villages. Planting materials were distributed in April 2015 to each village, farmers received again a hands-on explanation and at each village one “lead farmer” was available to explain the procedure to those farmers who had did not have their land t ready. In Atakunmosa East, the local extension agent engaged in the project. Farmers planted from mid-April to July 2015. As a consequence of the long planting period and infrequent rains in the 2015 season, the cassava planting material partially dried. We re-supplied a limited amount of planting material for gap filling. For the analysis of treatment effects on cassava root yields and cowpea pod yield, we used data collected from 20 farms. By the end of the wet season (October/November 2015), about 5–7 mo after planting 12 farmers had already left the group as they abandoned the trial or were not able to follow the protocol. Of the remaining 28 farms, two farms were lost to grass cutter (*Thryonomys swinderianus*) damage; two farms were abandoned, probably due to health reasons of the farmers; two farms were not well maintained and plots could not be clearly identified. On one farm, treatments were wrongly implemented, and one farm had too many trees and bananas interfering with the plots. Of the 20 farms that we used for agronomic analysis, three farms only established the intercropped treatments; (one farmer used only the treatment of 2 m inter row spacing). On one farm the mono-cropped plots were damaged by grass cutter and not harvested, while on another farm, the intercropped plot with 2 m row spacing was wrongly implemented and not harvested. We asked farmers three times (at cowpea and cassava harvests and at the start of the dry season in late October to early November 2015) about their field management, number of weeding operations, and insecticide applications.

2.3.1 | Field management

The choice of land for the on-farm trials was left to the farmers. Field sites were usually more or less flat except for two sites (one with a relatively steep slope and one with a gentler slope) in Atakunmosa East. Most of the sites were fallow before planting the trials; the average fallow period was 4 yr (average of 14 farm sites with a range of 1–7 yr; one site was cultivated again after a cassava/maize intercrop, one site was fallow for 30 yr). However, information on fallow duration may not be very reliable. We received sometimes contradictory information in the course of the experiment. Before planting all farmers slashed the previous vegetation and eight farmers also burned to clear the land and used hand hoes for manual soil tillage. Four farmers used herbicides before planting (Products: Slasher, Atraforce, Force-up, Paraforce, and Athrazine with the chemical components: Triclopyr {[(3,5,6-Trichloro-2-pyridinyl)oxy]acetic acid}+ Picloram (4-Amino-3,5,6-trichloro-2-pyridinecarboxylic acid), Athrazine [6-chloro-N^2-ethyl-N^4-(propan-2-yl)-1,3,5-triazine-2,4-diamine], glyphosate [*N*-(phosphonomethyl)glycine], paraquat (1,1′-Dimethyl-4,4′-bipyridinium dichloride)). As insecticide, the farmers used most often (18 times on 28 farms) Karate5EC (Lambda-cyhalothrin [(RS)-alpha-cyano-3-phenoxybenzyl 3-(2-chloro-3,3,3-trifluoropropenyl)-2,2,-dimethylcyclopropanecarboxylate] as this was distributed in a short training on safe pesticide application. Other products applied were Cyperforce, Cypermethrine, Magic force and Rocket with the chemical components Cypermethrine {[Cyano-(3-phenoxyphenyl)methyl]3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropane-1-carboxylate} and Profenofos {4-bromo-2-chloro-1-[ethoxy(propylsulfanyl)phosphoryl]oxybenzene}+cypermethrine. Other insecticides were "Samtoce", and "Photos-food". On farm 33, "Supergrow", a fertilizer product, was applied. The second legume, soya bean, was not planted on 9 out of 28 farms, that we visited at the end of the wet season, and were planted late on several other farms. The reasons for not planting or planting late were no rain or excessive rain fall, other priorities (two farmers named activities in cocoa), health issues, and concerns about the shading of the soya bean by the cassava.

2.3.2 | Fertilizer application

During the October/November 2015 monitoring, we asked farmers if and in which plots they applied the second rate of fertilizer. Of the 20 farms that we maintained for yield analysis, four farmers did not apply the second fertilizer dressing to (all) plots, and two farmers said that there was not sufficient rain.

2.3.3 | Harvest of cowpea and cassava

Cowpea was harvested from mid-July to early August 2015. The harvest procedure was shared between researchers/technicians and farmers as the crop matured over several weeks and the pods easily started rotting in the high humidity of the wet season. Therefore, researchers harvested from a designated harvest area (16 m^2 in plots with 2 m cassava row spacing and 32 m^2 in plots with 1 m cassava row spacing), while farmers harvested from the entire plot (as the plots finished with a cassava row on each side the effective area was 60 m^2). Yields were later lumped on dry pod and per hectare basis. Cassava was harvested from the end of March to mid-April 2016 by technicians only. Roots were separated into "marketable" healthy roots and non-marketable "poor" (diseased or non-marketable roots) counted and weighed in the field (mechanical hanging balance [Salter balance type 235-6S 25 kg DM-UL-HK, made in India]). The crop growth duration ranged from 10.3 (one trial) to 11.5 (one trial) mo, with an average of 11.1 mo. Soya bean, the second legume, was not harvested because establishment either failed or was very poor with the exception of only one farm.

