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Effect of integrated nutrient-pest management and planting geometry on the fall armyworm (*Spodoptera frugiperda*), stem borer (*Busseola fusca)* and weed infestation of maize (*Zea mays* L.) in Cameroon

DERESSA NEGASA AWATA[1,3,*], ANDREW E. EGBE[1,2] AND CHRISTOPHER NGOSONG[1]

[1]*Department of Agronomic and Applied Molecular Sciences*
Faculty of Agriculture and Veterinary Medicine, University of Buea, Cameroon
**(e-mail: deressaawata@gmail.com)*

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ABSTRACT

Maize productivity is frequently hampered as a result of poor soil fertility, insect pests, weed infestations and agronomic management in sub-Saharan Africa. The purpose of this study was to evaluate how integrated nutrient-pest management and planting geometry affected fall armyworm, stem borer, weed infestation, and maize growth performance. The experiment was laid out in a split-plot design with planting geometry as the main plot and nutrient-pest management strategies as subplots with three replications at Buea, Cameroon, from August to December 2022. Planting geometry significantly influenced weed infestation and maize growth performance but did not affect the incidence and severity of fall armyworm and stem borer. Planting one plant per stand at 25 cm intra-row spacing significantly reduced weed density by 11%, weed biomass by 14%, and increased maize ear formation by 5% as compared to planting two plants per stand at wider spacing. Chem + Org + Bio treatment significantly reduced maize grain damage incidence and severity by fall armyworm and stem borer by an average of 13% and 14%, respectively, as compared to chemical treatment alone. The use of an integrated Chem + Org + Bio nutrient-pest management strategy with planting one plant per stand at 25 cm intra-row spacing is the best and most effective method to reduce fall armyworm, stem borer, and weed infestation, reduce the consumption of chemical fertilizers and pesticides, and improve maize productivity in a sustainable way.

Key words: Biofertilizer, biopesticide, integrated nutrient-pest management, planting geometry, pest infestation

INTRODUCTION

Sub-Saharan Africa (SSA) is one of the regions on the globe that is most frequently referred to as having a food security problem (FAO, 2021). Maize (*Zea mays* L.) is one of the most widely grown crops in the area and contributes to food security and income generation for many smallholder farmers in the area (Denis Achiri, 2018; Ekpa *et al.*, 2018; Lalruatsangi, 2021). In Cameroon, alongside low usage of technology by farmers, lack of appropriate planting geometry, poor soil fertility, insect pest infestations such as fall armyworm [*Spodoptera frugiperda* (J. E. Smith)] and stem borer (*Busseola fusca* (Fuller)) (Tanyi *et al.*, 2020), and weed infestations (Felix *et al.*, 2019) have been reported as the major challenges of maize production in the area. Planting two or three plants per stand with wide intra-row spacing is commonly practiced in the area.

Fall armyworm (FAW) and stem borer (SB) are often considered the most important economic insect pests of maize (Matti *et al.*, 2021), which invariably cause economic losses in sub-Saharan Africa as well as around the world up to 100% grain yield losses (Kammo *et al.*, 2019). Furthermore, weeds can hinder maize production by up to 50% and sometimes cause a total failure of the crop (Imoloame and Jo, 2017). Accordingly, farmers are seemingly using various management options, including synthetic chemicals and organic products, as

[2]Department of Plant Science, Faculty of Science, University of Buea, Cameroon.
[3]Department of Plant Science, Faculty of Agriculture and Veterinary Medicine, Ambo University, Ethiopia.

well as increasing intra-row spacing by planting two or three plants per stand, to contend with these problems. However, the continuous use of synthetic chemicals results in pest resistance, soil fertility depletion, and severe environmental impacts (Tudi *et al.*, 2021). The use of solely organic products does not always produce the desired outcomes due to their relatively slow release of important ingredients at critical periods of pest severity and crops' nutrient needs (Halim *et al.*, 2019; Damalas and Koutroubas, 2020; Haroli *et al.*, 2023). Moreover, according to farmers' perceptions, increasing spacing between plants by planting two or three plants per stand reduces insect pest infestation compared to planting a single plant per stand at 25 cm of intra-row spacing. However, this practice causes a decline in crop yields. Therefore, it has become imperative to seek alternative options that can be adapted to the specific needs of farmers. Integrating beneficial microbes with other nutrient-pest management and appropriate plant spacing can manage insect pest infestations, crop-weed competitions, and crop nutrient needs in sustainable way. Therefore, this study was conducted to evaluate the effects of integrated nutrient-pest management and planting geometry on maize growth performance, stem borer, fall armyworm, and weed infestation.

