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Nitrogen Fertilizer Rates and Pesticides Interaction Effect on Maize and Fall Armyworm Performance in Northern Ghana

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Abstract

Maize is in high demand due to its significant contribution to food security and income generation. However, in Ghana, its production is adversely affected by low soil fertility and fall armyworm (FAW) infestation. The application of fertilizers and sound FAW control could contribute to increased maize yield in the country. This study was conducted to determine the effect of nitrogen fertilizer rates and FAW pesticide application on growth and yield of maize. The experiment involved four levels of fertilizer rates (No N-fertilizer, N-fertilizer at 40 $kg\cdot ha^{-1}$, N-fertilizer at 60 $kg\cdot ha^{-1}$, N-fertilizer at 80 $kg\cdot ha^{-1}$,N-fertilizer at 100 $kg\cdot ha^{-1}$), and two levels of pesticides application (Emastar 125 EC, Pesticide-free plot) in split-plots design with four replications. The results show that generally, fall armyworm number of egg mass, larvae, and leaf injury severity were significantly ($p < 0.01$) lower on the sprayed plots. The number of egg masses on unsprayed plots (51.4%) and sprayed plots (49.8%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg per/ha, compared to the control. The 100 kg/ha fertilizer rate with or without insecticides spray gave the highest number of egg mass, larvae, and mean crop damage while the least occurred on 40 kg/ha treatment. Grain yield, hundred seed weight, and stover dry weight were significantly (p

< 0.01) higher on sprayed plots, compared to unsprayed plots. Furthermore, the 80 and 100 kg/ha fertilizer rates with or without insecticides spray gave the highest grain yield, hundred seed weight, and stover dry weight. The present findings suggest that the appropriate nitrogen fertilizer application and strategic use of pesticides could improve maize yield as well as mitigate fall armyworm infestation.

Subject Areas

Agricultural Science

Keywords

Fall Armyworm, Nitrogen Fertilizer, Fertilizer Rate, Egg Mass, Leaf Injury, Pestisticides

1. Introduction

The fall armyworm (FAW) (*Spodoptera frugiperda*), which feeds on a wide variety of host plants, is a major pest across the world. It damages the leaves and stems of important crops such as maize, rice, sorghum, sugarcane, and some vegetable crops, causing significant economic losses [1]. In developing countries, fall armyworm has become a major threat to food security. The United Nations' efforts to improve everyone's well-being and health are threatened due to the global invasion of fall armyworms. Under favourable conditions, fall armyworms have higher fecundity, spread quickly, and can reduce yield by 40 - 70 percent [1].

The indirect effects of fertilization practices acting through changes in the nutrient composition of the crop have been reported to influence plant resistance to many insect pests. Primary pest defence of plants like physical and biochemical properties can be enhanced by balanced fertilization with plant nutrients. It is reported that fertilizers are applied to improve soil fertility, control pests to mitigate the effects of infestation of insect pests on crop productivity [2]. Rising levels of available nutrients have altered the global nutrient cycle substantially with consequential changes in terrestrial and aquatic systems [3]. For instance, lower doses of Nitrogen increased the chlorogenic acid which enhanced resistance against thrips. Cotton aphid population density was significantly decreased by the interaction of nitrogen and potassium fertilizers and the combination of potassium and nitrogen fertilizers in a proper rate [4].

Globally, maize (*Zea mays* L.) production is increasing at a faster rate in terms of tons per year. Maze is in high demand due to its significant contribution to food security and income generation for farmers [5]. Unfortunately, the devastating effects of insect pests such as fall armyworm have severely hampered production in recent times [6]. The fall armyworm feeds on the foliage, reproductive parts and grains and reduces the economic yields of the maize crop.

Feeding on reproductive parts inhibits or reduces fertilization and grain formation, hence reduced final grain yield [7]. Fall armyworm is also capable of partially or totally damaging maize cob, thereby reducing grain quality and ultimately grain yield [8]. Excessive and inappropriate use of nitrogen fertilizers can cause nutrient imbalances and lower pest resistance [5]. Therefore, the integration of proper nitrogen fertilizer application and strategic use of organic pesticides has the potential for successful fall armyworm management. This work is based on the hypothesis that appropriate nitrogen fertilizer and pesticide application can suppress fall armyworm infestation and damage severity. The purpose of this study was therefore to determine the interaction effect of nitrogen fertilizer rate and pesticide application on maize performance in fall armyworm infested fields.