2.4 | Soil sampling

Soil samples were collected with a core of 10 cm diam. to 20-cm depth. In the demonstration trials, two soil cores per plot were bulked into one composite sample per block. In the on-farm trials, five soil samples were collected from four corners and the center of each plot and bulked into one composite sample per field (four plots). For the demonstration trials, both sites had pH values of 6 to 7 and had less than 10 mg kg^{-1} available P. The Akindele site, had about twice as much total N as the Osunwoyin site and soil texture at Akindele was about 10% higher in clay (23-28%) at about equal silt contents (10-11%) (Table 3).

For the on-farm trials, median pH values at all sites were between 6.5 and 7.0, except for Atakunmosa East where it was slightly less than 6.0. Median organic C contents were highest in Atakunmosa East. Total N was lowest in Ayedire and exchangeable K highest at Ogo-Oluwa (almost 0.3 $cmol_c$ kg^{-1} K). Available P was low at all sites with a maximum of slightly more than 12.5 mg P kg^{-1}. Sand contents increased from Ido (about 60%) over Atakunmosa East and Ogo-Oluwa to Ayedire (about 70%) (Figure 2).

2.5 | Weather information

As an estimate of precipitation, we used CHIRPS data (Funk et al., 2015), a combination of satellite and weather station data at a resolution of 0.5 degrees (about 55.5 km at the equator). Unsurprisingly, the precipitation pattern for all on-farm sites was similar. Cumulative rain fall was lowest at the sites in Ogo-Oluwa (about 1,200 mm) and highest at the sites in Atakunmosa East (about 1,500 mm). Total rain fall at the demonstration trial site at Osunwoyin was estimated at 1,622 and 1,490 mm at the demonstration site in Akindele. Rains started in March and ended in November interrupted by a brief break in August. Long-term mean annual temperature was 26 °C; minimum and maximum temperatures ranged from 20–21 and 31–32 °C, respectively (Worldclim gridded datasets (1970–2000); Fick & Hijmans, 2017) in all LGAs.

2.6 | Data analysis

We analyzed our data by R (R Core Team, 2016). For yield data on cassava roots and cowpea pods from the

TABLE 3 Top soil properties of the demonstration trial sites at Osunwoyin and Akindele

Location	pH (H_2O)	Org. C	Total N	Olsen P	K	Sand	Silt	Clay
		g kg^{-1}		mg kg^{-1}	$cmol_c$ kg^{-1}	g kg^{-1}		
Osunwoyin Rep 1	6.5	11.7	1.6	7	0.32	770	90	140
Osunwoyin Rep 2	6.1	12.5	1.3	4	0.18	770	90	140
Akindele Rep 1	6.7	18.7	3.3	3	0.28	670	100	230
Akindele Rep 2	7.2	23.3	3.8	5	0.47	610	110	280

