Assessing arthropod pests and disease occurrence in cassava (*Manihot esculenta* Crantz) and cowpea (*Vigna unguiculata* L. Walp) intercropping system in the Ashanti Region, Ghana

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ABSTRACT

On-station trials were conducted at CSIR-Crops Research Institute's research farms at Kwadaso and Ejura, Ashanti Region, Ghana, during 2010/2011 cropping season, to assess the pests and disease occurrence in cassava-cowpea intercrop farming systems and their effect on yield of produce. Three improved cassava varieties and a local variety were intercropped with an improved cowpea variety, and cowpea only constituted the treatments. Abundance of *Bemisia tabaci* was comparable between sole cassava and cassava-cowpea intercrop, but was significantly less on the sole cowpea. The incidence and severity of cassava mosaic disease was higher on the local variety than on the improved varieties. Root yield of cassava did not differ between sole and intercropped cassava with cowpea. However, Kwadaso had higher root yield than Ejura. Dry grain yield of cowpea was similar at Kwadaso and Ejura for both sole and intercrop scenarios. This baseline information will be useful on disease and pests incidence in sole crop and cassava-cowpea intercropping system.

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Introduction

Cassava, *Manihot esculenta* Crantz (Euphorbiaceae) is an important staple and food security crop widely cultivated in the tropics, especially for the rural and urban populations in Africa (Yaninek, James & Bieler, 1994; Manu-Aduening, Lamboll & Dankyi , 2005; Ennin, Otoo & Tetteh, 2009). It is the fourth most important source of carbohydrates for human consumption in the tropics after rice, sugar and maize (FAO, 2003). Cassava is mostly cultivated on small plots with minimal inputs, and the plant is well adapted to seasonally dry environments, where rainfall is limited and erratic (Belotti, 1999). A wide gap exists between the potential yield and the realized yield across different agro-ecologies (Henry, 1995). The factors responsible for the yield loss include low soil fertility, harsh environmental conditions, arthropod pests and diseases, weeds, and the limited use of inputs such as fertilizers and insecticides (Lamptey *et al*., 1998; Belotti, 1999; Manu-Aduening *et al*., 2007; Fening *et al*., 2012a, b).

Cassava is regarded as more tolerant to pests than most crops, because it does not have critical periods that pests attack affects yield-forming organs (Cock, 1978). However, current research has proven that several pests can reduce yields significantly when their populations are high and tied with favourable environmental conditions (Belloti, 1999). Pests of cassava in Ghana include whitefly, *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae), cassava green mite, *Mononychellus tanajoa* Bondar (Acari: Tetranychidae), cassava mealybug, *Phenacoccus manihoti* Mat. Ferr. (Hemiptera: Pseudococcidae), variegated grasshopper, *Zonocerus variegatus* L. (Orthoptera: Pyrgomorphidae), spiraling whitefly, *Aleurodicus dispersus* Russell (Homoptera: Aleurodidae) and millipedes (Diplopoda) (Korang-Amoakoh *et al*., 1987; Fening *et al*., 2012b). *B. tabaci* and *Z. variegatus* are regarded as generalist native pests of cassava in Africa (Modder, 1994; Yaninek, James & Bieler, 1994; Bellotti, 1999; Manu-Aduening *et al*., 2007). *P. manihoti* and *M. tanajoa* are neotropical pests that were accidentally introduced from South America into Africa in the early 1970s and 1980s, but *P. manihoti* was successfully controlled through classical biological control effort (Herren & Neuenschwander, 1991; Neuenschwander, 1994; Bellotti, 1999). The cassava green mite (CGM), *M. tanajoa,* causes tiny yellow chlorotic spots (about the size of pin pricks) on the upper leaf surfaces of cassava (James *et al*., 2000). Young leaves attacked by CGM become small and narrow. CGM kills the terminal leaves and as they drop, the shoot tip has the appearance of a "candlestick" (James *et al*., 2000). Cassava mosaic disease (CMD) is transmitted by *B. tabaci* and is regarded as the most damaging disease constraint to cassava production in Africa (Thresh *et al.*, 1994; Bellotti, 1999; Ariyo, Dixon & Atiri, 2005).

Key insect pests found on cowpea in Ghana include cowpea aphid, *Aphis craccivora* Koch (Homoptera: Aphididae), pod borer, *Maruca vitrata* F. (Lepidoptera: Pyralidae), flower thrip, *Megalurothrips sjostedti* Trybom (Thysanoptera: Thripidae), the pod sucking bugs (PSBs) complex: *Clavigralla tomentosicollis* Stäl (Hemiptera: Coreidae), *Riptortus dentipes* F. (Heteroptera: Coreidae), *Nezara virudula* L. (Heteroptera: Pentatomidae), *Dysdercus superstitiosus* F. (Heteroptera: Pyrrhocoridae) and late field and storage pest, *Callosobruchus maculatus* F. (Coleoptera: Bruchidae) (Fening, 2004; Fening *et al.*, 2011).

