Impact of Soil Fertility Management Practices on Insect Pests and Diseases of Maize in Southwest Cote d'Ivoire

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ABSTRACT

Objectives: Integrated soil fertility management (ISFM) is essential for sustainable management of tropical soils. However, soil fertility management is able to affect plant susceptibility to pests and diseases. The study investigated impact of soil fertilization practices on maize pests and diseases during two identical and simultaneous trials setup in South-West Cote d'Ivoire.
Methodology and Results: Experiments were laid out using complete randomized block designs with three replicates and four treatments: (1) control; (2) chemical fertilization; (3) fertilization with cattle manure; (4) association "maize + legume" combined with chemical fertilization. Overall, 22 insect species collected and two diseases (maize streak disease and curvularia leaf spots) observed at both sites. Only cattle manure clearly increased pest and disease damages. The use of cattle manure significantly increased leaf infestation rate and maize streak disease frequency at both sites. Similar impact of NPK and cattle manure was obtained on maize yields either in monocropping or in mix cropping.
Conclusions and application of findings: This study clearly confirmed that ISFM is able to affect plant susceptibility to pests and diseases. Cattle manure attracted a diversity of insects of diverse functional groups such as air-borne pests. These latter affected some plant parts; in this case, maize leaves which infestation rate significantly increased. This attraction for multitude insects may increase vector-borne diseases such as maize streak which frequency significantly increased at both sites. Consequently, despite the potential of cattle manure to increase maize yield, their use as organic fertilizer requires to take some precautions. So, the promotion of cattle manure as organic fertilizer in substitution of chemical fertilizer in tropical regions where it is available is encouraged. However, it should be converted into compost or pre-treated for optimal use in agriculture. Finally, mix cropping could be suggested for optimization of economic profit.
Keywords: Maize, leaf infestation, maize streak disease, soil fertility management, cattle manure

INTRODUCTION

Maize is a major staple food crop grown in diverse agro-ecological zones and farming systems, and consumed by people with varying food preferences and socio-economic backgrounds in sub-Saharan Africa (Macauley & Ramadjita, 2015). In the Nawa region, Southwest Cote d'Ivoire, cocoa, coffee, rubber predominantly occupy arable lands and oil palm and food crops are facing land unavailability. These tree crops lead to high pressure on lands whereas a virtual absence of soil fertility management is noticed (Diby *et al*., 2014). As a result, soil fertility is declining hence. Food production is the most affected with extensive agricultural currently practiced creating an impasse for food security. Small-scale farmers such as women mainly ensure this food production. Due to land pressure, fallowing is being disappeared while farmers are not sensitized on crop rotation.

Maize is susceptible to a range of pests (Steffey *et al*., 1999; Jean & Boisclair, 2009) and diseases (CABI, 2015). In Côte d'Ivoire, various phytophagous and borer insects are able to feed on maize. However, borers are the most common and harmful. The main borers known are *Eldana saccharina* Walker, Pyralidae, which attacks both stem and cobs, *Busseola fusca* Fuller, Noctuidae, found mainly in stem and cob borer *Mussidia nigrivenella* Ragonot, Pyralidae (Pollet *et al*., 1978; Ortega, 1988; Moyal, 1993; 1998). Others insect-pests like jassids, vectors of streak virus, are among the main causes of crop losses (Moyal, 1988). Maize streak appears to be probably the main viral threat that reaches maize and curvularia leaf spot has been repeatedly encountered (Fauquet & Thouvenel, 1987; Karavina,

2014). Integrated soil fertility management (ISFM) appears as a dire need to address soil nutrient depletion and boost agricultural output in the Nawa region. ISFM is defined as "*a set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs and improved germplasm, combined with the knowledge of how to adapt these practices to local conditions, aimed at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity*" (Vanlauwe *et al*., 2010). ISFM allows expanding the choice set of farmers by increasing their awareness of the variety of options available and how they may complement or substitute for one another (Place *et al*., 2003). ISFM can affect plant susceptibility to pests and diseases by altering plant tissue nutrient levels. Crop plant ability to resist or tolerate insect pests and diseases is tied to optimal physical, chemical and mainly biological properties of soils (Altieri & Nicholls, 2003). Soils with high organic matter and active soil biology generally exhibit good soil fertility while excessive use of inorganic fertilizers can cause nutrient imbalances and lower pest resistance (Altieri & Nicholls, 2003). Despite the link between ISFM and integrated pest management, their advancement has proceeded separately. Thereby, it was suggested to increase studies comparing pest populations on plants treated with synthetic versus organic fertilizers are needed (Altieri & Nicholls, 2003; Place *et al*., 2003). This paper aims to assess impact of different ISFM options on maize by measuring their effect on incidence of maize pests and diseases.