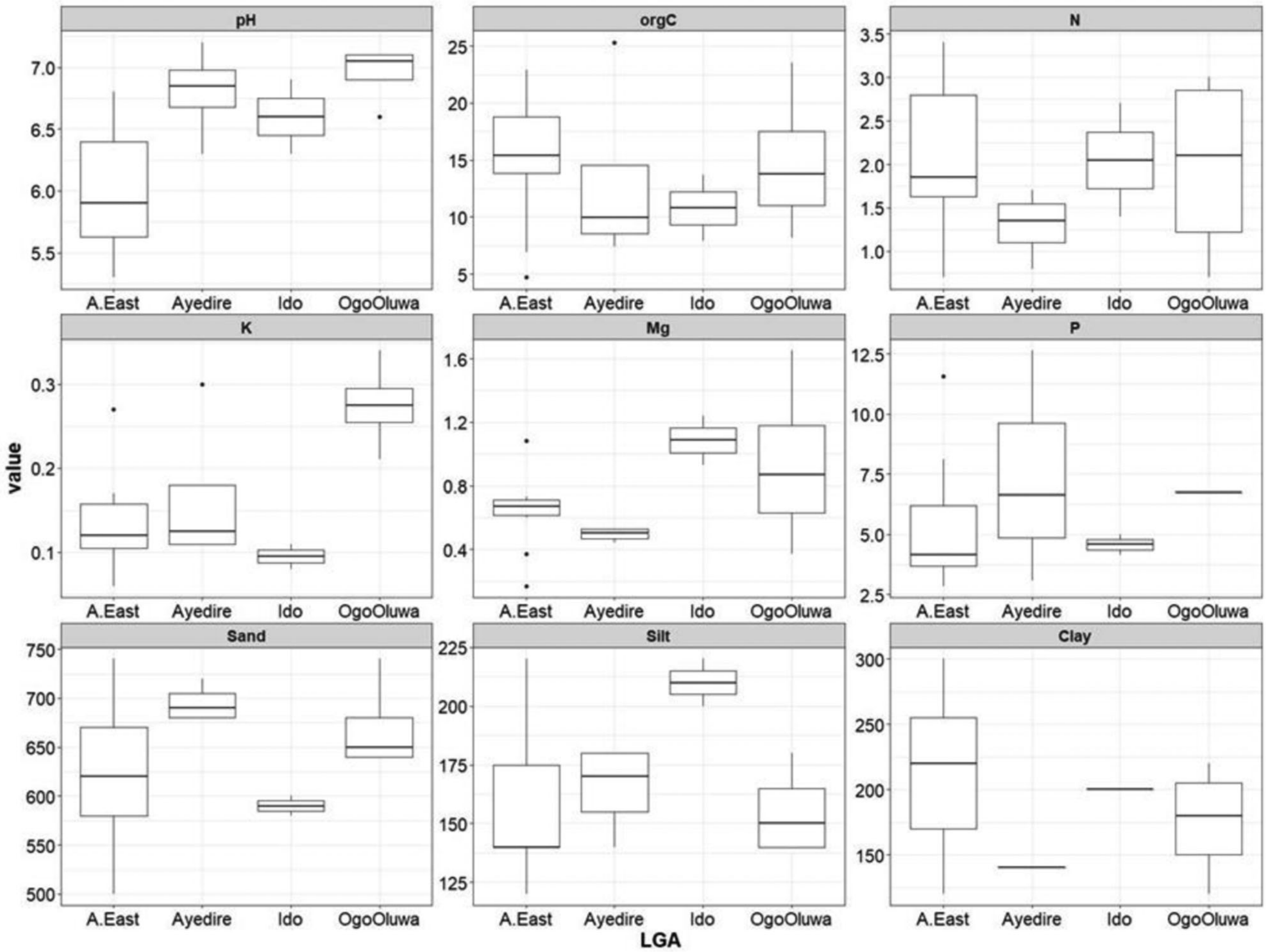

FIGURE 2 Top soil properties at or before trial implementation for the on-farm trial sites (Ido 2, Atakunmosa East 10, Ogo-Oluwa 4, and Ayedire 4 sites), pH in water, organic C (orgC) and total N in g kg^{-1}; exchangeable K and Mg as $cmol_c$ kg^{-1}; P as Bray 1 in mg kg^{-1}; and sand, silt, and clay as g kg^{-1}

demonstration trials, we applied *stats* (R Core Team, 2016) and *lsmeans* (Lenth, 2016) for linear fixed effects analysis by three groups: (a) T1–T9 evaluating the treatment effects in sole cassava or cassava intercropped with cowpea; (b) T1–T2 comparing the effect of cowpea and fertilizer with erect cassava; and (c) T4, T7, T8, and T9, comparing intercropped branching cassava with erect cassava at 2 and 1 m spacing (Table 1). For group (a) we used "treatment" plus "site" as fixed effects. For groups (b) and (c) spacing was omitted from the model. "Fertilizer" × "cowpea" or "Variety", respectively, plus "site" were used as fixed effects. For the analysis of cowpea pod yield, we used the treatments intercropped with cowpea T2, T4, T7, T8, and T9 (Table 1) and for this "treatment" plus site were considered fixed effects.

For the on-farm trials, we fitted linear mixed models using *lme4* (Bates, Maechler, Bolker, & Walker, 2015) and *lmerTest* (Kuznetsova, Brockhoff, & Christensen, 2016) for

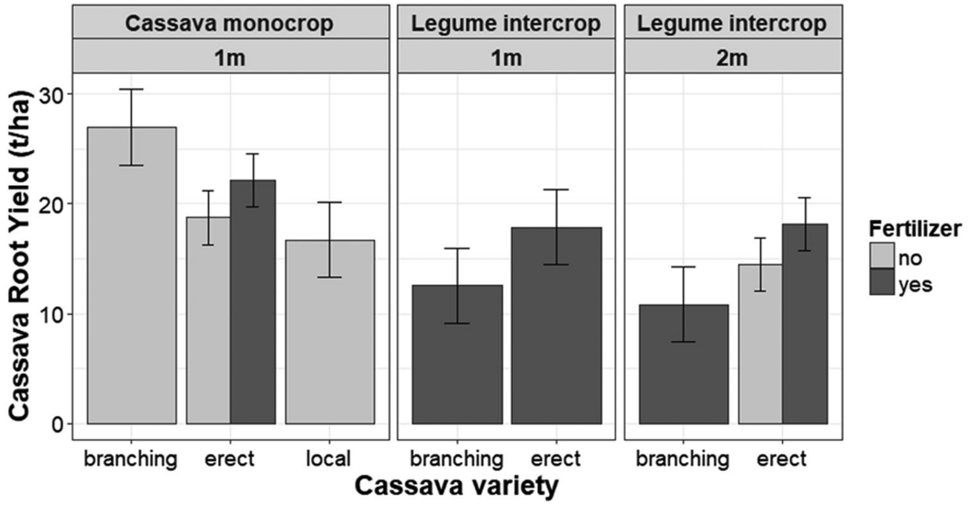

FIGURE 3 Average total fresh root yield in t ha^{-1} of the demonstration trials by treatments at Akindele and Osunwoyin. The effect of treatment had a significance level of $P = .07$; error bars indicate the model based standard error of the mean. The effect of variety tested for the subset of fertilized intercropped cassava (1 m and 2 m row spacing not differentiated) had a significance level of $P = .07$. Branching, erect or local cassava; Fertilizer or no fertilizer application; 1 m or 2 m inter row spacing of cassava; No C: no cowpea, C: cowpea as intercrop