In Africa, traditional cassava production usually involves intercropping (Nweke *et al*., 1994). The use of improved varieties and intercropping may have the potential to reduce the pest population and diseases occurrence (Legg *et al.*, 2005; Thresh & Cooter, 2005; Fening *et al.*, 2012a). In addition, intercropping may facilitate more efficient use of resources, greater return on available land, protection against soil erosion, improved soil fertility and weed management (Gold, 1993, 1994; Dapaah *et al*., 2009). Also, short duration intercrop provides an early return in cassava-based cropping systems. Furthermore, such diversified agro-ecosystems, including intercrops may often support lower herbivore load than corresponding monocultures (Riscal, Andow & Altieri, 1983). Manipulation of cropping systems, therefore, provides an important pest management tool which can be readily adopted by small scale farmers, many of whom already use intercropping systems to intensify production on limited areas of land (Gold, 1993, 1994). Intercropping cassava with cowpea may offer the small-scale farmer an effective means of reducing pests' population as well as improving soil fertility for enhanced growth of young cassava plants. This ultimately will result in increased productivity of crop, and additional income and nutritional gains to the small scale farmer.

The aim of the current study is to assess pests and disease occurrence within cassava-cowpea intercrop cropping system, and their effect on quality of harvested fresh cassava and dry grain yield of cowpea.

Materials and methods

Study sites

On-station field trials were conducted between June 2010 and June 2011 at the Council for Scientific and Industrial Research (CSIR)-Crops Research Institute's (CRI) experimental fields at Kwadaso and Ejura in the Ashanti Region of Ghana. Kwadaso and Ejura belong to the moist semi-deciduous forest and forest-Savanna transition zone, respectively, and fall within the key cassava producing agro-ecological zones in Ghana (FAO, 2005). Kwadaso (60° 42'N, 10° 40'W) lies 262 m above sea level with average temperature range of 21.5 – 30.7 °C and relative humidity (RH) of 60 – 84 per cent (MoFA, 2011). The annual rainfall is between 1200 – 1600 mm and the soil type is described as Orthic-Ferric Acrisols (well drained sandy clay loam soil) (Adu, 1992). The rainfall pattern at Kwadaso is reliable and evenly distributed (MoFA, 2011). Ejura (70° 23' N, 10° 21' W) lies 228 m above sea level with average temperature of 21 – 31 °C and RH of 55 – 90 per cent (MoFA, 2011).

Table 1

Soil Fertility Status at Kwadaso and Ejura in the Ashanti Region of Ghana at the Onset of the Experiment in June 2010

Soil nutrient	*Kwadaso*	*Ejura*	*t, P*
*p*H	5.73 ± 0.19	5.13 ± 0.09	2.92, 0.0432*
Organic matter (%)	1.65 ± 0.05	0.77 ± 0.08	9.56 ± 0.0007*
Total Nitrogen (%)	0.11 ± 0.00	0.11 ± 0.00	0.00, 1.000
P (mg kg^{-1})	17.45 ± 1.71	16.29 ± 2.64	0.37, 0.7313
K (mg kg^{-1})	87.37 ± 10.00	87.04 ± 3.87	0.02, 0.9825
Organic Carbon (%)	0.96 ± 0.03	0.45 ± 0.04	9.84, 0.0006*
PBS	90.00 ±1.83	69.90 ± 2.58	6.36, 0.0031*
Al (cmol kg^{-1})	0.38 ± 0.04	0.63 ± 0.07	2.94, 0.0423*
K (cmol kg^{-1})	0.22 ± 0.03	0.08 ± 0.00	4.85, 0.0083*
Na (cmol kg^{-1})	0.06 ± 0.01	0.04 ± 0.01	2.21, 0.0913
Mg (cmol kg^{-1})	0.94 ± 0.13	0.40 ± 0.00	4.03, 0.0158*
Ca (cmol kg^{-1})	2.40 ± 0.03	0.93 ± 0.00	4.77, 0.0088*
ECEC	4.00 ± 0.44	2.09 ± 0.06	4.30, 0.0126*
TEB	3.62 ± 0.46	1.46 ± 0.01	4.67, 0.0095*

Student's t test ($P < 0.05$) was performed between rows.

The annual rainfall is between 1100 – 1400 mm, and the soil type is described as Dystric Cambisol or Ejura Series with 20 – 30 cm top layer of loamy soils (FAO, 1988). The rainfall pattern at Ejura is erratic (MoFA, 2011). Soil nutrient parameters obtained for Kwadaso and Ejura field sites are shown in Table 1, with Kwadaso having high fertility status than Ejura.

Experimental design and treatments

The experiment was laid in a randomised complete block design (RCBD) with nine treatments replicated three times. Three improved cassava varieties, bred for resistance to some pests and diseases, from CSIR-CRI (‘Doku-duade’, ‘Afisiafi’ and ‘Ampong’) and a local farmer variety (‘Akosua tuntum’) was intercropped with an improved cowpea variety (‘Nhyira’), and ‘Nhyira’ only constituted the treatments. ‘Doku-duade’ and ‘Afisiafi’ are old cassava varieties than Ampong. This selection of varieties were done in order to establish if the varietal resistance or tolerance to pests and disease breakdown with time.

Establishment of cassava and cowpea intercrop fields and data collection

Cassava cuttings were planted on 16th and 29th June 2010 at Ejura and Kwadaso, respectively. Cowpea seeds (‘Nhyira’) were sown 4 weeks after planting cassava. The spacing was 100 cm × 100 cm for cassava, 60 cm × 20 cm for cowpea, with one row of cassava plants and two rows of cowpea plants. There were six rows of cassava plants per plot and five plants were randomly selected from the two inner rows for sampling. *B. tabaci* counts were made fortnightly, and begun 4 weeks after planting the cassava until plants were 6 months old. On each scoring day, between 0600 and 0800 h when the whiteflies were relatively immobile, adult whitefly populations on the five topmost expanded leaves of cassava were counted and recorded as whitefly number per cassava plant (Ariyo, Dixon & Afiri, 2005). Other pests found on the sole cassava, cassava and cowpea intercrop and sole cowpea were also counted. The number of spiraling whiteflies, *A. dispersus,* and cassava mealybug, *P. manihoti,* were also counted during the dry season.

