EFFECT OF INORGANIC AND ORGANIC FERTILIZERS IN THE MANAGEMENT OF THE FALL ARMYWORM *SPODOPTERA FRUGIPERDA* IN BENIN

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ABSTRACT

The present study has investigated the effect of NPKSBZn (13-17-17-6-0.5-1.5) and urea fertilizers and compost in the management of *S. frugiperda*. Experiments were carried out at the Djidja and N'Dali sites using a randomized complete block design (RCBD) with four replications and four treatments which are : (i) unfertilized plots (control), (ii) plots fertilized with compost applied at the rate of 30 t/ha as basal dressing, (iii) plots fertilized with NPK at a rate of 200 kg/ha and urea at a rate of 100 kg/ha, and (iv) plots fertilized with NPK and urea mixture applied at a rate of 150 kg/ha. Results indicated that the number of *S. frugiperda* larvae per plant was significantly lower in fertilized plots compared to unfertilized ones at Djidja and N'Dali sites. Similar results were obtained for the severity of damage caused by *S. frugiperda* at N'Dali site. Plant growth parameters were significantly improved in the plots fertilized with NPK and urea mixture at Djidja and those fertilized with compost at N'Dali. The maize grain yield was higher on these plots with 4357 kg/ha at Djidja and 3597 kg/ha at N'Dali. The population of natural enemies was significantly higher at N'Dali and in plots fertilized with compost. These results show the importance of organic manure in the sustainable management of *S. frugiperda* in maize production.

Keywords : Fall armyworm, agro-ecological approach, organic fertilizer, natural enemies, sustainable crop protection

EFFET DES ENGRAIS INORGANIQUES ET ORGANIQUES DANS LA GESTION DE LA CHENILLE LÉGIONNAIRE D'AUTOMNE *SPODOPTERA FRUGIPERDA* AU BÉNIN

RÉSUMÉ

La présente étude a évalué l'effet des engrais minéraux, NPKSBZn (13-17-17-6-0.5-1.5) et urée, et du compost dans la gestion de *S. frugiperda*. L'expérimentation a été conduite dans les communes de Djidja et de N'Dali dans un dispositif de Bloc Aléatoire Complet (BAC) avec quatre répétitions et quatre traitements que sont : (i) parcelles non fertilisées (témoin), (ii) parcelles ayant reçu le compost appliqué à la dose de 30 t/ha en fumure de fonds, (iii) parcelles ayant reçu le NPK à la dose de 200 kg/ha et l'urée à la dose de 100 kg/ha, et (iv) parcelles ayant reçu le mélange de NPK et urée à la dose de 150 kg/ha. Les résultats ont indiqué que le nombre de chenilles par plant était significativement faible sur les parcelles ayant reçu de fumures, comparé à celles n'ayant reçu aucune fumure, aussi bien sur le site de Djidja que de N'Dali. Il en est de même pour la sévérité des dégâts sur le site de N'Dali. Les paramètres de croissance étaient significativement élevés sur les parcelles ayant reçu le mélange NPK et urée à Djidja et sur les parcelles ayant reçu de compost à N'Dali. Sur ces parcelles, le rendement de maïs grain était plus élevé avec respectivement 4357 kg/ha à Djidja et 3597 kg/ha à N'Dali. Les ennemis naturels étaient plus abondants à N'Dali et sur les parcelles ayant reçu de compost. Ces résultats montrent l'importance de l'amendement organique des sols dans la gestion durable de *S. frugiperda* en culture de maïs.

Mots clés : Chenille légionnaire d'automne, approche agro-écologique, engrais organique, ennemis naturels, protection durable

INTRODUCTION

Maize (*Zea mays* L.) is under high pest pressure since the recent invasion of the fall armyworm (FAW) *Spodoptera frugiperda* J. E. Smith (Lepidoptera : Noctuidae) into the African continent (Goergen *et al.*, 2016; CABI, 2017). FAW (hereafter referred to *Spodoptera frugiperda*) is considered as an economically important pest that attacks all stages of maize development from seedling to ear development (Sisay *et al.*, 2019). Houngbo *et al.* (2020) estimated the average yield losses caused by FAW in Benin at 797 kg of maize per hectare, or 49 % of the average yield obtained by producers before FAW invasion. Thus, this notorious insect pest represents a threat to food security and endangers the economic development of the country, suggesting the development of effective and sustainable control measures.