the effect of treatment on cassava root yield. We used "treatment" and "cowpea" as fixed effect and "cowpea" × "site" as random effect. We used this model to extract best linear unbiased predictors (BLUPs) to predict the effect of cowpea on cassava yield. These BLUPs were then linked to selected soil properties of each site (pH, organic C content, total N content, or percent sand of the soil) to grow a conditional inference tree using *party* (Hothorn, Hornik, & Zeileis, 2006). To assess the effect of fertilizer, we used the sole cassava treatments with the factors "fertilizer" as fixed effect and "farm" as random effect. Figures were produced using *gplots* (Gregory et al., 2016) and *ggplot2* (Wickham, 2009) after aggregation with *Rmisc* (Hope, 2013). For the map, we used *sf* (Pebesma, 2018) and shape files for selected Nigerian State and local government areas from Global Administrative Unit Layers (GAUL, http://www.fao.org/geonetwork/).

3 | RESULTS

3.1 | Demonstration trials

The trial at Akindele had a higher median cassava yield (~20 t ha^{-1}) than the trial at Osunwoyin (~15 t ha^{-1}). Maximum and minimum yields at both sides were similar, >25 t ha^{-1} and about 7–8 t ha^{-1}, respectively. Within the erect variety, average yields of treatments with fertilizer application were higher than without fertilizer (with and without intercropping). Within the subgroup of T1–T4, the average yield increase by fertilizer was about 4 t ha^{-1}, but not significant. At the same time intercropping with cowpea reduced cassava root yield on average by about 4 t ha^{-1}, but was also not significant. The branching variety produced lower yields than the erect variety at 1 and 2 m spacing when intercropped. However, the average yield of the sole cropped branching variety was the highest of all treatments without fertilizer application. The effect of treatment (T1–T9) had a significance level of $P = .07$ (Figure 3). In the subset of fertilized intercropped cassava (1 and 2 m row spacing not differentiated), the erect cassava variety had on average 6 t ha^{-1} higher yield than the branching variety ($P = .07$). While median cassava yield was higher at Akindele, median cowpea yields were higher at Osunwoyin (about 1.5 t ha^{-1} pod yield) than at Akindele (about 1 t ha^{-1} pod yield). None of the treatments had a significant effect on cowpea yields (Figure 4). The second legume, soya bean, did not establish in Akindele where it was probably destroyed by animals and did not establish even after one re-seeding (4 June). Thus, soya was only harvested at Osunwoyin, but here as well, crop establishment was poor, probably due to the rapid development of the cassava canopy. At harvest, close to physiological maturity, in August 2016, the quality of the harvested pods was poor; many seeds were already germinating in the pod on the plant. Pod yield ranged from 48 to 290 kg ha^{-1}.

3.2 | On farm trials

For the analysis of cassava fresh root and cowpea pod yield, we used the data of 20 farms.

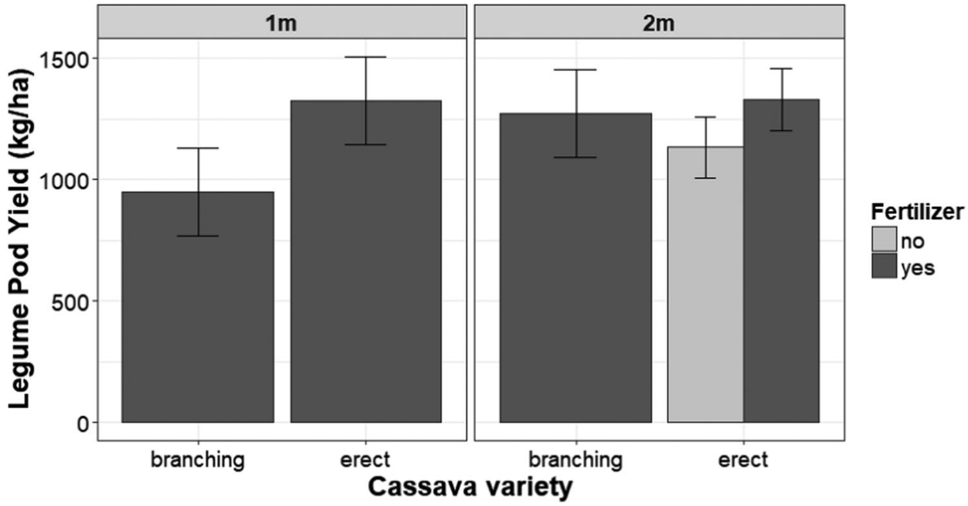

FIGURE 4 Average dry pod yield (kg ha^{-1}) of cowpea of the intercropped treatments in the demonstration trials at Akindele and Osunwoyin; The effect of treatment and factors (fertilizer, variety, and row spacing) was not significant; error bars indicate the model based standard error of the mean. Branching, erect or local cassava; Fertilizer or no fertilizer application; 1 or 2 m inter row spacing of cassava