MATERIAL AND METHODS

Study area and sites: This study was conducted in the Nawa region, Southwest Cote d'Ivoire, where 30% of the cocoa is produced (Diby *et al*., 2014). This region is one of the most densely populated of the country mainly because of cocoa economy, which attracts many migrants from other parts of the country and West African countries (Smoot *et al*., 2013). This has led to strong pressure on arable lands that are mainly devoted to cash crops. The global landscape of the region is very heterogeneous and dominated by agriculture with mosaic of tree crop

plantations and food crops (Diby *et al*., 2014). Agricultural production faces soil fertility constrains depletion that constitutes a real threat for food security. Food crops are grown on very small areas (<1ha) notably by women for household consumption and for making money. In this context, maize is grown for its high nutrition value, market value and high potential for crop association. Two participatory maize trials were set up in Krohon 1 (05.3453 N; 06.5255 W; 120 m) and Krohon 2 (05.3584 N; 06.5249 W; 130 m) that differed by their initial soil nutrient contents (Table 1).

Table 1: Soil parameters recorded as means±standard-errors.

Sites	pH	C (%)	N (%)	P (ppm)	CEC (cmol/kg)	Ca^{2+} (cmol/kg)	K$^+$ (cmol/kg)
Krohon 1	5.59±0.01a	1.46±0.15a	0.13±0.01a	09.67±0.27a	5.23±0.76a	1.15±0.12a	0.13±0.00a
Krohon 2	5.68±0.02a	0.84±0.04b	0.08±0.00b	06.67±0.88b	3.76±0.39b	1.02±0.00a	0.10±0.02a

Experimental design and treatments: Two identical and simultaneous trials were set up at the beginning of the rainy season. Experiments were laid out using a complete randomized block design with three replicates and four treatments on plots of 18 m² (4.0 m x 4.5 m) size. Blocks were distant from 3 m and plots were distant from 2.5 m. Maize variety named *PR9151* was sown at a 0.75 m x 0.40 m density with two plants grown per hole. The treatments were: (1) control with no supply in fertilizer and no association with other crop; (2) chemical fertilization consisting in application of NPK (12 22 22) at 150 kg/ha before sowing and urea (46% N) at 150 kg/ha four weeks after sowing (WAS); (3) organic fertilization consisting in application of cattle manure at about 15,000 Kg/ha before sowing; (4) association "maize + legume" combined with chemical fertilization. Legume was sowed three WAS using soybean in Krohon 1 and beans in Krohon 2. Two rounds of weeding were systematically performed at four and eight WAS. At four WAS, all plots received a Deltamethrin (15g/l)-based insecticide treatment at 0.5 l/ha. The application was performed at 1-3 bar using a pressurized hand backpack sprayer equipped with a 16 l-container and a simple nozzle.

Insect sampling and pests infestation evaluation: Field surveys were performed to determine infestation rate of major insect pests. For that purpose, twice a week all parts of maize were examined in each block and collected stages of all insect pests. The number of plants with damages was also determined to estimate infestation rate of different plant parts. In addition to direct observation of insects on different plant parts, we also used pitfalls per plot (Upton *et al.*, 2010). Traps were set up two WAS and consisted in plastic jars containing soapy water and salt renewed all two days. Insects collected were identified and counted. Insects' identification was based on morphology characteristics using a binocular microscope (G x 50). The observed characteristics were compared with those of lab collection and identification keys (Ortega, 1988; Bordat & Arvanitakis, 2004; Jean & Boisclair, 2009; James *et al.*, 2010). Insect damages were evaluated counting plants with leaves, stems and fruits. Leaf infestation rate was assessed at four WAS before insecticide application and stem attacks were assessed 12 WAS through the following calculation: *Infestation rate* (%) = (*Plants attacked*/*Plants observed*) x 100.