MATERIALS AND METHODS

Experimental Site and Set Up

The field experiment was conducted in University of Buea, South-west Region of Cameroon in 2022 from August to December. The area is located between latitudes 3.54°N to 4.12°N and longitudes 9.0°E to 9.36°E. The area has an elevation of about 450 m asl with 2800 mm of annual rainfall between June and September, a mean annual temperature of 27 °C, and 80 to 86% relative humidity (Egbe *et al.*, 2022). The experiment consisted of two planting geometries and eight types of nutrient-pest management (NPM) strategies, giving a total of 16 treatment combinations. Planting geometry comprised planting one plant per hole at 25cm intra-row spacing and planting two plants per hole at 50 cm intra-row spacing while NPM strategies contained chemical, organic and biological fertilizer and pesticides in various combinations (Table 1).

The experiment was laid out as a split plot design (plant geometry as the main plot and NPM as the subplots) in a factorial arrangement with three replications. A total experimental land area of 1196 m^2 (46 × 26 m) was demarcated into 48 experimental plots, measuring 15 m^2 (4 × 3.75 m) each. The distance between blocks and plots was separated by 1.5 m of spacing.

Preparation and Application of Biofertilizer and Biopesticide

Eleven strains of plant growth-promoting bacteria as biofertilizers and two fungal strains as bio-controls were used (Table 2). The strains were grown and formulated following the laboratory's protocol. Maize seeds were inoculated at a ratio of 125 ml/kg of seeds

Table 1. Combination of different levels of fertilizers and pesticides with planting geometry

Treatments	Descriptions
25 cm + Control	Control= No input
25 cm + Chem	Chem=100% NPK+100% Lamida gold
25 cm + Org	Org= 100% Poultry manure +100% piper extract
25 cm + Bio	Bio= 100% Biofertilizers +100% biopesticides
25 cm + Chem + Org	50% Chem + 50% Org
25 cm + Chem + Bio	50% Chem + Bio
25 cm + Org + Bio	50% Org + Bio
25 cm + Chem + Org + Bio	25% Chem + 25% Org + Bio
50 cm + control	Control= No input
50 cm + Chem	Chem=100% NPK +100% Lamida gold
50 cm + Org	Org= 100% Poultry manure +100% piper extract
50 cm + Bio	Bio= 100% Biofertilizers +100% biopesticides
50 cm + Chem + Org	50% Chem + 50% Org
50 cm + Chem + Bio	50% Chem + Bio
50 cm + Org + Bio	50% Org + Bio
50 cm + Chem + Org + Bio	25% Chem + 25% Org + Bio

for each biofertilizers and biopesticides. Six weeks after planting, 350 ml of each biofertilizers and biopesticides (Efthimiadou *et al.*, 2020) were sprayed on the whole plant parts and the entire soil up to 10 cm from the plant roots for the respective plots.

Preparation and Application of Organic Pesticide (Piper Extracts)

West African black pepper (*Piper guineense* Schumach. & Thonn.) seeds were collected from the local market, then fully dried and milled with a kitchen blender to produce a fine powder. Two hundred and fifty (250 g) of *Piper* powder was dissolved in 1 L of vegetable oil (OILIO®, Douala, Cameroon) with the addition of 20 g of detergent (OZIL®, Douala, Cameroon). Then the solution was thoroughly stirred to produce a sticky emulsion, and the extracted solution was filtered by using a double-folded muslin cloth for field spraying. About 9.6 ml per plot on the respective plots were applied twice at three and five weeks after planting in the ratio of 100 ml of extract solution to 15 L of water.

Application of Poultry Manure, NPK and Lamida Gold

The dried poultry manure was incorporated into the soil two weeks before planting for plots receiving poultry manure based on the recommended rate of 6 ton/ha. NPK fertilizer 20-10-10 (5 g/plant) was applied by split application (at three and six weeks after planting) through ringing at 5 cm from the plant. Lamida gold comprising 90 EC was applied at a ratio of 0.75 L/ha on the respective plots using a knapsack sprayer with a ratio of 30 ml to 15 L of water twice at three weeks after planting and five weeks after planting for the respective plots.