CGM infestation severity on cassava leaves was scored using a scale of 1–5 to assess its damage, where 1 = no symptoms and 5 = severe damage symptoms (IITA 1990; Okechukwu & Dixon, 2009). Soil arthropods were also counted during the harvesting of cassava. Six cassava stands were randomly selected from the two inner rows of each plot and harvested for assessment and counting of soil arthropods. Approximately 1 kg of soil was taken from a depth of 0 – 10 cm from the surface, where the cassava was uprooted and was placed on a flat tray for counting of millipedes and other soil arthropods. Number of roots with millipede holes and number of millipede holes per root, the total number of millipede per cassava stand and the number of other soil arthropods such as termites were counted.

Data on CMD were obtained by using two disease parameters, disease incidence (DI) calculated as number of plants infected per total number of plants evaluated per plot (Lamptey *et al*., 1998), and index of symptom severity (ISS) on a scale 1–5, where 1 indicates no symptoms on leaves; 2 indicates mild chlorotic pattern on entire leaflets or mild distortions of the base of leaflets, the rest of leaflets looking green and healthy; 3 indicates strong mosaic pattern on entire leaf, narrowing and distortion of lower one-third of leaflets; 4 indicates severe mosaic and distortion of two-thirds of leaflets and general reduction of leaf size; and 5 indicates severe mosaic and distortion of four-fifths or more of leaflets, twisted and misshapen leaves (IITA, 1990). These were scored on a plant basis each month for 6 months, starting from 1 month after planting of the cassava at each of the locations.

Data on cowpea pests were also collected. Pod sucking bugs and *M. vitrata* damage in pods were assessed by sampling 10 pods at random from each field at weekly intervals. The visible scars, narrowing and deformation of pods, which is characteristic of the sucking activity of PSBs, were used as an indicator of PSBs infestation in cowpea pods. The characteristic round holes in pods by *M. vitrata* were used as an indicator to assess its damage (Fening, 2004). Thirty dry pods were randomly selected from each plot for assessment of seed damage attributable to either *M. vitrata* larvae or *C. maculatus* following the methods of Fening (2004).

Soil sample analysis, field maintenance and yield assessment

Soil samples were taken prior to the planting of cassava for nutrient analysis. The soil samples were randomly taken at depths of 0 – 20 cm using an auger and were bulked for all the plots in each of the locations to offer baseline information on the soil nutrient levels. The soil nutrient analysis was conducted at the soil fertility laboratory of the CSIR-Soil Research Institute (SRI) in Kumasi, Ghana. All cultural practices were observed. Hand weeding was employed as and when necessary but pesticides and fertilizers were not applied.

The dry grain yield of harvested cowpea was obtained and expressed in kg ha^{-1}. Quality of grain was measured by assessing the seed damage attributable to *C. maculatus* and *M. vitrata* larvae. Cassava was harvested 12 months after planting at both locations. The fresh root yield was weighed and reported in t ha^{-1}. The number of holes and any visible sign of damage on the harvested cassava roots caused by soil arthropods were recorded after harvesting for each plot as an indicator of root quality.

Data analysis

Count and proportion data were log (x+1) and arcsine square root transformed, respectively, before they were analysed. The data were analysed with analysis of variance (ANOVA) using the SAS programme (SAS Instititute Inc. 2011), and where significant differences occurred, mean separation was done using SNK ($P < 0.05$). Back transformed means were presented. Data on scores of GCM infestation and CM incidence were analysed using Kruskal-Wallis H test ($P < 0.05$).

Results

At the onset of the trials, the fertility of the soils were generally low to medium (Table 1). The soil at Kwadaso had higher *p*H, organic matter (OM), organic carbon (OC), K, Mg, Ca, percentage base saturation (PBS), total exchangeable bases (TEB), and effective cation exchange capacity (ECEC) than the soil at Ejura (Table 1). Al was, however, higher at Ejura than Kwadaso soil.

B. tabaci adults on cassava were more abundant at Kwadaso than at Ejura (Table

2). Generally, the abundance of *B. tabaci* was similar for sole cassava and cassava-cowpea intercrop, and was, however, significantly ($P < 0.05$) lower on the sole cowpea. The incidence and severity of CMD were significantly ($P < 0.05$) higher on the local variety, 'Akosua tuntum' than on the improved varieties ('Ampong', 'Doku-duade'

TABLE 2

Mean (± se) Abundance of Adult Bemisia tabaci *under Cassava-Cowpea Cropping Systems during the Major Season of 2010 at Kwadaso and Ejura in the Ashanti Region of Ghana*

Cropping system	*Total no. of adult* B. tabaci		*t, P*
	Kwadaso	*Ejura*	
Sole Akosua tuntum	13.05 ± 4.37dc	3.07 ±0.85a	3.21, 0.0325*
Sole Ampong	37.53 ± 3.80a	4.07 ± 1.05a	3.86, 0.0495*
Sole Doku-duade	32.53 ± 7.65ab	2.53 ± 0.07a	3.97, 0.0463*
Sole Afisiafi	13.53 ± 0.98bcd	3.00 ± 0.12a	3.86, 0.0495*
Akosua tuntum + Nhyira	19.67 ± 5.50abcd	3.07 ± 0.29a	3.86, 0.0495*
Ampong + Nhyira	33.73 ± 7.48ab	4.53 ± 1.10a	6.31, 0.0032*
Doku-duade + Nhyira	24.00 ± 2.65abcd	3.20 ± 0.31a	13.56, 0.0002*
Afisiafi + Nhyira	10.73 ± 2.48d	1.87 ± 0.47a	5.10, 0.0070*
Sole Nhyira	0.13 ± 0.13e	0.80 ± 0.70b	0.48, 0.4867
F	29.22	3.98	
P	< 0.0001*	0.0048*	

Means within the same column with the same letter(s) are not significantly different. SNK test ($P < 0.05$) was performed within columns and Student's t test ($P < 0.05$) was performed between rows.