Disease sampling and infection evaluation : Field surveys were performed to examine all parts of maize to record symptom of maize streak disease (Fig. 1.A), fungal diseases, notably curvularia leaf spot (Fig. 1.B).

Fig. 1. A. Symptoms of maize streak due to *Maize streak virus*; B. Curvularia leaf spot; C. Conidia of *Curvularia* sp. causing leaf spots.

Samples of infected leaves were collected and taken to laboratory for more detailed assessment. Parts of leaf samples located between healthy and infected areas was cut into small pieces, sterilized by immersion in 1% Sodium Hypochlorite (NaOCl) solution for five minutes and three-time rinsed in sterile distilled water for another three minutes. Thereafter, leaf pieces were air dried for three minutes and put into several Petri dishes (90 mm diameter) containing PDA and incubated at 30°C for a few days. Fungal colonies growing on leaf pieces were

purified by transferring again into PDA. After few other days, conidia and mycelium (Fig. 2.C) were identified using a microscope. Disease incidence was evaluated through frequency and severity nine WAS. Disease frequency was calculated by the following formula:

Disease frequency (%) = (*Plants infected*/*Plants observed*) x 100.

For severity index, we examined, for each disease, symptom degree on leaves of infected plants based on visual assessment (Welz *et al.*, 1998) as followed: 1 = no symptom; 2 = ≤ 25% leaf area presented symptoms; 3 =

26-50% leaf area presented symptoms; 4 = 51-75% leaf area presented symptoms; 5 = 76-100% leaf area presented symptoms. Then we determined the severity index for each block (Kranz, 1998):

Severity index = $\sum$ (*Xi* x *ni*)/ (*N* x *Z*) x 100. (Xi = Severity i of disease on the plant; ni = Number of plants with severity i; N = Total number of plants observed; Z = 5, highest value of severity).

Data analysis : All data are reported as mean ± standard errors of three replicates per plot. Data analyses were performed with STATISTICA 7.1 using one-way non-parametric Kruskal-Wallis ANOVA. Significant differences were tested using U-Mann-Whitney test at $p = 0.05$.

RESULTS

Insects collected: Twenty-two species distributed into eighteen families and nine orders were identified at both sites (Table 2). Coleoptera was most diversified with seven species followed by Orthoptera (five species), Lepidoptera (three species) and Hymenoptera (two species). Most of species collected have a phytophagous status (Orthoptera, Coleoptera, Lepidoptera, Homoptera, Heteroptera, Diptera and Isoptera) while others are omnivores (Orthoptera and Dictyoptera), predators (Coleoptera and Hymenoptera), coprophagous (Diptera) and virus vectors (Homoptera). These insects were mainly observed at growth stage and during flowering.

Helicoverpa zea and *Microtermes sp.* were observed during fructification. Species richness was 19 and 20 respectively at Krohon 1 and Krohon 2. Homopterous was the most abundant order dominated by *Rhopalosiphum maidis* at both sites. *Chrotogonus senegalensis* was also abundant at both sites and followed by *Gryllus bimaculatus* mainly observed in cattle manure-fertilized plots and "maize+legume" plots (Fig. 2). *Pachycondyla sylvestri* (Hymenoptera) was fairly well represented at both sites for all the treatments. Unlike the previous species, *Delia* sp. was observed only on cattle manure-fertilized plots.

Table 2: Insects collected on maize during the trials at the two sites.