Incidence of FAW and SB on the Field (%)

Incidence of FAW and SB was determined from three to seven weeks after planting (WAP) from 10 randomly tagged plants per plot by counting the number of plants colonized or showed symptoms of damage which was calculated as under:

$$\text{Pest incidence (\%)} = \frac{\text{Number of infested plants/plot}}{\text{(Total number of plants per plot)}} \times 100 \quad ...(1)$$

Grain Damage Incidence (%)

Grain damage incidence was determined at the harvesting stage from the cobs harvested from 10 randomly assigned plants per plot by counting the number of cobs colonized or showed symptoms of damage which was calculated as follows:

$$\text{Grain damage incidence (\%)} = \frac{\text{Number of infested cobs/sample}}{\text{Total number of cobs sampled}} \times 100 \quad ...(2)$$

Table 2. List of biofertilizer (PGPB) and biopesticide (fungal endophytes)

S. No.	Isolates	Genus	Family	Functions
PGPB				
1	V12	*Paenibacillus*	Paenibacillaceae	N-fixation
2	V18	*Paenibacillus*	Paenibacillaceae	N-fixation
3	V47	*Lysinibacillus*	Bacillaceae	N-fixation and P-solubilization
4	VA9	*Bacillus*	Bacillaceae	P-solubilization
5	V22	*Bacillus*	Bacillaceae	P-solubilization
6	V62	*Bacillus*	Bacillaceae	P-solubilization
7	V74	*Sinomonas*	Micrococcaceae	P-solubilization
8	V64	*Arthrobacter*	Micrococcaceae	P-solubilization
9	V84	*Arthrobacter*	Micrococcaceae	P-solubilization
10	V127	*Arthrobacter*	Micrococcaceae	P-solubilization
11	D5/23	*Kosakonia*	Enterobacteriaceae	N-fixation and P-solubilization
Fungal endophytes				
1	Tr-Sv-CG40	*Trichoderma*	Hypocreaceae	Biocontrol activity
2	Bb-Sv-CG24	*Beauveria*	Cordycipitaceae	Biocontrol activity

Source: Rhizobiology Laboratory (University of Buea, 2022.

Severity of FAW and SB on the field

FAW and SB severity were measured every week from three to seven WAP from 10 randomly tagged plants per plot by counting the number of larvae per entire plant.

Grain Damage Severity

Grain damage severity was estimated with the help of following equation by measuring the percentage of damaged portions of the cobs which were harvested from 10 randomly tagged plants per plot.

$$\text{Grain damage severity (\%)} = \frac{\text{Area of damaged/cob}}{\text{Total area of the cob)}} \times 100 \quad ...(3)$$

Weed Density and Biomass

Weed density was determined by counting the number of weeds per meter square (from two randomly placed 50 x 50 cm quadrants) prior to weeding at the early maize tasseling stage. The weeds were counted and categorized into broadleaf, grassy, and sedges. These were later summed to give the total weed density per meter square. Counted weeds were cut at ground level, chopped, dried at 65 °C to a constant weight and the dry biomass was measured with a laboratory balance.

Maize Growth Performance

Maize leaf was collected from 10 randomly selected plants per plot at the maize tasseling stage, and the actual leaf area was measured in the laboratory using a leaf area meter. The leaf area index was determined as the ratio of the total leaf area (cm^2) of the plant to the ground area. Two maize plants per plot were cut at the tasseling stage, chopped into small pieces, and oven-dried at 65 °C to constant weight to determine maize dry biomass. The number of ears per plant was counted from 10 randomly chosen plants at crop physiological maturity.

Statistical Analysis of Data

All collected data were subjected to analysis of variance (ANOVA) by using the R software (R Core Team 2023). In the case where the analysis of variance test showed significant test results, Tukey's post-hoc tests at a 5% probability level were used to identify treatment means that were significantly different from each other.