TABLE 3

Mean (± se) Incidence of Cassava Mosaic Disease under Cassava-Cowpea Cropping Systems During the Major Season of 2010 at Ejura and Kwadaso in the Ashanti Region of Ghana

Cropping system	*Mean incidence (%)*		*t, P*
	Ejura	*Kwadaso*	
Sole Akosua tuntum	91.07 ± 1.78a	95.57 ± 2.63a	1.22, 0.2683
Sole Ampong	0.00 ± 0.00c	1.28 ± 1.28c	1.00, 0.3173
Sole Doku-duade	0.00 ± 0.00c	0.72 ± 0.72c	1.00, 0.3173
Sole Afisiafi	4.93 ± 2.52bc	8.88 ± 5.17bc	0.78, 0.3758
Akosua tuntum + Nhyira	68.55 ± 2.19a	84.57 ± 4.00a	3.86, 0.0495*
Ampong + Nhyira	0.75 ± 0.75c	0.00 ± 0.00c	1.00, 0.3173
Doku-duade + Nhyira	0.00 ± 0.00c	0.00 ± 0.00c	0.00, 1.0000
Afisiafi + Nhyira	14.78 ± 10.20b	14.07 ± 7.20b	0.00, 1.000
F	34.25	30.40	
P	< 0.0001*	< 0.0001*	

Means within the same column with the same letter(s) are not significantly different. SNK test ($P < 0.05$) was performed within columns and Student's t test ($P < 0.05$) was performed between rows.

and 'Afisiafi') (Table 3 and 4). However, the incidence of the CMD on 'Akosua tuntum' and 'Nhyira' intercrop was significantly ($P < 0.05$) higher in Kwadaso than in Ejura. The number of *A. dispersus* on sole 'Afisiafi' cropping system was significantly ($P < 0.05$) higher than on sole 'Ampong', and 'Doku-duade' - 'Nhyira' intercrop (Fig. 1).

TABLE 4

Mean (±se) Severity of Cassava Mosaic Disease (scale of 1-5) for Different Cassava-Cowpea Cropping Systems during the Major Season of 2010 at Ejura and Kwadaso in the Ashanti Region of Ghana

Cropping system	*Mean severity score*		*t , P*
	Ejura	*Kwadaso*	
Sole Akosua tuntum	3.50 ± 0.58a	3.67 ± 0.33a	0.25, 0.8149
Sole Ampong	1.00 ± 0.00c	1.25 ± 0.25b	1.00, 0.3739
Sole Doku-duade	1.00 ± 0.00c	1.00 ± 0.00b	0.00, 1.0000
Sole Afisiafi	2.00 ± 0.58bc	1.50 ± 0.29b	0.77, 0.4818
Akosua tuntum + Nhyira	3.00 ± 0.29ab	2.67 ± 0.88ab	0.00, 1.0000
Ampong + Nhyira	1.17 ± 0.17c	1.00 ± 0.00b	1.00, 0.3173
Doku-duade + Nhyira	1.00 ± 0.00c	1.00 ± 0.00b	0.00, 1.0000
Afisiafi + Nhyira	1.83 ± 0.44bc	1.33 ± 0.33b	0.89, 0.3458
F	6.30	5.55	
P	0.0006*	0.0012*	

Means within the same column with the same letter(s) are not significantly different. SNK test ($P < 0.05$) was performed

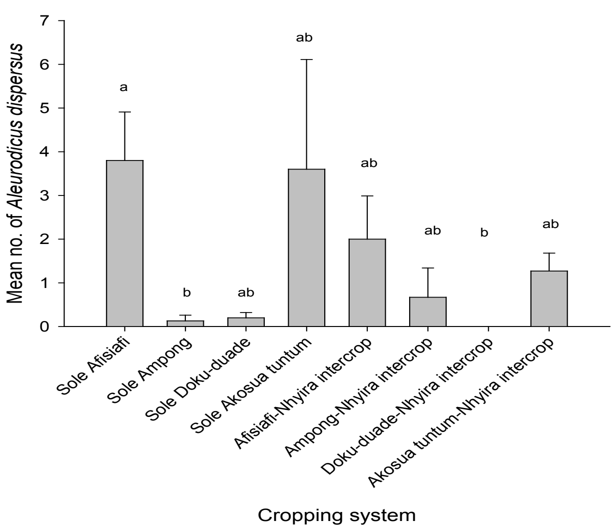

Fig. 1. Mean (± se) number of spiraling whitefly (*Aleurodicus dispersus*) under cassava- cowpea cropping systems during the off-season of 2011 at Kwadaso in the Ashanti Region. Bars having means with the same letter(s) are not significantly different. SNK test ($P < 0.05$).