| Order	Familiy	Species	Stage[+]	Part observed	Status	Site 1	Site 2
Orthoptera	Gryllidae	*Gryllus bimaculatus*	Growth	Litter, soil	O	*	*
	Pyrgomorphidae	*Zonocerus variegatus*	Growth	Leaf	Ph	*	*
		Chrotogonus senegalensis	Growth	Leaf	Ph	*	*
	Acrididae	*Locusta migratoria*	Growth	Leaf	Ph	*	*
		Ochrilidia gracilis	Growth	Leaf	Ph		*
Coleoptera	Cetoniidae	*Pachnoda marginata*	Growth	Flower	Ph	*	*
		Diplognatha gagates	Growth	Flower	Ph	*	*
	Scarabeidae	*Phyllophaga sp.*	Growth	Soil, root, stem	Ph ; D		*
	Elateridae	*Agriotes sp.*	Flowering	Soil, stem, cob	Ph ; D	*	*
	Tenebrionidae	*Eleodes sp.*	Growth	Soil, stem, cob	Ph ; D	*	
		Tenebrio molitor	Growth	Soil, stem, cob			
	Cerambycidae	*Cerambyx milles*	Flowering	Leaf	Pr		*
	Coccinellidae	*Cheilomenes sulphurea*	Growth	Leaf	Pr	*	*
Hymenoptera	Formicidae	*Pachycondyla sylvestri*	Growth	Soil, Leaf	Pr	*	*
	Apidae	*Apis mellifera*	Flowering	Flower	Ph	*	*
Diptera	Antomyiidae	*Delia sp.*	Growth	Soil, cob	Ph ; C	*	*
Homopterous	Aphididae	*Rhopalosiphum maidis*	Growth	Leaf, cob	Ph ; Vv	*	*
Heteroptera	Coreidae	*Pseudotheraptus devastans*	Flowering	Leaf	Ph	*	*

| Lepidoptera	Noctuidae	*Spodoptera littoralis*	Flowering	Leaf, cob	Ph (borer)	*	*
		Helicoverpa zea	Fructification	Cob	Ph (borer)	*	*
	Pyralidae	*Eldana saccharina*	Flowering	Leaf, stem, cob	Ph (borer)	*	*
Dictyoptera	Blattidae	*Blatta sp.*	Growth	Litter, soil	O	*	
Isoptera	Termitidae	*Microtermes sp.*	Fructification	Root, stem	Ph	*	*
09	**18**	22				**19**	**20**

+ Stage of observation of the insect

C = Coprophage; D = Detritivores; O = Omnivores; Ph = Phytophagous; Pr = Predator; Vv = Virus vector.

Krohon 1
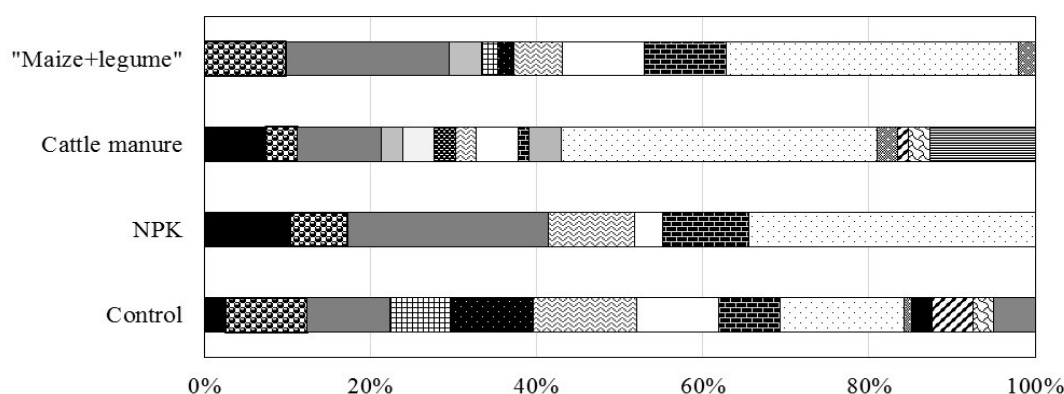
Krohon 2
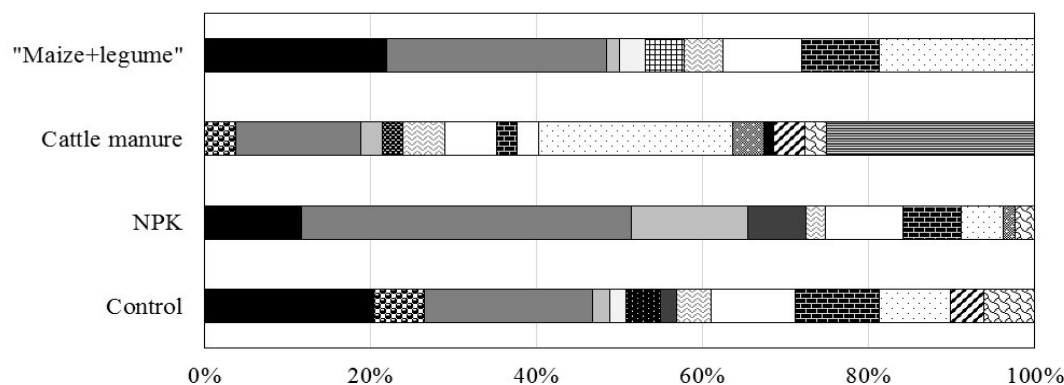
- *Gryllus lucens*
- *Zonocerus variegatus*
- *Chrotogonus senegalensis*
- *Locusta migratoria*
- *Ochrilidia gracilis*
- *Pachnoda marginata*
- *Diplognatha gagates*
- *Phyllophaga sp.*
- *Agriotes sp.*
- *Eleodes sp.*
- *Cerambyx milles*
- *Cheilomenes sulphurea*
- *Pachycondyla sylvestri*
- *Apis mellifera*
- *Delia sp.*
- *Rhopalosiphum maidis*
- *Pseudotheraptus devastans*
- *Spodoptera littoralis*
- *Helicoverpa zea*
- *Eldana saccharina*
- *Blatta sp.*
- *Microtermes sp.*