RESULTS AND DISCUSSION

Incidence and Severity of Fall Armyworm and Stem Borer

The incidence and severity of FAW and SB from three to seven WAP (Fig. 1 and Table 3), grain damage incidence (Fig. 2a), and grain damage severity (Fig. 2b) were significantly ($P<0.01$) affected by NPM. However, planting geometry and the interaction effect did not show any significant effect on these parameters. The highest incidence of FAW and SB was recorded in the control (48.32%), while the lowest was recorded in the combination of Chem + Org (0.83%) treatment, which did not differ from Chem + Org + Bio and Chem treatments at seven WAP (Fig. 1). The least number of larvae per plant was counted at the same weeks for the Chem + Org + Bio treatment (0.05) while the highest number of larvae per plant was recorded for the control (2.00) plot (Table 3). The incidence and severity of FAW and SB increased from three to seven WAP for the control plot, while it started decreasing from four WAP for Chem, Chem + Org, Chem + Bio and Chem + Org + Bio treatments, but from five weeks for the left treatments (Fig. 1). This shows that the involvement of chemical fertilizer and pesticides in the treatment combination might support the system due to its quick and immediate action on pest and nutrient supply at critical times of pest infestation and nutrient demands. But the lack of significant difference between treatments which integrated with different levels of chemicals highlighted that integrating half or one-fourth of the recommended rate of chemical fertilizer and pesticide with organic and microbes can sustain the efficiency of the system which reduces chemical usage by 50 to 75%. In line with this result, Kumar *et al.* (2022) reported that integrating other intercultural and non-chemical pest control strategies with chemical pest management showed encouraging results for sustainable management of fall armyworm. Balanced nutrition, which is supplied through

Table 3. Effect of nutrient-pest management strategies on fall armyworm and stem borer severity of maize (number of larvae per plant; mean ±SD) from three to seven weeks after planting

Treatments	Weeks after planting				
	3	4	5	6	7
Control	0.97±0.4^{aC}	1.08±0.3^{aC}	1.22±0.4^{aBC}	1.64±0.1^{aAB}	2.00±0.2^{aA}
Chem	0.97±0.3^{aA}	0.38±0.2^{bB}	0.11±0.1^{dB}	0.11±0.1^{dB}	0.11±0.1^{cB}
Org	0.86±0.3^{aA}	0.94±0.5^{abA}	0.38±0.1^{cdAB}	0.18±0.1^{cdB}	0.11±0.1^{cB}
Bio	0.55±0.4^{aBC}	0.93±0.1^{abA}	0.75±0.1^{bAB}	0.55±0.1^{bBC}	0.38±0.1^{bC}
Chem + Org	1.05±0.2^{aA}	0.36±0.3^{bB}	0.18±0.2^{cdB}	0.12±0.1^{dB}	0.08±0.1^{cB}
Chem + Bio	1.02±0.3^{aA}	0.50±0.3^{abB}	0.33±0.2^{cdB}	0.23±0.1^{cdB}	0.14±0.1^{bcB}
Org + Bio	1.00±0.2^{aA}	0.72±0.2^{abAB}	0.44±0.1^{bcBC}	0.41±0.1^{bcBC}	0.22±0.1^{bcC}
Chem + Org + Bio	0.86±0.3^{aA}	0.41±0.2^{bB}	0.30±0.1^{cdB}	0.21±0.1^{cdBC}	0.05±0.1^{cC}
P-value	0.16	<0.001	<0.001	<0.001	<0.001

Values within columns with different lowercase letters are significantly different between treatments for each week while values within rows with different uppercase letters are significantly different between weeks for each treatment, at (P=0.05), according to Tukey's mean separation test.

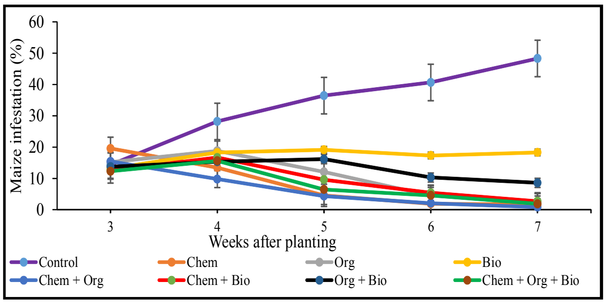

Fig. 1. Effect of nutrient-pest management on the incidence of fall armyworm and stem borer from three to seven weeks after planting.

integrated nutrient management, also helps the plants become more resistant to pests (Bala *et al.*, 2018).