The management of FAW since its invasion in West Africa is mainly achieved through the use of synthetic insecticides (Kumela *et al.*, 2019). However, several studies have highlighted the drawbacks of their irrational use (Roubos *et al.*, 2014). Since then, more attention has been paid to alternative control methods. In addition, agro-ecological approaches, based on culturally appropriate low-cost pest management, are also desirable (Harrison *et al.*, 2019).

The agro-ecological approaches are based on three complementary strategies: (i) sustainable management of soil fertility, that improves crop health and pest resistance (Altieri & Nicholls, 2003); (ii) promotion of biodiversity at different specific scales from the field to the landscape, that provides living space for natural enemies (Nicholls & Altieri, 2004); and (iii) specific management activities designed to prevent outbreaks or reduce their impact (Harrison *et al.*, 2019). However, little research has investigated the effect of soil fertility in the management of FAW in maize. In Benin, about 54.4% of maize producers facing FAW attacks applied NPK and urea fertilizers (Houngbo *et al.*, 2020). This is because healthy plants with vigorous growth are more resistant to pests and diseases. Many maize producers also testified that yield losses from a fertile soil with a vigorous plant are low. However, mineral fertilizers are very often applied regardless to the recommended rates and timing of application. Altieri & Nicholls (2003) mentioned that inappropriate use of inorganic fertilizers can increase pest damage. In fact, the application of inorganic fertilizers increases foliar growth and consequently foliar nitrogen which attracts pests. A low population of insect pests such as flea beetle *Phyllotreta cruciferae* Goeze, aphids *Rhopalosiphum maidis* Corn and planthoppers *Sogatella furcifera* Horváth has been recorded in soils with organic matter (Altieri & Nicholls, 2003). In the present study, we investigated the effect of organic and inorganic nutrition of maize plants in FAW management.

METHODS

Study sites

This study was carried out in the districts of Djidja in the agro-ecological zone V (Cotton region of the Centre) and N'Dali, in the agro-ecological zone III (Food crop region of South Borgou) of Benin. Experiments were carried out in the village Djérékpédji (7° 37.408' N, 1°47.141' E) in the district of Djidja from June to November 2020, and in the village Wèrèkè (09°44.097' N, 002°36.447' E) in the district of N'Dali from July to December of the same year. The both districts were selected based on their high potential for maize production and the outbreaks of FAW in the last years.

The district of Djidja experimental site is characterized by a transitional climate between the sub-equatorial climate of southern Benin and the humid tropical Sudano-Guinean climate of northern Benin, with two rainy seasons, from March to July and from August to October, and an average rainfall of 908.3 mm and temperature ranging from 26.01 °C to 30.97 °C in 2020 (Météo-Bénin, 2021). Different types of soils are found: ferralitic soils, tropical ferruginous soils, Vertisols and hydromorphic soils (Azontondé *et al.*, 2009). The district of N'Dali is characterized by a Sudano-Guinean climate with a rainy season (April to October) and a dry season (November to March) with harmattan winds from November to February. The average rainfall was 1163.2 mm with an average temperature varying between 25.20 °C and 31.12 °C in 2020 (Météo-Bénin, 2021). The tropical ferruginous type with varying degrees of depth is the main type of soil at N'Dali (Afrique Conseil, 2006).

Fertilizers used

Two types of fertilizers were used: organic and inorganic fertilizers. The organic fertilizer was the compost made with crop residues and poultry manure. It was provided by the company "BioLife-Benin". The inorganic fertilizers used were NPKSBZn (13-17-17-6-0.5-1.5) and urea (46 % N) recommended by research and extension services for maize production.

Chemical analyses of soil and compost samples used for the experiments

Three soil samples were collected from each experimental site at 0 to 20 cm depth diagonally using an auger to form a composite sample. Collected soil samples were then transported to the Laboratory of Soil Science of the Faculty of Agronomic Sciences of the University of Abomey-Calavi, Benin for chemical analyses as described by Saïdou *et al.* (2012). The pH (H_2O), organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and cation exchange capacity (CEC) were assessed. These parameters revealed the initial physico-chemical properties of soils prior to experiments. The readily available chemical nutrients of soils that are crucial for plant growth were targeted. A sample of the used compost was also subjected to the same chemical analyses.