Fig. 2: Distribution of insect species collected at each site during all the production cycle

Insect infestation: Significant differences (p<0.001) were observed between leaf infestation rates. The highest leaf infestation rates were recorded under cattle manure-fertilized plots (26.50 ± 0.79 for Krohon 1 and 42.74 ± 2.34 for Krohon 2). Besides cattle manure-fertilized plots, almost none significant difference was observed between the others plots (Fig. 3). Unlike leaf infestation rate, no significant difference (p>0.05) was observed between stem infestation rates calculated for each treatment at each site. Stem infestation rate was comprehensively highest at Krohon 1 (Fig. 3).
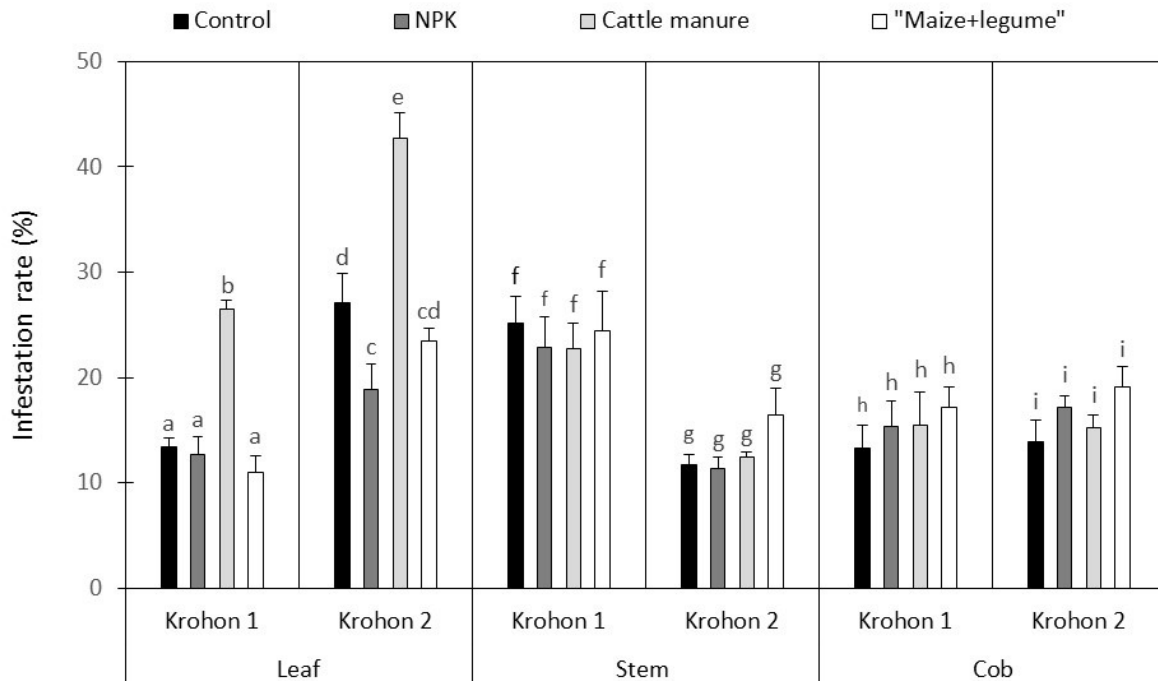