3.2.1 | Yields

Overall, cassava root yields in the on-farm trials were lower than in the demonstration trials and median fresh root yields ranged around 10 t ha^{-1} (Figure 5). Median plant numbers at harvest by treatment were closer to 0.8 m^{-2} than 1.0 (0.4 1.4 plants m^{-2}; 0.84 plants m^{-2} across all treatments). Yield, across all treatments, was weakly correlated with planting density ($r^2 = .32$; $P < .01$). Intercropping with cowpea reduced cassava root yields of both varieties on average by 2.4 t ha^{-1} ($P < .06$) but yield losses of the branching variety appeared slightly higher when intercropped (Figure 5). Yield reductions through cowpea intercropping were significantly higher on soils with a higher pH (pH > 6.1; $P = .02$) as indicated by the conditional inference tree for the expected effect of the legume intercrop on cassava fresh root yield (t ha^{-1}) using the soil parameters pH, organic C content, total N content, and percent sand as factors (data not shown). This hardly reflected in slightly depressed cowpea pod yields at the sites of higher pH. Nevertheless, cowpea pod yields of 1-1.5 t ha^{-1} were attainable along with cassava root yields of more than 10 t ha^{-1} at the better performing sites. For fertilizer application and row spacing, we did not find significant effects, although fertilizer application increased cassava root yield on average by about 1 t ha^{-1} in sole cassava. Four farms had lower yields in their fertilized plots, losses ranging from 0.5 to 5.8 t ha^{-1}. On the other hand, 12 farms had higher yields in the fertilized plots with yield gains ranging from 0.1 to 8.2 t ha^{-1}. Gains or losses could not be related to specific causes.

4 | DISCUSSION

System productivity could be increased under good agricultural practice in the demonstration trials where the cowpea matured during the dry season. FAO records on cassava fresh root yield in Nigeria from 2012 to 2014 were below 10 t ha^{-1} (FAOSTAT, 2017). For cowpea, the obtained pod yields of 1 to 1.5 t ha^{-1} would translate to about 750-1,125 kg ha^{-1} grain yield (estimated from a subsample of our on-farm data, where the empty pods contributed about 25% of the total dry weight; data not shown). Dugje, Omoigui, Ekeleme, Kamara, and Ajeigbe (2009) estimated the potential yield to range from 1.4 to 2 t ha^{-1} in a sole crop of the same cowpea variety as used in our demonstration trials. At Abeokuta, Southwest Nigeria, Adigun, Osipitan, Lagoke, Adeyemi, and Afolami (2014) obtained about 0.5 t ha^{-1} in a sole crop and 0.3-0.9 t ha^{-1} in a cassava intercrop at Umudike in Southeast Nigeria. When crop management was less controlled in the on-farm trials, cassava yields dropped. Some fields may have received less than farmer's best management because the original approach of integrating the test trials into the regular fields of the participating farmers could not be realized. Thus, site selection, land clearing and preparation, planting and weeding time of the on-farm trials needed additional attention and labor input. Also, timing of the various activities may have differed from those in farmers' main or their "own" fields. The rather wide range of plant densities in the fields may also reflect challenges in timely planting and field management. On the other hand, some trials were well managed as observed during the monitoring visits, but this did not