Experimental design

The experiment was conducted in a randomized complete block design (RCBD) with four replicates and four treatments: (i) control plots (unfertilized plots); (ii) plots fertilized with compost at 30 t/ha as basal dressing 14 days prior to sowing (Enujeke, 2013); (iii) plots fertilized with NPK (NPKSBZn) at 200 kg/ha 14 days after sowing (DAS) and urea at 100 kg/ha 35 DAS (NPK [NPKSBZn] +urea) (Tovihoudji *et al.*, 2017); and (iv) plots fertilized with the NPK (NPKSBZn) and urea mixture (NPK [NPKSBZn] +urea M) at a rate of 150 kg/ha at 14 and 35 DAS respectively. NPK (NPKSBZn) was applied at 6.4 g/hill for the rate of 200 kg/ha while urea was applied at 3.2 g/hill for the rate of 100 kg/ha. The mixture of NPK (NPKSBZn) and urea was applied at 3.2 g of NPK (NPKSBZn) and 1.6 g of urea per hill. Inorganic fertilizers were applied in a hole at 5 cm to the maize plant and then closed to avoid losses by volatilization (Saïdou *et al.*, 2012). The compost was mixed with the soil during plowing at a rate of 30 t/ha two weeks before sowing.

Trial implementation

Maize seeds, variety SYNEE 2000 (extra-early maturing variety of 80 days with an expected yield of 2.5 t/ha), were provided by the Agricultural Research Center of South-Benin of the National Institute of Agricultural Research of Benin (INRAB). Maize seeds were sown the 25th June 2020 at Djidja and the 23rd July 2020 at N'Dali in holes with spacing of 80 cm and 40 cm within rows and plants respectively. Two plants per hole were managed 10 DAS. Weeding was performed three times manually using hoe. The fertilizers were applied on time. No phytosanitary products were applied during the experiments.

Data collection

Data collections were performed weekly and began at 21 DAS until tasseling on 42 DAS. Thirty plants were randomly selected from the innermost experimental units and considered to collect the following data: number of living FAW larvae per plant; damage severity based on modified rating scale of Adéyè *et al.* (2018), (0—No damage, to 5—Plant completely destroyed); number of natural enemies per plant (ants, spiders, ladybug beetles, carabid beetles, praying mantis, earwigs, Tachinid fly and pentatomid bug) based on visual examination as proposed by Wade *et al.* (2006). Natural enemies were then identified using identification guides from Prasanna *et al.* (2018) and FAO (2018); growth parameters (number of leaves, stem thickness, and plant height) recorded at 60 DAS; maize yield (cob and grain) harvested in three 4 m^2 quadrats at Djidja, and one at N'Dali from each plot at physiological maturity. The number of quadrats set per sites is related to the experimental plot sizes. The weight of maize cobs was recorded per quadrat. Then, they were manually threshed by hand, and the grains were sun-dried for five days, and dry weight was recorded using a scale balance to calculate the total grain yield in kg/ha.

Statistical analyses

The generalized linear model (with interaction) was used to assess the effect of sites and treatments on the number of FAW larvae per plant from each assessment date. ANOVA was performed using Pearson's Chi-square adjustment to determine the significance of the main factors and their interaction. Multiple comparisons between sites and treatments were performed using the Student Newman–Keuls test ($\alpha = 0.05$). Damage severity scores were subjected to Kruskal-Wallis test followed by Dunn's post hoc test for multiple comparisons ($\alpha = 0.05$). Data on the percentage of damaged plants were generated and subjected to a linear mixed effects model (Pinheiro *et al.*, 2017). Maize cob and grain yield, plant height, and stem thickness were analyzed in a linear mixed-effects model (Pinheiro *et al.*, 2017), while the number of leaves was analyzed in a generalized linear mixed-effects model (Brooks *et al.*, 2017). The Student Newman–Keuls test was performed for data means discrimination. Data on the presence (1) and absence (0) of natural enemies were subjected to binary logistic regression while their abundance was subjected to ANOVA using a generalized linear model. All statistical analyses were performed using R software (Version 4.0.0, R Foundation for Statistical Computing, Vienna, Austria) (R Development Core Team, 2020).

RESULTS

Physico-chemical properties of the soil samples collected and the compost used

The results indicated high composition in nutrients of the compost compared to the experimental sites soils. The soils were acid with the pH (water) of 5.79–5.86. The soil in the district of Djidja was slightly richer than that of N'Dali in total nitrogen, with 0.0518 % and 0.049 %, available phosphorus 21.74 and 16.97, and potassium with 0.280 and 0.082, respectively (Table 1).