Fig. 3. Infestation rates of leaves, stems and corn cobs calculated per treatment for both sites.

Frequency of diseases: Two diseases (maize streak and curvularia leaf spots) were observed at both sites. Significant differences were observed according to maize streak disease frequency (p<0.001). Cattle manure-fertilized plots and "maize+legume" plots were more infected compared to the others treatments. However, plots of Krohon 1 were comprehensively more infected than those of Krohon 2: 7.05 ± 0.62 and 1.56 ± 0.05 respectively for cattle manure-fertilized plots. For curvularia leaf spots, no significant difference was observed (Fig. 4).
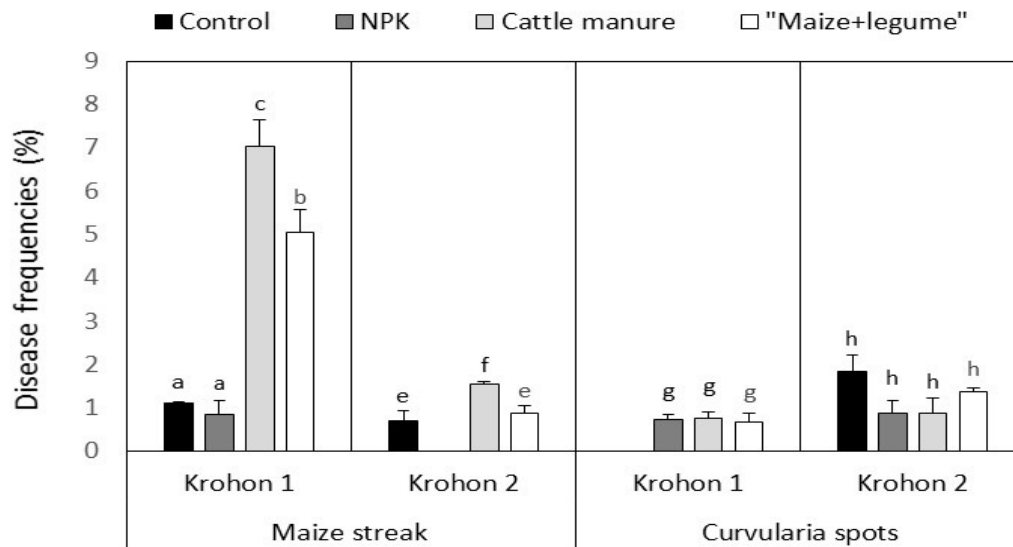
Fig. 4: Disease frequency recorded for each treatment at both sites.