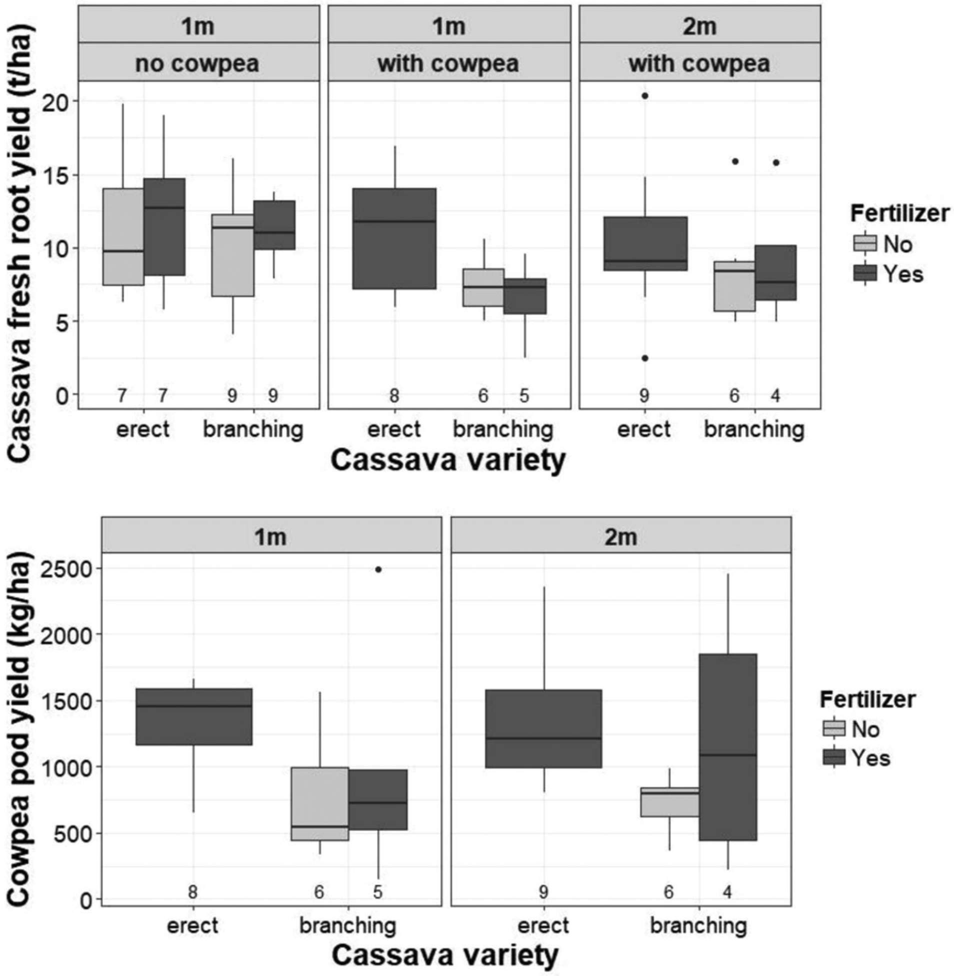

FIGURE 5 Cassava fresh root yield (t ha^{-1}, top) and dry legume pod yield (kg ha^{-1}, bottom) of 20 on farm trials with erect (TME 419) and branching (TMS 30572) cassava, with cowpea intercropping and without inter cropping, with fertilizer application and without fertilizer application at 1 m inter row spacing or 2 m inter row spacing . Small numbers below each boxplot indicate the number of trial plots used for the respective boxplot, not all on-farm trials were complete with all four treatments

necessarily translate into high yields in all plots, for example, farms 30 (7.9-12.6 t ha^{-1}), 37 (6.5-11.1 t ha^{-1}), and 40 (4.9-13.2 t ha^{-1}). However, median cowpea pod yields in the on-farm trials were comparable with the yields in demonstration trials especially when intercropped with the erect cassava variety TME 419.

4.1 | Management options

The cowpea intercrop reduced cassava root yields, an effect that can be expected when intercropping cassava with legumes (Mutsaers et al., 1993). Yield loss was apparently higher on the soils with higher pH but the reasons for this remain unclear.

Fertilizer application had neither in the on-farm nor in the demonstration trials significantly positive effects on the crop yields, although on average yield increased. For the on-farm trials, side by side comparisons for sole cassava with and without fertilizer showed that yields increased in 12 sets of plots but decreased in 4 sets of plots. Reasons for this heterogenous response may be the same as those for the overall lower cassava root yields in the on-farm than the demonstration trials as discussed above. In addition, rains may have been unfavorable, two of our farmers, for example, did not apply the second rate of fertilizer in the absence of rain. On the other hand, heavy rain just after fertilizer application may displace most of the nutrients as run-off or through leaching. Thus, the benefit of the fertilizer application appears highly site and situation specific.

Row spacing did not significantly affect cassava fresh root yield but the 2-m spacing may be the safer option when a farmer prefers the branching variety and would still like to intercrop. The wider row spacing may also be more practical for weeding after harvest of cowpea as reported by farmers in our study. Olasantan (1988) tested different row arrangements and obtained higher cowpea yields at wider row spacing of two rows of cowpea to one or two rows of cassava. Results from CIAT show that cassava yields were not affected by row arrangement when the population density was maintained (Leihner, 1979).

The branching habit of cassava affected cowpea yields: median cowpea yields were higher with the erect than the branching cassava, which is also reported by Howeler (2014) and Leihner (1983). The growth type apparently also influenced the level of yield reduction as yields of the branching variety were lower than of the erect variety in the demonstration trials. In the on-farm trials, the quality of the planting material of the branching variety proved to be problematic as a small portion of stakes originated from different branching varieties, albeit dominated by the intended variety TMS 30572. Some sites showed cassava mosaic disease symptoms (strongly at one farm during the early season), but this abated until harvest at most sites. At harvest, only plants on one farm were severely affected by a mix of diseases and pests. On the other hand, the erect variety TME 419, which was hardly affected by disease, yielded also low. Therefore, the disease may not fully explain the poor performance in the branching cassava and management may be assumed as the primary reason. The branching variety TMS 30572 has been shown to be less vigorous and lower yielding than TME 419 (Hauser & Ekeleme, 2017). In their review, Mutsaers et al. (1993) point out that in cassava/legume mixtures, the legume is often the dominant crop and the cassava suffers a higher yield reduction than the companion crop. They concluded that most suitable cassava varieties would have moderate early vigor and be able to direct assimilates efficiently to the roots after harvest of the companion crop.

Including soya bean as a second legume failed in our experimental set-up although there is proof of concept available from the Sud-Kivu highlands, the Democratic Republic of Congo, for common bean (*Phaseolus vulgaris* L.) as a second intercrop (Pypers et al., 2011). Sud-Kivu is at a higher altitude, and the climate is cooler, thus cassava growth is probably less vigorous than in Southwest Nigeria. For our study, we chose soya bean because communication with farmers indicated that soya was a more interesting intercrop for them than groundnut. However, development of the cassava canopy even in the 2 m cassava interrow spacing was apparently already too advanced after the harvest of cowpea to allow a successful establishment of the soya bean crop in demonstration and on-farm trials. The only on-farm site where a relatively good stand of soya was present coincided with a less dense cassava canopy.