Table 1. Initial physico-chemical composition of the soils and compost used

N°	Samples (compost/soils)	pH (H_2O)	C_{org} (%)	N_{tot} (%)	P_{avail} (ppm)/ $P2O5_{tot}$ (Mg/100g)	CEC (Mg/100 g)	K (Meq/100g)
1	Compost	8.29	23.19	0.1778	92.81	18.8	6.980
2	Djidja	5.79	0.79	0.0518	21.74	9.6	0.280
3	N'Dali	5.86	0.94	0.049	16.97	11.2	0.082

pH (H_2O) : pH (water) ; C_{org} : Organic carbon ; P_{avail} : Available phosphorus; N_{tot} : Total nitrogen ; CEC : cation exchange capacity; $P205_{tot}$: Total Phosphorus; K : Potassium.

$P205_{tot}$ was determined only for the compost while P_{avail} was determined for soils from experimental sites.

Effect of inorganic fertilizers and compost on FAW larval population

Statistical analyses indicated that the factors treatments (df = 3; Deviance = 28.90; $P < 0.001$), assessment dates (df = 1; Deviance = 343.51; $P < 0.001$), and sites (df = 1; Deviance = 456.30; $P < 0.001$) as well as their interaction induced significant differences (df = 3; Deviance = 11.10; P = 0.01122) in the average number of FAW larvae per plant. The larval density of FAW was significantly higher at N'Dali than Djidja. The number of larvae per plant gradually decreased in the treatments from 28 to 42 DAS at Djidja (Figure 1a). At N'Dali, the average number of larvae per plant was significantly lower in plots fertilized with compost than in other treatments at 35 and 42 DAS (Figure 1b).

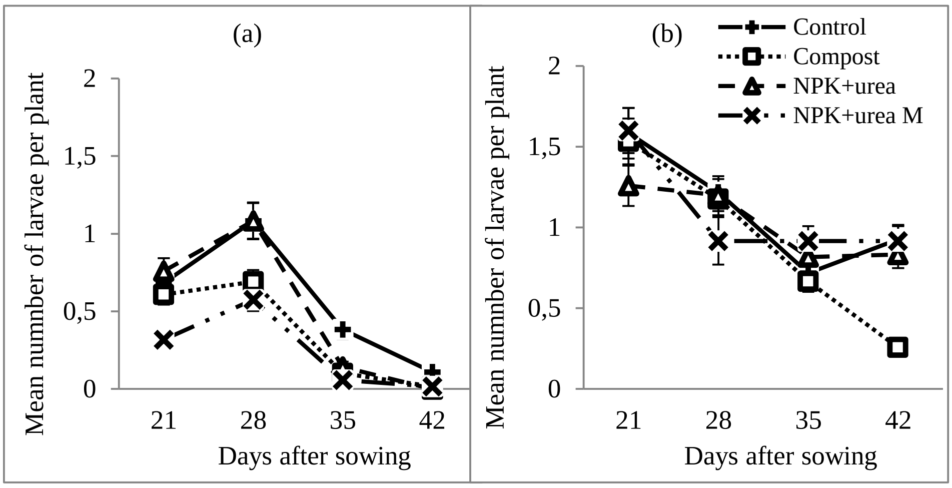

Figure 1. Effect of fertilizers on *S. frugiperda* larvae population at (a) Djidja and (b) N'Dali.

NPK +urea means application of NPK (NPKSBZn) and urea 14 and 35 DAS respectively; NPK +urea M means application of the mixture of NPK (NPKSBZn) and urea 14 and 35 DAS respectively.

Effect of inorganic fertilizers and compost on FAW damage severity

Severity of FAW damage did not differ significantly among treatments (df = 3; Chi2 = 6.5808; P = 0.08653). However, damage severity was significantly different between experiment sites (df = 1 ; Chi2 = 4.9731 ; P = 0.02574). The damage severity scores were higher with compost and the mixture of NPK (NPKSBZn) +urea treatments in both sites respectively at 21 and 28 DAS. At Djidja the higher damage severity scores were recorded with NPK (NPKSBZn) +urea at 21 DAS and at 28 DAS at N'Dali (Figure 2).