Severity of diseases: Comprehensively, severity degree varied around 20 and 25% when the disease was observed. No significant difference was observed among treatments (Fig. 5).
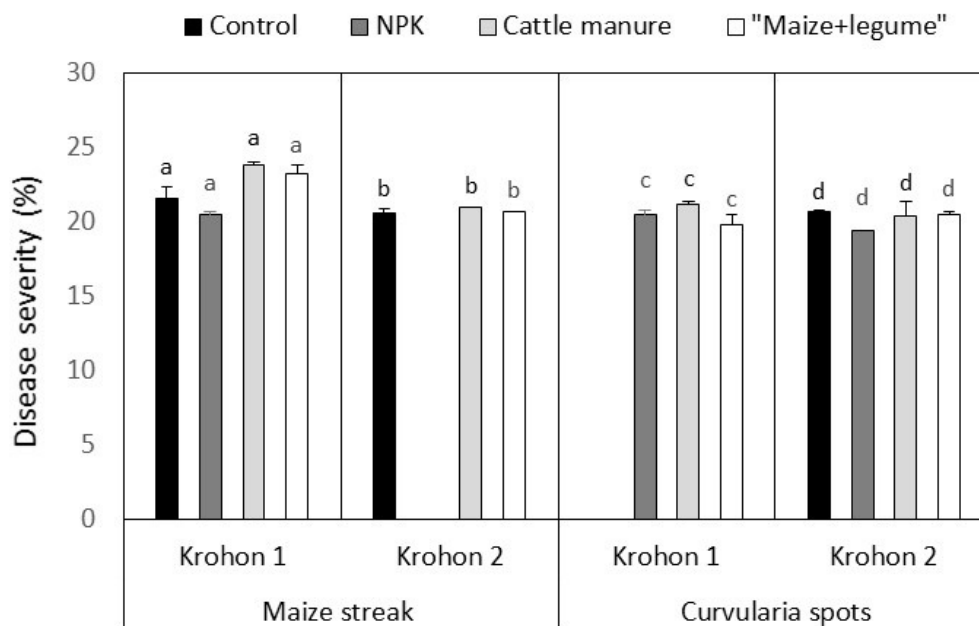

Fig. 5: Disease severity recorded for each treatment at both sites

Maize yields: All fertilization options significantly affected maize yields. Overall, no difference was recorded between maize yields recorded for the different fertilization option either in maize monocropping or in maize associated with legume (Fig. 6).
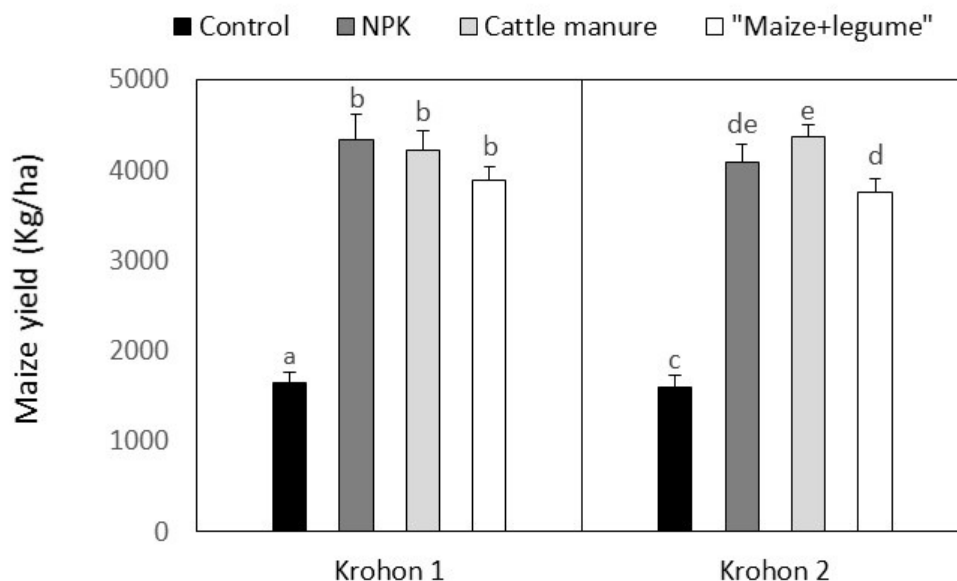
Fig. 6: Yields in dry matter (kg/ha) recorded as means±standard-errors during the second year experiment.

DISCUSSION

Significance of insects and diseases observed on maize during the trials: Maize was sensitive to a diversity of insects as indicated by Steffey *et al.*, 1999 and Jean & Boisclair (2009). Lepidoptera are more likely to cause damage to maize (Ortega, 1988; Kfir, 1997; Tafera *et al.*, 2016). Among Lepidopteran pests known in Cote d'Ivoire, only *E. saccharina* was found in this study. The others pests are likely to be observed in the Nawa region, South West Côte d'Ivoire (Moyal, 1998). However, the setup of trials on April, could explain why these species were not observed. Indeed, their infestation in the study region is more probable between June-July, when the second generation of adults emerge after diapause (Moyal, 1998). In addition, insecticide applied four WAS probably allowed reducing insect's communities such as virus vectors and then virus transmission to plants (Goré Bi *et al.*, 2011; Adja *et al.*, 2014). Maize streak appears to be probably the main viral threat that reaches maize and curvularia leaf spots were repeatedly encountered in Côte d'Ivoire (Fauquet & Thouvenel, 1987; Karavina, 2014). Several other diseases attack maize in Côte d'Ivoire. These two diseases observed bring out two hypotheses: (1) the study area would favour specifically these two of diseases; (2) the variety used was resistant to some diseases. Until now, no study inventoried maize diseases of the region and characteristics of maize variety used are still poorly known. However, it should be noted that observations were made after plant maturity so that some