Cassava intercropping with cowpea is often reported to have a positive (>1) land equivalent ratio. In the review by Delaquis, de Haan, and Wyckhuys (2018), this was the case for all their analyzed studies. Nevertheless, there was a substantial risk of a reduction in cassava root yields (Figure 5). Therefore, the farmer needs to value the cowpea as addition to food security or even a source of extra cash income, to make intercropping a useful option. In our study, the intercrop cowpea reduced the cassava yield by an average 2.4 t ha^{-1}. Cassava root prices fluctuate strongly across years as well as between seasons and across locations. For July 2014, cassava root prices were recorded with 30 Nigerian Naira kg^{-1} in Osun state but with only 10.9 Naira kg^{-1} in Oyo state (NAERLS, 2014). Thus, the cowpea could cause a loss of 72,000-26,160 Naira ha^{-1}. To break even, the minimum cowpea yield would need to be 368 or 134 kg ha^{-1} when a price of 261 Naira kg^{-1} (Iromini, 2017) is assumed. In our trials, these yield levels were usually exceeded (Figure 5), however seed quality during the wet season was very poor. One of the farmers we worked with started investing in cassava–cowpea intercropping and planted about 0.81 ha for household consumption of cowpea and selling of cassava.

5 | CONCLUSIONS

This study confirmed that intensification measures need to be tailored for their user and the site of their implementation. The intensification options that we tested, intercropping cassava and legume, fertilizer application and modifying the planting pattern of cassava and the associated legume, did not show clear responses in farmer's fields. Intercropping led to appreciable yields of cowpea, however, during the wet season the quality of the grains was dubious. Thus, this option may best be recommended for the dry season. Intercropping also reduced cassava yields as expected, therefore the companion crop cowpea needs to represent an appreciated added value to warrant intercropping. This added value needs to be ascertained for any intensification measure. For fertilizer application, the additional yield would need to have a higher value than the cost of the fertilizer, and its application probably needs to be aligned with a better targeted application schedule and a more stringent field management than in some of the farms where we worked.

ACKNOWLEDGMENTS

This research was funded by the EC and IFAD under the Grant Agreement no. COFIN - ECG - 57 – IITA (Achieving development impact and environmental sustainability through intensification of pro-poor cropping systems based on cassava, yam, and legume). The first author was supported by the Center for International Migration (CIM).

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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REFERENCES

Adigun, J., Osipitan, A. O., Lagoke, S. T., Adeyemi, R. O., & Afolami, S. O. (2014). Growth and yield performance of cowpea (*Vigna unguiculata* (L.) Walp) as influenced by row-spacing and period of weed interference in South-West Nigeria. *Journal of Agricultural Science*, *6*, 188–198. https://doi.org/10.5539/jas.v6n4p188

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1–48. https://doi.org/10.18637/jss.v067.i01

Dapaah, H. K., Ennin, S. A., & Asafu-Agyei, J. N. (2004). Performance of cassava intercropped with maize, soybean and cowpea in the forest zone of Ghana. *Agricultural and Food Science Journal of Ghana*, *3*, 193–202

Delaquis, E., de Haan, S., & Wyckhuys, K. A. G. (2018). On-farm diversity offsets environmental pressures in tropical agro-ecosystems: A synthetic review for cassava-based systems. *Agriculture, Ecosystems & Environment*, *251*, 226–235.

Dugje, I. Y., Omoigui, L. O., Ekeleme, F., Kamara, A. Y., & Ajeigbe, H. (2009). *Farmers' guide to cowpea production in West Africa*. Ibadan: IITA.

FAO, IFAD. (2005). *A review of cassava in Africa with country case studies on Nigeria*, Ghana, the United Republic of Tanzania, Uganda and Benin. Proceedings of the validation forum on the global cassava development strategy. 2. Rome: FAO and IFAD.

FAOSTAT. (2020). FAOSTAT. Retrieved from http://www.fao.org/faostat/en

Fawole, O. P., & Oladele, O. I. (2007). Sustainable food crop production through multiple cropping patterns among farmers in South-Western Nigeria. *Journal of Human Ecology*, *21*, 245–249. https://doi.org/10.1080/09709274.2007.11905980

Fick, S. E., & Hijmans, R. J. (2017). Worldclim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*, 4302–4315. https://doi.org/10.1002/joc.5086

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., … Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—A new environmental record for monitoring extremes. *Scientific Data*, *2*, 150066. https://doi.org/10.1038/sdata.2015.66

Gregory, R. W., Bolker, B., Bonebakker, L., Gentleman, R., Huber, W., Liaw, A., … Venables, V. (2016). gplots: *Various R Programming Tools for Plotting Data*. *R package version 3.0.1*. Retrieved from https://CRAN.R-project.org/package=gplots

Hauser, S., & Ekeleme, F. (2017). Weed control in cassava cropping systems. In C. Hershey (Ed.), Achieving sustainable cultivation of cassava. *Volume 2*. Genetics, breeding, pests and diseases. *No. 21. Cambridge: Burleigh Dodds Science Publishing*.