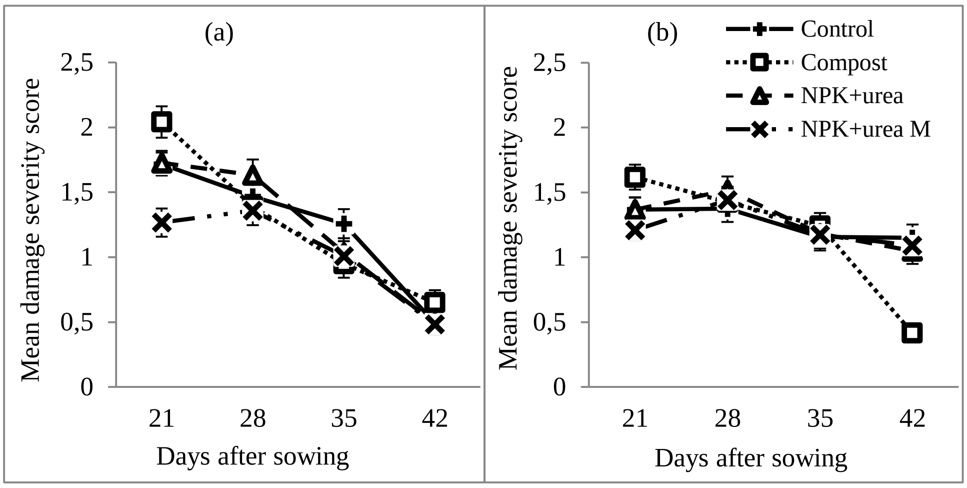

Figure 2. Effect of fertilizers on *S. frugiperda* damage severity at (a) Djidja and (b) N'Dali.

Effect of inorganic fertilizers and compost on FAW damage rate

Statistical analyses indicated that the percentage of damaged plants was not significantly different among treatments (df = 3, 109; F = 0.6922; P = 0.5587), but differed significantly between experimental sites (df = 1, 109; F = 7.3156; P = 0.0079). Overall, the average percentage of damaged plants was higher at N'Dali compared to Djidja (Figure 3).

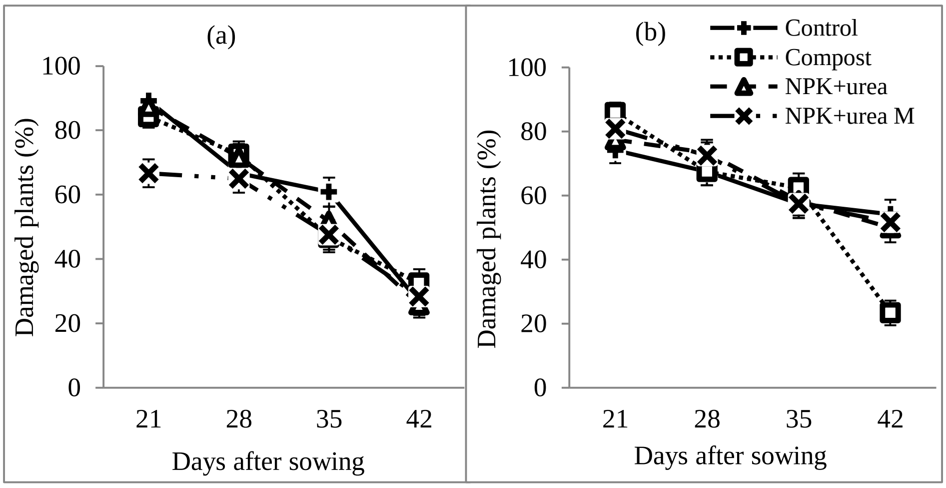

Figure 3. Effect of fertilizers on *S. frugiperda* damage rate at (a) Djidja and (b) N'Dali

Effect of inorganic fertilizers and compost on growth parameters

The application of inorganic fertilizers and compost resulted in significant differences (P < 0.001) in number of leaves, plant height and stem thickness. These growth parameters differed significantly (P < 0.001) between experimental sites. In general, the number of leaves, plant height, and stem thickness were lower in unfertilized plots compared to others (Table 2). At

Djidja, plots fertilized with compost promoted the highest number of leaves and plant height while the thickest stems were recorded in plots fertilized with compost and NPK (NPKSBZn) +urea M at both sites.