maize diseases (rust and helminthosporiasis) could not be observed (CIMMYT, 2004).

Effect of fertilization type on incidence of pest insects and diseases and yields: Agrosystems management impact insect's pests. According to Kfir *et al.* (2002), it was observed that, stem borers were marginally more prevalent in fertilized crops than in unfertilized crops. Fertilized crops could increase borer infestation and survival through an increase in plant nitrogen content. In this study, borers' attack was the same for all treatments suggesting that this attack was not influenced by soil fertilization management. In previous a study carried at in Brobo (savannah area in the Centre of Côte d'Ivoire) and Gagnoa (forest area in Southwest region) by Moyal (1993), the same result was observed. In this study, comparing various modalities of maize cultivation (pure vs intercropped with peanut, at high or low density and fertilization level), with good or bad weeding, and with or without protection against borers, no interaction between various factors was observed. The borer density was the same for any cultivation modality or weeding frequency. These results suggested that borer attacks, mainly by *E. saccharina*, are little influenced by environment (Moyal, 1993). For leaf infection rate, it was significantly affected by cattle manure. Several studies indicated that cattle manure would attract a large number of insects, namely Diptera, Lepidoptera, Coleoptera and Apidae. In addition, cattle dung could attract virus vectors that could explain

the higher maize streak frequencies observed in organic-fertilized plots (Bosque-Perez *et al*., 2000; Konaté *et al*., 1994). Field observations showed in addition that the use of cattle dung increase weed development. These weeds are mainly Poaceae (*Imperata cylindrica*, *Panicum* spp., *Digitaria* spp., *Bracharia* spp.) and appear as probable source of inoculum of Maize streak virus (MSV). Wild Poaceae are natural hosts of MSV and play important role in maize streak epidemiology (Konaté *et al*., 1994; Magenya *et al*., 2008). The range of MSV hosts was evaluated at 106 species of Poaceae (ICTVdB Management, 2006), including those observed in this study but not formally recorded. The symptom severity observed evolves considerably with the source of inoculum, and proportional to the abundance of the reservoirs (Konaté *et al*., 1994). These observations are therefore consistent with those made at both study sites. Cattle dung application requires additional weeding to limit weed populations. Despite the potential advantage of mixing crop related to better control of pests and diseases (Malézieux *et al*., 2009), no positive effect of mixing maize with legume was revealed in this study. From leaf and stem infestation by insect pest to maize streak and curvularia leaf spot, no clear evidence demonstrated positive/negative effect of mixing maize with beans or soybeans. It is difficult to explain the particularly high maize streak frequency observed on maize associated with soybeans at Krohon 1. This effect of crop association on reducing the incidence of pests and diseases is not always true. The ability of some pests and pathogens to use a wide range of plants as alternative hosts/reservoirs is the main limitation to the suppressive role of this strategy, but all other pathways identified for the control of pests and disease based on plant species diversity also have certain limitations (Ratnadass *et al*., 2012). If air-borne diseases can also be avoided to some extent through crop selection and crop rotations that include some non-host crops, this strategy is more effective for soil or residue-borne pathogens (Krupinsky *et al*., 2002, Gao *et al*., 2014). Insect responses to cues are not fixed but depend on the context, the physiological state of the insect and prior learning experiences (Bruce, 2015). Although biologists often study individual interactions of one species of insect with one species of plant, the reality in nature is more complicated because plants are exposed to multiple pest and beneficial organisms. Much less is known about the effect of multiple, co-occurring stress factors than individual biotic and abiotic stresses, despite the fact that multiple stresses are probably the rule under natural conditions (Bruce, 2015).

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