Hope, R. M. (2013). *Rmisc: Rmisc: Ryan Miscellaneous. R package version 1.5*. Retrieved from https://CRAN.R-project.org/package=Rmisc

Hothorn, T., Hornik, K., & Zeileis, A. (2006). Unbiased recursive partitioning: A conditional inference framework. *Journal of Computational and Graphical Statistics*, *15*, 651–674 https://doi.org/10.1198/106186006X133933

Howeler, R. (2014). *Sustainable soil and crop management of cassava in Asia. A reference manual*. Cali, Columbia: CIAT.

Iromini, O. M. (2017). *Socio-economic evaluation of intensification options in cassava-legume cropping systems in southwestern Nigeria* (Master of Science thesis. Obafemi Awolowo University, Ile Ife).

Kuyper, W. T., & Adejeh-Nsiah, S. (2017). Intercropping and crop rotation in cassava cultivation: A production system approach. In C. Hershey (Ed.), *Achieving sustainable cultivation of cassava. Volume 2. Genetics, breeding, pests and diseases* (pp. 1–20). Cambridge: Burleigh Dodds Science Publishing.

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2016). *lmerTest: Tests in Linear Mixed Effects Models*. *R package version 2.0-33*. Retrieved from https://CRAN.R-project.org/package=lmerTest

Leihner, D. E. (1979). Agronomic implications of cassava-legume intercropping systems. In E. Weber, B. Nestel, & M. Campell (Eds.), *Intercropping with cassava. Proceedings of an international workshop, 27 Nov.-1 Dec., Trivandrum, India* (pp. 103–112). Ottawa, ON: International Development Research Centre (IDRC).

Leihner, D. E. (1983). *Management and evaluation of intercropping systems with cassava*. Cali: Centro International de Agricultura Tropical.

Length, R. V. (2016). Least-squares means: The R package lsmeans. *Journal of Statistical Software*, *69*, 1–33.

Mutsaers, H. J. W., Ezumah, H. C., & Osiru, D. S. O. (1993). Cassava-based intercropping: A review. *Field Crops Research*, *34*, 431–457. https://doi.org/10.1016/0378-4290(93)90125-7

NAERLS, FDAE. (2014). *Agricultural Performance Survey Report of 2014 Wet Season in Nigeria*. Zaria, Nigeria: NAERLS, Ahmadu Bello University Zaria NAERLS Press.

Ogola, J. B. O., Mathews, C., & Magongwa, S. M. (2013). The productivity of cassava-legume intercropping system in a dry environment. In J. S. Tenywa, & M. P. Nampala (Eds.), *Nelspruit, South Africa: African crop science conference proceedings, 14–17 October, Entebbe, Uganda. 11* (pp. 61–65). Entebbe, Uganda: African Crop Science Society.

Olasantan, F. O. (1988). Intercropping of cassava (Manihot esculenta) with maize or cowpea under different row arrangements. *Field Crops Research*, *19*, 41–50. https://doi.org/10.1016/0378-4290(88)90032-9

Otekunrin, O. A., & Sawicka, B. (2019). Cassava, a 21st century staple crop: How can Nigeria harness its enormous trade potentials? *Acta Scientific Agriculture*, *3*, 194–202. https://doi.org/10.31080/ASAG.2019.03.0586

Pebesma, E. (2018). Simple features for R: Standardized support for spatial vector data. *The R Journal*, *10*(1), 439. Retrieved from https://journal.r-project.org/archive/2018/RJ-2018-009/, https://doi.org/10.32614/RJ-2018-009/

Pypers, P., Sanginga, J. M., Kasereka, B., Walangululu, M., & Vanlauwe, B. (2011). Increased productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo. *Field Crops Research*, *120*, 76–85. https://doi.org/10.1016/j.fcr.2010.09.004

Raseduzzaman, M. D., & Jensen, E. S. (2017). Does intercropping enhance yield stability in arable crop production? A meta-analysis. *European Journal of Agronomy*, *91*, 25–33. https://doi.org/10.1016/j.eja.2017.09.009

R Core Team. (2016). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from https://www.R-project.org/

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K. E., Merckx, R., Mokwunye, U., … Sanginga, N. (2010). Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*, *39*, 17–24. https://doi.org/10.5367/000000010791169998

Wickham, H. (2009). *ggplot2: Elegant Graphics for Data Analysis*. New York: Springer.

Wossen, T. G., Tessema, G., Abdoulaye, T., Rabbi, I., Olanrewaju, A., Alene, A., … Manyong, V. (2017). *The cassava monitoring survey in Nigeria final report*. Ibadan: International Institute of Tropical Agriculture (IITA).

How to cite this article: Kreye C, Hauser S, Pypers P, Vanlauwe B. Intensification options of small holders' cassava production in Southwest Nigeria. *Agronomy Journal*. 2020;1–13. https://doi.org/10.1002/agj2.20419