Table 2. Effect of fertilizers on leaf number, plant height, and stem thickness

Sites	Treatments	Growth parameters		
		Plant height (m)	Stem thickness (cm)	Leaf number
Djidja	Control	2.08 ± 0.02c	2.99 ± 0.03b	10.70 ± 0.10c
	Compost	2.64 ± 0.11a	3.20 ± 0.03a	11.95 ± 0.11a
	NPK+urea M	2.39 ± 0.03b	3.15 ± 0.03a	11.49 ± 0.10b
	NPK+urea	2.58 ± 0.05b	3.01 ± 0.02b	11.55 ± 0.08b
N'Dali	Control	1.60 ± 0.02c	2.48 ± 0.04b	9.15 ± 0.16c
	Compost	2.01 ± 0.02a	2.75 ± 0.04a	10.88 ± 0.17a
	NPK+urea M	1.83 ± 0.02b	2.70 ± 0.05a	9.80 ± 0.16b
	NPK+urea	1.87 ± 0.02b	2.61 ± 0.04ba	9.70 ± 0.16cb

Means (± SE) within columns followed by different letters are significantly different, SNK multiple comparison test ($p \leq 0.05$)

Effect of inorganic fertilizers and compost on maize cob and grain yield

Maize cob and grain yields differed significantly ($P < 0.001$) among treatments and between experiment sites. In general, grain yields were higher in the fertilized plots compared to the control with the highest yields recorded in plots fertilized with NPK (NPKSBZn) +urea M and compost, respectively at Djidja and N'Dali (Table 3).

Table 2. Effect of fertilizers on maize cob and grain yields

Sites	Treatments	Yield (kg/ha)	
		Maize cob	Maize grain
Djidja	Control	2228.75 ± 572.07b	1780.75 ± 488.61b
	Compost	3203.75 ± 251.51ba	2324.75 ± 124.41b
	NPK+urea M	4357.00 ± 373.20a	3419.50 ± 308.75a
	NPK+urea	3011.50 ± 308.90ba	2124.75 ± 201.43b
N'Dali	Control	1766.25 ± 139.76c	1136.25 ± 123.91c
	Compost	3597.50 ± 115.33a	2812.50 ± 94.57a
	NPK+urea M	2873.75 ± 234.49b	2156.25 ± 268.95b
	NPK+urea	3085.00 ± 241.90b	2200.00 ± 169.06b

Means (± SE) within columns followed by different letters are significantly different, SNK multiple comparison test ($p \leq 0.05$).

Effect of inorganic fertilizers and compost on FAW natural enemies population

The results of logistic binary regression indicated that treatments and experimental sites, as well as their interactions induced significant differences ($P < 0.001$) in the prevalence of FAW natural enemies per maize plant. The probability of maize plant harboring natural enemies was higher at N'Dali than Djidja. Overall, the prevalence of natural enemies was higher in plots fertilized with compost compared to other treatments (Figure 4).

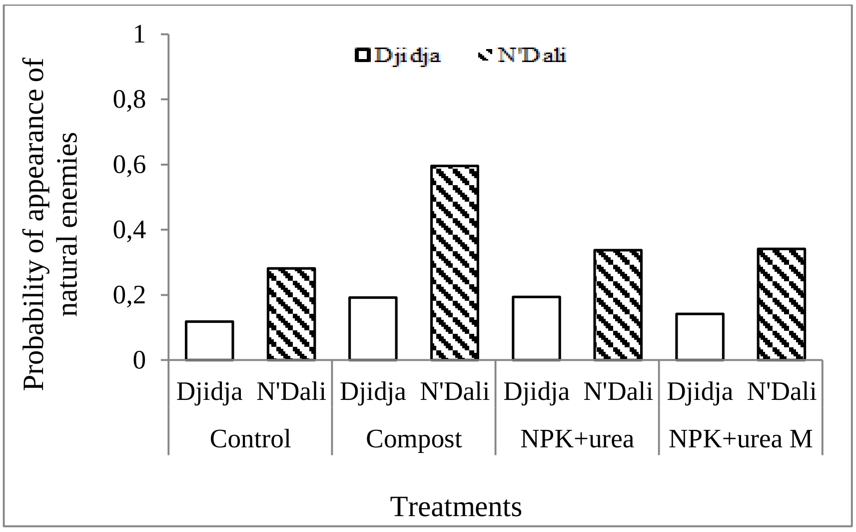

Figure 4. Effect of fertilizers on natural enemies' prevalence

The different groups of natural enemies identified were represented by ants (Hymenoptera : Formicidae), earwigs (Dermaptera : Forficulidae), ladybug beetles (Coleoptera : Coccinellidae), spiders (Araneae), carabid bettles (Coleoptera : Scarabidae), praying mantis (Mantodea : Mantidae), pentatomid bugs, and Tachinid flies (Diptera : Tachinidae). Their abundance varied significantly among the groups, the treatments and the experimental sites (df = 21 ; Deviance = 35.81 ; P = 0.02294). Natural enemies were more abundant at N'Dali compared to Djidja. Overall, they were more abundant in plots fertilized with compost compared to other treatments. In the treatment of compost, ladybug beetles and ants were more abundant at Djidja, while earwigs, ladybug beetles and ants were very abundant at N'Dali. However, no Tachinid flies were observed at N'Dali (Table 4).