However, at the harvesting stage, treatments integrated with biofertilizer and biopesticide showed the least grain damage incidence and grain damage severity as compared to other treatments (Fig. 2a and b). This might be due to the fact that integrating biofertilizers and biopesticides with other nutrient-pest control enhances nutrient uptake efficiency and fights against insect pests through nutrient supply (Gao *et al.*, 2020), phytohormone production (Ramírez and Maiti, 2016), releasing antifeedant compounds, and activating systemic plant defensive responses (Selim, 2020). Similar to this finding, the ability of different species of *Trichoderma* to produce antifeedant compounds against various insect pests has been reported by Contreras-Cornejo *et al.* (2018). The effectiveness of *Beauveria* spp. against fall armyworm eggs and second-instar larvae was also reported by Akutse *et al.* (2019). The

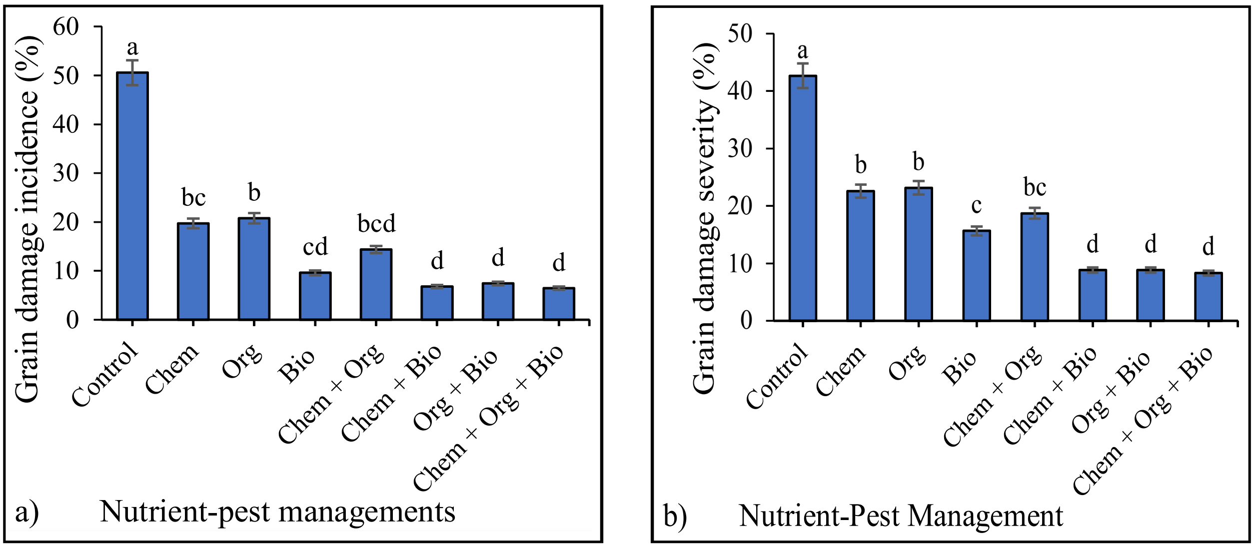

Fig. 2. Effect of nutrient-pest management on maize grain damage incidence and grain damage severity by fall armyworm and stem at harvesting stage.

aggravated pest incidence and severity on the maize grain for Org treatment might be due to the fact that important ingredients found in organic pesticide might have a shorter life span (Scott *et al.*, 2004), while probably due to the development of chemical-resistant pests for Chem treatment (Goergen *et al.*, 2016).

Planting geometry had no significant effect on the incidence and severity of FAW and SB at all maize growth stages (Table 4). This highlights the lesser impact of this agronomic practice on the incidence and severity of these insect pests. Under a monocropping system, the larvae of these insects can easily move from one plant to the next nearby plant due to the absence of any traps between the host plants. The high dispersal ability of FAW was reported in the absence of non-host plants (Mutyambai *et al.*, 2022). In Uganda, 95% of FAW infestations were reported under the monocropping system of maize production (Hailu *et al.*, 2018).