The incidence of CM, *P. manihoti,* and CGM, *M. tanajoa,* were similar among the different cropping systems at Kwadaso (Table 5). The infestation by millipedes (Diplopoda) and termites (Isoptera) in the soil at the time of harvesting the cassava was generally significantly ($P < 0.05$) higher at Kwadaso than at Ejura (Tables 6 and 7). Number of cassava roots with millipede holes was significantly higher ($P < 0.05$) for sole 'Ampong' than the other cropping systems at Kwadaso (Table 6). However, the highest number of termites occurred on sole 'Ampong' and 'Ampong-Nhyira' intercrop at Kwadaso. Sole 'Afisiafi' had significantly ($P < 0.05$)

TABLE 5

Mean (± se) Number of Cassava Plants Infested with Cassava Mealybug (CM), P. manihoti *and Mean Score of Cassava Green Mite (CGM),* M. tanajoa *(scale of 1-5) under Cassava-Cowpea Cropping Systems during the Major Season of 2010 at Kwadaso in the Ashanti Region of Ghana*

Cropping system	*Mean no. of cassava plants infested with CM (%)*	*Mean injury score of CGM on top five expanded leaves*
Sole Afisiafi	80.00 ± 20.00a	3.20 ± 0.76a
Sole Ampong	26.67 ± 6.67a	1.93 ± 0.74a
Sole Doku-duade	13.33 ± 13.33a	2.20 ± 0.20a
Sole Akosua tuntum	53.33 ± 24.04a	3.40 ± 0.50a
Afisiafi + Nhyira	40.00 ± 11.55a	3.47 ± 0.24a
Ampong + Nhyira	20.00 ± 11.55a	2.33 ± 0.67a
Doku-duade + Nhyira	6.67 ± 6.67a	1.20 ± 0.12a
Akosua tuntum + Nhyira	13.33 ± 13.33a	2.87 ± 0.33a
χ^2	11.85	12.73
P	0.1580	0.1214

Kruskal-Wallis H test ($P < 0.05$) was performed within columns. The χ^2 approximation of the Kruskal-Wallis H value is given in the table. Means within the same column with the same letter(s) are not significantly different.

higher infestation of millipedes and termites at Ejura (Table 7). It also had a significantly ($P < 0.05$) higher number of centipedes (Chilopoda) per plant stand than the other cropping systems at Ejura. The improved cassava variety, 'Afisiafi' had significantly ($P < 0.05$) high levels of *A. dispersus*, cassava mealybugs, millipedes, termites and incidence of CMD. Damage by pod sucking bugs (PSBs), *M. vitrata* larvae in cowpea pods and *C. maculatus*, PSBs and *M. vitrata* larvae in cowpea seeds was similar among the different cassava-cowpea cropping systems at Ejura (Table 8). Sole 'Nhyira' had significantly ($P < 0.05$) higher infestation of PSBs in seeds than when it was intercropped with 'Ampong' and 'Doku-duade' at Ejura.

Generally, the fresh root yield of cassava at Kwadaso was higher than at Ejura (Table 9). Root yield of cassava planted as sole crop or intercropped with cowpea were also comparable at both Kwadaso and Ejura. Sole 'Afisiafi', 'Ampong-Nhyira' intercrop, sole 'Ampong', 'Afisiafi-Nhyira' intercrop and sole 'Doku-duade' had significantly ($P < 0.05$) higher root yield at Kwadaso. Sole 'Ampong' had significantly ($P < 0.05$) higher root yield at Ejura, followed by the other cropping systems with sole 'Akosua tuntum' and 'Akosua tuntum-Nhyira' intercrop having the least root yield (Table 9). Dry grain yield of cowpea was similar at Kwadaso and Ejura for the different cropping systems (Table 10). Dry grain yield of cowpea planted as a sole crop or intercropped with cassava were comparable at Kwadaso. 'Akosua tuntum' and 'Nhyira' intercrop, however, had significantly ($P < 0.05$) higher dry grain yield of cowpea at Ejura (Table 10).

Discussion

The soil at Kwadaso had significantly higher fertility status than at Ejura as depicted in its high organic matter, organic carbon and oth-

TABLE 6

Mean (± se) Millipede Infestation on Cassava Roots and other Soil Arthropods in the Vicinity of Harvested Roots at Kwadaso in September 2011

Cropping system	*No. of roots with millipede holes (%)*	*No. of millipede holes per root*	*No. of millipedes per plant stand*	*No. of rotten tubers per plant stand*	*No. of termites per plant stand*	*No. of black ants per plant stand*	*No. of centipedes per plant stand*
Sole Akosua tuntum	7.39 ± 0.81b	0.53 ± 0.18b	0.43 ± 0.09c	1.00 ± 0.29a	0.00 ± 0.00b	0.20 ± 0.06c	0.91 ± 0.38a
Sole Doku-duade	6.80 ± 1.95b	0.13 ± 0.03c	3.67 ± 0.88a	0.13 ± 0.03b	1.10 ± 0.10b	5.40 ±0.49b	0.00 ± 0.00a
Sole Ampong	16.99 ± 4.25a	0.87 ± 0.07a	1.67 ± 0.20abc	0.07 ± 0.03b	14.90 ± 2.72a	5.87 ± 0.87b	0.00 ± 0.00a
Sole Afisiafi	0.76 ± 0.39b	0.00 ± 0.00c	2.57 ± 0.69ab	0.00 ± 0.00b	0.00 ± 0.00b	1.43 ± 0.30c	0.56 ± 0.11a
Akosua tuntum + Nhyira intercrop	4.74 ± 0.88b	0.07 ± 0.03c	0.33 ±0.04c	0.07 ± 0.03b	0.44 ± 0.08b	1.89 ± 0.31c	0.21 ± 0.07a
Doku-duade + Nhyira intercrop	2.63 ±0.43b	0.40 ± 0.12bc	1.33 ± 0.19bc	1.27 ± 0.07a	0.22 ± 0.08b	5.78 ± 1.06b	0.10 ± 0.06a
Ampong + Nhyira intercrop	0.00 ± 0.00b	0.00 ± 0.00c	2.56 ± 0.63ab	1.00 ± 0.29a	11.78 ± 0.97a	1.44 ± 0.29c	0.10 ± 0.06a
Afisiafi + Nhyira intercrop	0.67 ± 0.17b	0.37 ± 0.13bc	2.00 ± 0.29abc	0.00 ± 0.00b	3.11 ± 0.67b	6.11 ± 1.06b	0.00 ± 0.00a
F	10.68	10.70	6.59	15.50	34.60	21.72	1.24
P	< 0.0001*	< 0.0001*	0.0005*	< 0.0001*	< 0.0001*	< 0.0001*	0.6065