Table 4. Effect of fertilizers on population of natural enemies

Sites	Treatments	Natural enemies (Mean ± SE)							
		Ladybug beetles	Ants	Carabid beetles	Praying mantis	Earwigs	Pentatomid bugs	Tachinid fly	Spiders
Djidja	Control	1.18 ± 0.20	1.81 ± 0.36	0.00 ± 0.00	0.40 ± 0.16	0.00 ± 0.00	0.62 ± 0.20	0.23 ± 0.10	0.37 ± 0.15
	Compost	2.70 ± 0.31	4.38 ± 0.62	0.25 ± 0.17	0.35 ± 0.16	0.68 ± 0.21	0.62 ± 0.20	0.37 ± 0.17	0.80 ± 0.22
	NPK+urea	2.56 ± 0.35	2.56 ± 0.49	0.29 ± 0.14	1.00 ± 0.34	0.62 ± 0.15	0.62 ± 0.20	0.37 ± 0.22	0.60 ± 0.23
	NPK+urea M	2.25 ± 0.42	2.87 ± 0.53	0.18 ± 0.13	0.20 ± 0.10	0.11 ± 0.11	0.35 ± 0.20	0.50 ± 0.24	0.33 ± 0.15
N'Dali	Control	1.50 ± 0.24	6.18 ± 0.53	0.06 ± 0.06	0.18 ± 0.10	0.25 ± 0.14	0.50 ± 0.18	0.00 ± 0.00	0.06 ± 0.06
	Compost	1.18 ± 0.27	6.87 ± 1.06	0.00 ± 0.00	0.06 ± 0.06	11.50 ± 1.98	0.81 ± 0.22	0.00 ± 0.00	0.12 ± 0.12
	NPK+urea	1.56 ± 0.25	7.06 ± 0.69	0.18 ± 0.18	0.06 ± 0.06	1.43 ± 0.40	1.00 ± 0.27	0.00 ± 0.00	0.31 ± 0.17
	NPK+urea M	1.93 ± 0.30	6.62 ± 0.95	0.00 ± 0.00	0.00 ± 0.00	1.31 ± 0.45	0.93 ± 0.28	0.00 ± 0.00	0.12 ± 0.08

DISCUSSION

The management of soil fertility, as an agro-ecological approach against FAW in maize crop, was studied in the districts of Djidja and N'Dali. The effect of the application of inorganic fertilizers commonly used in soil fertility management with the "compost" was evaluated on FAW population, leaf damage severity, yield and density of natural enemies.

The number of FAW larvae recorded per plant varied significantly among treatments and between experiment sites, with a higher larval density recorded at N'Dali. The average number of larvae per plant was significantly higher in unfertilized plots. At Djidja, no significant difference was observed in the number of larvae per plant among the fertilized plots, with the lowest larvae density recorded in the compost treatment at N'Dali. These variations could be due to the difference in the types of soils in the both districts. Several studies have demonstrated the rational use of inorganic fertilization in reducing the population of some pests and diseases of crops (Asiwe, 2009). Rao (2002) observed significant decreases in populations of jassids, aphids and spider mites on peanut plants grown in soils amended with vermicomposts, neem cake or farmyard manure, compared to those grown in soils amended with inorganic fertilizers. Biradar *et al.* (1998) also reported a decrease in population of psyllids *Heteropsylla cubana* Crawford (Hemiptera: Psyllidae) on *Leucaena leococephala* [(Lam.) de Wit] (Fabales: Fabaceae) grown with vermicomposts. Likewise, Nitiema *et al.* (2019) recorded a low population of *Maruca vitrata* Fabricius (Lepidoptera: Crambidae) and *Clavigralla tomentosicollis* Stäl (Hemiptera: Coreidae) on cowpea *Vigna unguiculata* L. Walp. (Fabales: Fabaceae) from plots applied with a combination of organic and mineral fertilizers. Pest performance was reported to positively correlate with plant nitrogen (Scriber, 1984). Fertilizer application increases the production and release of plant secondary metabolites that reduce pest performance (Salas *et al.*, 1990).