Weed Infestation

Weed density and biomass were significantly ($P<0.01$) affected by planting geometry, NPM, and their interactions (Table 5). The least mean values of weed density (112.67 per m^2) and weed dry biomass (13.89 g/m^2) were recorded for the treatment of Chem + Org under 25 cm planting geometry, which did not differ from the Chem + Bio, Chem + Org + Bio, and Chem treatments under the same planting geometry. The highest mean values were recorded for the control plot under 50 cm (Table 5). Reducing the number of plants per stand from two to one and minimizing the intra-row spacing of plants from 50 to 25 cm reduced the weed population and weed biomass by 11 and 14%, respectively. This is due to less intra-competition of plants for resources which can speed up plant growth and canopy development, which in turn reduce weed emergence and weed biomass accumulation (Andrade *et al.*, 2002).

Table 4. Effects of planting geometry (PG) on the incidence and severity of fall armyworm (FAW) and stem borer (SB) from three to seven weeks after planting

PG	Weeks after planting				
	3	4	5	6	7
			Incidence of FAW and SB (%)		
25 cm	15.15 ± 4.2^{a}	18.38 ± 6.4^{a}	14.66 ± 9.9^{a}	10.43 ± 11.2^{a}	17.05 ± 15.8^{a}
50 cm	14.32 ± 6.3^{a}	19.10 ± 6.7^{a}	12.54 ± 11.7^{a}	10.01 ± 13.6^{a}	16.88 ± 16.7^{a}
P-value	0.8	0.66	0.05	0.47	0.91
			Severity of FAW and SB (Number of larvae per plant)		
25 cm	0.91 ± 0.2^{a}	0.74 ± 0.4^{a}	0.53 ± 0.4^{a}	0.46 ± 0.5^{a}	0.38 ± 0.6^{a}
50 cm	0.91 ± 0.4^{a}	0.59 ± 0.4^{a}	0.39 ± 0.3^{a}	0.41 ± 0.4^{a}	0.39 ± 0.6^{a}
P-value	0	0.91	0.11	0.24	0.77

Means in columns with the same letters for each parameter are not significantly different at (P=0.05), according to Tukey's mean separation test.

Table 5. Interaction effect of planting geometry and nutrient-pest management (NPM) on weed density and weed dry biomass (mean ±SD) at early tasseling stage of maize growth

PNM	Weed density/m^2		Weed dry biomass (g/m^2)	
	25 cm	50 cm	25 cm	50 cm
Control	216.66 ± 19.5^{ab}	223.60 ± 15.7^{a}	24.06 ± 2.0^{b}	27.03 ± 1.1^{a}
Chem	128.99 ± 11.8^{ef}	$172.40\pm7.4^{b-e}$	15.35 ± 0.2^{ef}	19.85 ± 1.4^{cd}
Org	$172.12\pm19.3^{b-e}$	$175.93\pm21.9^{a-e}$	19.07 ± 0.5^{d}	22.26 ± 0.8^{bc}
Bio	$190.33\pm13.8^{a-d}$	209.40 ± 7.2^{abc}	20.87 ± 0.2^{cd}	23.94 ± 0.6^{b}
Chem + Org	112.76 ± 8.2^{f}	$183.33\pm10.4^{a-d}$	13.89 ± 0.3^{f}	20.95 ± 0.7^{cd}
Chem + Bio	$162.02\pm24.6^{c-e}$	$178.46\pm15.6^{a-d}$	14.48 ± 0.9^{f}	18.22 ± 0.6^{de}
Org + Bio	$200.46\pm21.2^{a-d}$	$199.80\pm11.3^{a-d}$	20.36 ± 1.3^{cd}	21.00 ± 0.8^{cd}
Chem + Org + Bio	$151.56\pm8.9^{d-f}$	$160.60\pm10.3^{c-f}$	19.32 ± 0.9^{d}	20.46 ± 1.0^{cd}
P-value	0.009		<0.001	

Means in columns with different letters are significantly different at (P=0.05), according to Tukey's mean separation test; MSD-mean significance difference.

Integrating two and more than two fertilizers and pesticides enhances the plant's growth quickly and gives it the chance to shade the area, thus, in turn, improving crop health, growth, and competitive performance compared to the sole treatments. Nagavani and Subbian (2015) reported that integrating 50% of the recommended chemical fertilizer with poultry manure effectively reduced weed density compared to the sole application. A similar finding was reported by Ghosh *et al.* (2020), who found that integrated nutrient management with concentrated organic manure enhanced nutrient uptake by maize and diminished weed growth. Under low intra-competition, plants can be more competitive against weeds because the canopy closes earlier than wide row spacing, which affects light penetration to the soil surface, modifying weed emergence patterns and growth (Mohammadi *et al.*, 2012).