Means within the same column with the same letter(s) are not significantly different. SNK test ($P < 0.05$).

TABLE 7

Mean (± se) Millipede Infestation on Cassava Roots and other Soil Arthropods in the Vicinity of Harvested Roots at Ejura in September 2011 and other Soil

Cropping system	*No. of roots with millipede holes (%)*	*No. of millipede holes per root*	*No. of millipedes per plant stand*	*No. of rotten tubers per plant stand*	*No. of termites per plant stand*	*No. of black ants per plant stand*	*No. of centipedes per plant stand*
Sole Akosua tuntum	0.00 ± 0.00c	0.00 ± 0.00b	0.00 ± 0.00b	0.00 ± 0.00b	0.13 ± 0.03bc	0.00 ± 0.00b	0.07 ± 0.02b
Sole Doku-duade	0.00 ± 0.00c	0.00 ± 0.00b	0.00 ± 0.00b	0.00 ± 0.00b	0.60 ± 0.02a	0.00 ± 0.00b	0.00 ± 0.00b
Sole Ampong	0.00 ± 0.00c	0.00 ± 0.00b	0.07 ± 0.02a	0.00 ± 0.00b	0.00 ± 0.00c	0.07 ± 0.02b	0.00 ± 0.00b
Sole Afisiafi	5.08 ± 0.62a	0.04 ± 0.01a	0.00 ± 0.00b	0.37 ± 0.18a	0.47 ± 0.07ab	0.30 ± 0.06a	0.00 ± 0.00b
Akosua tuntum + Nhyira intercrop	0.00 ± 0.00c	0.00 ± 0.00b	0.00 ± 0.00b	0.00 ± 0.00b	0.47 ± 0.18ab	0.07 ± 0.02b	0.00 ± 0.00b
Doku-duade + Nhyira intercrop	0.00 ± 0.00c	0.00 ± 0.00b	0.00 ± 0.00b	0.00 ± 0.00b	0.13 ± 0.03bc	0.00 ± 0.00b	0.00 ± 0.00b
Ampong + Nhyira intercrop	0.00 ± 0.00c	0.00 ± 0.00b	0.00 ± 0.00b	0.00 ± 0.00b	0.07 ± 0.02bc	0.00 ± 0.00b	0.27 ± 0.07a
Afisiafi + Nhyira intercrop	0.78 ± 0.10b	0.00 ± 0.00b	0.00 ± 0.00b	0.13 ±0.03b	0.20 ± 0.06bc	0.07 ± 0.02b	0.07 ± 0.02b
F	63.08	43.79	16.00	4.34	5.16	7.70	13.00
P	< 0.0001*	< 0.0001*	< 0.0001*	0.0046*	0.0019*	0.0002*	< 0.0001*

Means within the same column with the same letter(s) are not significantly different. SNK test ($P < 0.05$).

TABLE 8

Mean (± se) Number of Pod and Seed Damage by Pod Sucking Bugs, Maruca vitrata *and* Callosobrunchus maculatus *on Cowpea Variety, Nhyira Intercropped with Different Cassava Cultivars during the Major Season of 2010 at Ejura and Kwadaso.*

Cropping system	*EJURA*				
	No. of pods with PSB damage (%)	*No. of pods with* M. vitrata *damage (%)*	*No. of seeds with* C. maculatus *damage (%)*	*No. of seeds with PSB damage (%)*	*No. of seeds with* M. vitrata *damage (%)*
Afisiafi + Nhyira	66.67 ± 8.82a	33.33 ± 3.33a	3.75 ± 1.96a	2.32 ± 1.64a	5.00 ± 1.59a
Doku-duade + Nhyira	73.33 ± 3.33a	46.67 ± 6.67a	5.90 ± 0.26a	2.76 ± 0.66a	9.72 ± 0.86a
Ampong + Nhyira	75.00 ± 8.66a	50.00 ± 0.00a	5.68 ± 0.68a	1.54 ± 0.24a	8.06 ± 2.71a
Akosua tuntum + Nhyira	75.00 ± 2.89a	37.67 ± 1.45a	6.40 ± 0.29a	2.54 ± 0.03a	5.92 ± 0.07a
Sole Nhyira	83.33 ± 6.67a	36.67 ± 8.82a	5.74 ± 0.77a	2.24 ± 0.25a	3.26 ± 0.72a
F	0.89	1.77	0.98	0.46	2.81
P	0.5026	0.2123	0.4599	0.7610	0.0843
			KWADASO		
Afisiafi + Nhyira	75.00 ± 2.89ab	45.00 ± 2.89a	9.18 ± 0.60a	3.31 ± 0.06ab	6.26 ± 0.32ab
Doku-duade + Nhyira	60.00 ± 5.77ab	45.00 ± 2.89a	7.81 ± 0.07a	2.09 ± 0.06b	5.83 ± 1.08ab
Ampong + Nhyira	80.00 ± 5.77a	35.00 ± 2.89ab	7.66 ± 0.95a	2.39 ± 0.71b	7.71 ± 0.42a
Akosua tuntum + Nhyira	70.00 ± 5.77ab	25.00 ± 2.89b	7.11 ± 0.34a	4.92 ± 0.30a	4.92 ± 0.33b
Sole Nhyira	55.00 ± 2.89b	35.00 ± 2.89ab	7.79 ± 0.26a	4.54 ± 0.10a	7.03 ± 0.02ab
F	4.48	8.54	1.71	10.50	3.60
P	0.0248*	0.0029*	0.2233	0.0013*	0.0455*