The relationship between soil fertility levels and insect damage is well documented (Cruz *et al.,* 1999). In the present study, the application of fertilizers reduced FAW damage severity but not significantly. These results corroborated with those of Baudron *et al.* (2019) who reported significant reduction of FAW damage by the application of compost. Similar results were obtained by Ramesh (2000) who observed significant reduction of sucking pest attacks due to the application of vermicompost. The results in this study could be explained by the gradual release of nutrients from organic matter (compost) which is known to be very slow (Bot & Benites, 2005), and in most of the cases nutrient are not available to plants at the right time (Giroux *et al.*, 2007). In our study, the compost applied as a basal dressing two weeks prior to the sowing is highly rich in carbon. As a result, the mineral nitrogen from its transformation may not be available for maize plants at the early whorl stage. Amanullah & Khan (2015) found that compost applied at sowing, produced higher yield and yield components of maize under semiarid conditions. However, Altieri & Nicholls (2003) revealed high levels of FAW attack on maize plants with high leaf nitrogen composition. This suggests applying fertilizers at the recommended rates.

The growth parameters, plant height, number of leaves and stem thickness measured in the present study, were significantly higher in plots fertilized with compost compared to other treatments. These results are consistent with those of Hong (2005) who showed a positive effect of organic fertilizers on the growth of rice plant. The yields obtained in the present study were significantly higher in fertilized plots with highest yield recorded with compost at N'Dali. These results may be attributed to the richness of the compost in nutrients, which increased the organic matter in the soil, the cation exchange capacity, and the biomass of microorganisms and their activities (Mulaji, 2011), that could allow damaged plants to recover and achieve their optimal growth and development.

The present results revealed a higher prevalence and abundance of natural enemies at N'Dali than at Djidja. This variation could be explained by the difference in rainfall patterns and temperature (previously mentioned in materials and methods section) prevailing in these regions. In addition, the diversity of neighboring crops observed at N'Dali, which was dominated by soybeans and cotton, unlike Djidja where only cotton crop was cultivated during the period of the experiments, may favor the abundance of natural enemies at N'Dali. The abundance of natural enemies was higher in plots fertilized with compost at both experiment sites. Brown & Tworkoski (2004) reported that organic fertilizers affect negatively the population of insect pests, but are harmless to natural enemies. Organic fertilizers can reduce pest attacks by increasing the species diversity of pest and predator (Edwards & Stinner, 1990). Several studies have shown the abundance of natural enemies in plots fertilized with compost compared to those applied with conventional fertilizers. According to Karungi *et al.* (2006), compost can increase the population of natural enemies by affecting density of leaves, and therefore the microclimate and their surface activity. Garratt *et al.* (2011) revealed that organic fertilizers can provide individual prey suitable to natural enemies. In addition, the natural regulation of pest population by natural enemies involves substances known as volatile organic compounds (Khan *et al.*, 2008) which may include semiochemicals that act as repellents for plant pests, and as attractants for antagonistic organisms of these pests, such as predators and parasitoids (Khan *et al.*, 2008). Several studies have highlighted the importance of kairomones in biological pest control (Ayelo *et al.*, 2021). We can state that, maize plants infested by FAW larvae from plots fertilized with compost can produce and release more kairomones to attract natural enemies during the experiments. However, the rate of production of volatile organic compound from plants grown with inorganic and organic fertilizers needs to be investigated.

The results revealed black ants, earwigs and ladybug beetles as the most abundant predators identified in the present study. These results support those of Morales *et al.* (2001) who reported ladybug beetles as the most abundant predators on maize plants fertilized with organic fertilizers, compared to those grown with synthetic fertilizers. Several studies have highlighted the main natural enemies recorded in the present study as potential biological control agents of FAW (Prasanna *et al.*, 2018; FAO, 2018). Most of these natural enemies are predators which have been found effective in regulating the population of insect pests (Symondson *et al.*, 2002).

CONCLUSION

This study evaluated the effect of inorganic and organic fertilizers as an agro-ecological approach of FAW management. The application of fertilizer decreases significantly the FAW population. Compost application significantly improved maize plant growth. The population of natural enemies was higher in plots fertilized with compost. These results show the importance of organic fertilization, as one of the agro-ecological approaches in the sustainable management of FAW in maize crop. Thus, the organic fertilizers could be a suitable part of control strategy of FAW for sustainable maize production.

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