Maize Growth Performance

Leaf area index, maize stover dry biomass and percentage of plants that produced ears were significantly affected by planting geometry (P<0.05) and NPM (P<0.01) (Table 6), but their interaction did not show any significant effect. The higher mean values of leaf area index (3.14), dry biomass (4.59 t/ha), and percentage of plants that produced ears (91.28%) were recorded for planting one plant per stand at 25cm intra-row spacing. Planting at 25 cm intra-row spacing increased plant ear production by an average of 5% over 50 cm (Table 6). This might be due to the fact that planting a single plant per stand reduces overlapping from adjacent plants, which could enable the plant to get a wider spacing to utilize its energy for more horizontal growth and reduce competition for resources (Kebede, 2019). It also ensures that the crop canopy effectively covers the ground surface, thereby over shade and suppress weeds (Mhlanga *et al.*, 2016). Intra-plant competition influences synchrony of flowering and promotes barrenness (Pagano *et al.*, 2007).

The maximum maize stover dry weight was observed with the Chem + Bio treatment. The highest leaf area index (3.28) from Chem treatment and the highest percentage of plants that produced ears (98.18%) from Chem + Org were obtained. The lowest mean values were obtained for the control plot on these parameters (Table 6). The high maize leaf area and dry biomass accumulation might have enhanced the ear-forming capacity of plants for the treatments. In this integration, organic fertilizer represents a good source of macro- and micronutrients for plants and also supplies energy for microbes (Boateng *et al.*, 2006). Microbes promote the availability of nutrients through solubilization, providing plant growth-promoting hormones, and producing antifeedant compounds, which may result in improved plant growth and health (Bala *et al.*, 2018; Subbaiah and Ram, 2019). Several researchers have reported that integrating chemical fertilizer with biofertilizers and

Table 6. Effect of planting geometry and nutrient-pest management (NPM) strategies on leaf area index, maize dry biomass, number of ears per plant and percentage of effective plants (mean +SD) of maize

Treatments	Leaf area index	Maize dry biomass (t/ha)	Productive plants/ha (%)
Planting Geometry			
25cm	3.14±0.8[a]	4.59±1.2[a]	91.28±9.0[a]
50cm	1.95±0.6[b]	4.00±1.0[b]	86.50±8.7[b]
P-value	0.005	0.3	0.04
NPM			
Control	1.41±0.5[c]	2.31±0.4[c]	75.55±4.8[d]
Chem	3.28±0.9[a]	4.94±0.7[a]	97.12±2.3[a]
Org	2.54±0.9[ab]	4.18±0.6[ab]	87.69±3.4[bc]
Bio	2.12±0.7[bc]	3.72±0.7[b]	82.74±5.0[cd]
Chem + Org	3.20±0.9[a]	4.91±0.6[a]	98.18±3.4[a]
Chem + Bio	2.94±0.9[ab]	5.23±0.9[a]	94.52±7.4[ab]
Org + Bio	2.21±0.8[bc]	4.50±1.1[ab]	83.23±6.7[cd]
Chem + Org + Bio	2.84±0.9[ab]	4.55±0.6[ab]	92.08±1.1[ab]
P-value	<0.001	<0.001	<0.001

Means in columns with different letters are significantly different at (P=0.05), according to Tukey's mean separation test.

organic fertilizer increases plant growth and maize productivity (Al-Suhaibani *et al.*, 2021).

CONCLUSION

Based on the obtained results, planting geometry did not show any significant impact on the incidence and severity of fall armyworm and stem borer at different growth stages of maize, which provides clear information on the farmers' perceptions. Planting one plant at 25 cm intra-row spacing improved maize growth performance and reduced weed infestation compared to planting two plants at 50 cm intra-row spacing. Integration of Chem + Org, Chem + Bio, and Chem + Org + Bio reduced fall armyworm, stem borer, and weed infestations and improved maize growth performance, which is essential to improve maize productivity and contribute to food security. It could be concluded that integrating Chem + Org + Bio with planting one plant per stand at 25 cm intra-row spacing is the best and most effective method to improve maize productivity and reduce the consumption of chemical fertilizer and pesticides.

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