PSBs (Pods Sucking Bugs): Anoplocnemis curvipes, Clavigralla tomentosicollis, Riptortus dentipes, Nezara virudula and Dysdercus superstitiosus. Means within the same column with the same letter(s) are not significantly different. SNK test ($P < 0.05$).

TABLE 9

Fresh Root Yield of Cassava Planted Under Cassava-cowpea Cropping Systems in 2010 at Kwadaso and Ejura

Cropping system	*Fresh root yield (tons/ha)*		*t , P*
	Kwadaso	*Ejura*	
Sole Akosua tuntum	37.33 ± 8.11dc	17.33 ± 5.33c	2.06, 0.1084
Sole Doku-duade	65.00 ± 13.00abcd	42.33 ± 1.76b	0.81, 0.3687
Sole Ampong	93.00 ± 3.51ab	65.67 ± 4.41a	4.85, 0.0083*
Sole Afisiafi	98.33 ± 8.44a	39.67 ± 0.88b	3.86, 0.0495*
Akosua tuntum + Nhyira intercrop	27.00 ± 3.61d	12.67 ± 0.33c	3.98, 0.0463*
Doku-duade + Nhyira intercrop	59.33 ± 3.18bcd	38.33 ± 8.67b	3.14, 0.0765
Ampong + Nhyira intercrop	94.67 ±13.84a	44.67 ± 2.91b	3.86, 0.0495*
Afisiafi + Nhyira intercrop	85.33 ± 15.67abc	34.33 ± 5.24b	3.98, 0.0463*
F	7.27	13.10	
P	0.0002*	< 0.0001*	

SNK test ($P < 0.05$) was performed within columns and Student's t test ($P < 0.05$) was performed between rows. Means within the same column with the same letter(s) are not significantly different.

TABLE 10

Mean (± se) Dry Grain Yield of Cowpea (Nhyira) under Cassava-cowpea Cropping Systems During the Major Season of 2010 at Kwadaso and Ejura

Cropping systems	*Dry grain yield (kg ha^{-1})*		*t , P*
	Kwadaso	*Ejura*	
Afisiafi + Nhyira intercrop	23.33 ± 1.73a	30.14 ± 8.23b	0.05, 0.8273
Doku-duade + Nhyira intercrop	54.36 ± 2.71a	56.91 ± 5.29b	0.43, 0.6904
Ampong + Nhyira intercrop	39.05 ± 1.67a	57.44 ± 16.90b	0.43, 0.5127
Akosua tuntum + Nhyira intercrop	68.01 ± 29.52a	147.98 ± 34.74a	1.75, 0.1543
Sole Nhyira	82.40 ± 36.02a	42.02 ± 21.79b	0.96, 0.3918
F	1.24	5.29	
P	0.3544	0.0150*	

SNK test ($P < 0.05$) was performed within columns and Student's t test ($P < 0.05$) was performed between rows. Means within the same column with the same letter(s) are not significantly different.

er important extractable cations, base saturation and also being less acidic. Nevertheless, the mean values obtained from the soil nutrient analysis are in line with that documented for the Ashanti Region of Ghana (FAO, 2005). The low *p*H of the soils might have affected the availability and solubility of other important plant nutrients, thus, the observed low values of P, K, Ca and Mg. Although most plant prefers a *p*H range of 6 – 6.8 for optimum absorption of important soil nutrients, cassava can tolerate low *p*H (< 4) (Islam, Edwards & Asher, 1980; Howeler, 1991) and have optimum *p*H of 4.5 – 7.5 (Howeler, 1981).

The abundance of *B. tabaci* adults did not differ among the sole cassava and cassava-cowpea intercrop, except the sole cowpea which had the least number (0.13 – 0.80) of *B. tabaci*. This result differ from other opinions that intercropping cassava with cowpea is likely to attract *B. tabaci* to the alternative host, cowpea, and cause a reduction in their number on the main host, cassava (Riscal, Andow & Altieri, 1983; Gold, Altieri & Belloti, 1990; Gold 1994; Nweke *et al.*, 1994). This means *B. tabaci* may prefer cassava which is the main host than cowpea as an alternative host. A subsequent study at Ejura in the minor season of 2011 where cowpea was sown without cassava recorded high numbers of *B. tabaci* (9.00 – 54.60) depending upon the variety (Fening, unpublished). Thus, varietal effect may also influence the preference of *B. tabaci* on cowpea.

Despite the similarity in abundance of *B. tabaci* adults, the incidence and severity of CMD was highest on the local cassava variety, 'Akosua tuntum', than the CSIR-CRI improved varieties. The improved varieties exhibited some good levels of tolerance against CMD. Most studies support the finding that improved varieties of cassava often exhibit some level of resistance or tolerance to CMD as opposed to the traditional local varieties that are highly susceptible to the disease (Fargette & Thresh, 1994; Okechukwu & Dixon, 2009). Cassava is more cultivated at Kwadaso than Ejura and this may partly explain why abundance of *B. ta-*

baci and incidence of CMD was higher for 'Akosua tuntum' and 'Nhyira' intercrop at Kwadaso than at Ejura.

As observed in the study, *A. dispersus* is regarded as an important pest of cassava, especially during the dry season in Ghana, Nigeria and other African countries (Neuenschwander, 1994; Banjo 2010). The results revealed the upsurge in the abundance of CGM and, especially, CM, which were taught to have been successfully controlled in the early 1990s in Ghana, Nigeria and other neighbouring countries through biological control (Herren &Neuenschwander, 1991; Neuenschwander, 1994; Bellotti, 1999; James *et al.*, 2000). There is, therefore, the need to intensify the biological control efforts to ensure that resurgence of the CM does not occur. As observed in the study, sole cowpea and 'Nhyira' had higher infestation of PSBs in seeds than when it was intercropped with the improved cassava varieties, 'Ampong' and 'Doku-duade' at Ejura. This is because diversified agroecosystems such as intercropping may often support lower herbivore load than their corresponding monocultures (Riscal, Andow & Altieri, 1983).

The high numbers of millipedes and termites observed in the soil at Kwadaso than at Ejura could be attributable to the fact that Kwadaso had high rainfall (MOFA, 2011) and soil organic matter content than Ejura, and this may favour their development. Interestingly, the millipedes and termites seem to prefer the roots of the improved cassava varieties than the local variety, probably due to their large sizes and succulence, which serve as a source of abundant food for them. Termites are known as important pests of cassava by burrowing into roots and stem cuttings (James *et al*., 2000). The study had also shown that millipedes are increasingly becoming important pest of cassava in Ghana. A recent study in three districts of the Western Region of Ghana reported millipedes as causing significant damage to cassava roots and sprouting buds of stem cuttings (Fening *et al*., 2012b). Generally, the abundance of cowpea pests did not differ so much between sole cowpea and cowpea-cassava intercrop. Despite the high levels of *B. tabaci* found on both the improved and local cassava varieties, the local variety was more susceptible to CMD compared to the improved varieties which will be regarded as being tolerant to the disease. The fresh root yields of the improved varieties were, therefore, higher than the local variety.

The root yield in Kwadaso was higher than at Ejura, and this could be partly due to the enhanced soil fertility and high rainfall at Kwadaso (MOFA, 2011). The observed trend whereby the root yield was similar between cassava planted as sole crop and cassava intercropped with cowpea at Kwadaso agrees with the findings of Njoku & Muoneke (2008) in Kenya, where the root yield of sole cassava and cassava intercropped with cowpea had similar yields during the 2004/2005 cropping season. The study showed that yield of sole 'Ampong' was significantly higher than when it was intercropped with cowpea. This observation also differs from the study by Njoku & Muoneke (2008), where the root yield of cassava intercropped with cowpea was higher than yield obtained from sole cassava during the 2005/2006 cropping season. According to their study, higher yield obtained from cassava intercropped with cowpea could be due to the additional nitrogen supplied by the cowpea in the intercropping system. On the other hand, absence of competition of cassava with cowpea for space and nutrients uptake may also lead to higher root yield as observed at Ejura.

Generally, the dry grain yield of cowpea was lower than expected for both sole cowpea and when intercropped with cassava. This could partly be because no insecticide spray was undertaken to manage the insect pests of cowpea in the field. Cowpea dry grain yield being similar between cowpea planted as sole crop or intercropped with cassava at Kwadaso and Ejura concurs with the results obtained by Njoku & Muoneke (2008) in Nigeria, where there was no significant difference between the dry grain yields of cowpea planted as sole or intercropped with cassava for the 2004/2005 and 2005/2006 cropping seasons.

Although there were varied responses to the occurrence of pests, disease and obtainable yields for cassava and cowpea planted as sole crops and intercrops at the two locations, which belong to different agro-ecologies, the important role of planting improved varieties in terms of their resistance or tolerance to pests and diseases and associated high yield cannot be overemphasized. Even though farmers may prefer local cassava varieties due to their special attributes like taste and ease of pounding it into fufu (Fening *et al.*, 2012b), it is recommended that farmers should plant more of the improved cassava varieties as sole crops, which turn to be tolerant to most of the pests and are resistant to CMD in the field leading to increased root yields. The sole cassava cropping system may be more preferred than the cassava-cowpea intercrop, since the intercrop did not have any advantage in terms of disease and pests' incidence and yield increases for both cassava and cowpea. It appears that farmers may have to spray the cowpea with an appropriate insecticide in order to get reasonable yields. The effect of the insecticide on the pests and natural enemies within the cassava-cowpea ecosystem, however, needs to be investigated fully before this advice could be adopted.

The study has offered useful baseline information of the disease and pests incidence in sole crop and cassava-cowpea intercropping systems so as to inform management decisions to be put in place to increase crop productivity.

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