2. Materials and Methods

2.1. Study Area

In the 2022 cropping season, a field experiment was established on the research field of the Council for Scientific and Industrial Research—Savanna Agricultural Research Institute (CSIR-SARI) in Wa, Upper West region, Ghana. The trial site is located within the Guinea Savannah ecological zone. This zone has a unimodal rainfall pattern that usually begins in May and ends in October, followed by a dry season from November to April. Annual rainfall ranges between 900 and 1200 mm. The daily mean temperature in this zone ranges from 26 to 45 degrees Celsius. The soil type in the experimental area is Savannah Ochrosol. The top soil is about 25 cm deep, made up of greyish brown loamy sand. Planting was done in mid-July. Weeds were controlled manually at three and six weeks after seedling emergence.

2.2. Experimental Design, Planting Material and Treatments

The experiment involved five levels of fertilizer rates (No N-fertilizer, N-fertilizer at 40 $kg \cdot ha^{-1}$, N-fertilizer at 60 $kg \cdot ha^{-1}$, N-fertilizer at 80 $kg \cdot ha^{-1}$, N-fertilizer at 100 $kg \cdot ha^{-1}$), and two levels of pesticides (Emastar 125 EC and No Pesticide) in a split-plot design with four replications. The fertilizer treatments were assigned to the main-plot, whereas, the pesticide treatments were assigned to the sub-plots. The Wang dataa maize variety variety was used for the experiment. This variety matures in 90 days, has excellent seed quality and drought tolerant. It has a yield potential of 4.0 t/ha. The trial was monitored for FAW larvae infestation, and insecticide treatments began when there was a 20% field infestation. This was two weeks after their emergence.

2.3. Assessment of Growth Parameters

Five plants were randomly selected and tagged from the middle rows of each plot for data measurement. Plant height was measured at two weeks interval starting from 2WAP, using a tape measure until 8WAP, when all plants have reached their full heights. The average was obtained as the height of plants for each plot. Five plants were randomly selected and harvested from each plot at 40 DAP and weighed. The samples were oven dried at 80˚C for forty-eight hours. The dry samples were weighed for dry weight. The inner rows from each plot were observed till the date when the flag leaf appeared and recorded. Plants were observed for tasseling on each plot and the number of days to 50% tasseling was recorded. Plants were critically observed and the number of days to 50% silking was calculated from the date of sowing.

2.4. Assessment of Yield Parameters

Grains were harvested from 20 inner rows per plot, enveloped, weighed and readings used to determine grain yield (kg/ha). From each plot, 100 grains were randomly selected and weighed to obtain 100 grain weight. Stovers were harvested from 2 × 2 m^2 inner rows per plot, enveloped, oven dried at 80˚C for 48 hours, weighed and recorded. After harvest, ten maize plants from each plot were selected from the inner row of each plot. Samples were put in sampling bags and weighed. Samples were oven dried at 80˚C in the laboratory.

2.5. Fall Armyworm Sampling

Data were collected from 20 plants randomly selected along two diagonals on each plot prior to and seven days after treatment application. The following variables were measured from the plants sampled: the number of egg masses; the number of larvae (non-destructively); and leaf injury severity using the Davis scale (from 0—no injury, to 9—severe injury). At harvest, the percentage of cobs with FAW damage was calculated using 20 randomly selected plants per plot.

2.6. Data Analyses

Count data had heterogeneous variances and were therefore square root-transformed ($\sqrt{x}+1$) before subjecting them to statistical analysis. An analysis of variance (ANOVA) for split-plots design, with fertilizers as the main-plot and Insecticides treatments as sub-plot treatments was performed. This was done using GenStat® statistical program (12th edition). Differences among the treatment means were compared using Fishers' Protected Least Significant Difference (LSD) test at 5% probability level.

3. Results

3.1. Interaction Effect of Nitrogen Fertilizer and Pesticides Application on Fall Armyworm Infestation

There was a significant ($p < 0.01$) nitrogen and pesticide application effect on number of egg mass, larvae, and leaf injury severity (Figure 1). Generally, number of egg mass, larvae, and mean crop damage were significantly ($p < 0.01$) higher on the unsprayed plots, compared to the sprayed plots. The number of egg masses on unsprayed plots (51.4%) and sprayed plots (49.8%) were highest on plots treated with nitrogen fertilizer at 100 kg/ha and least on the 40 kg/ha,

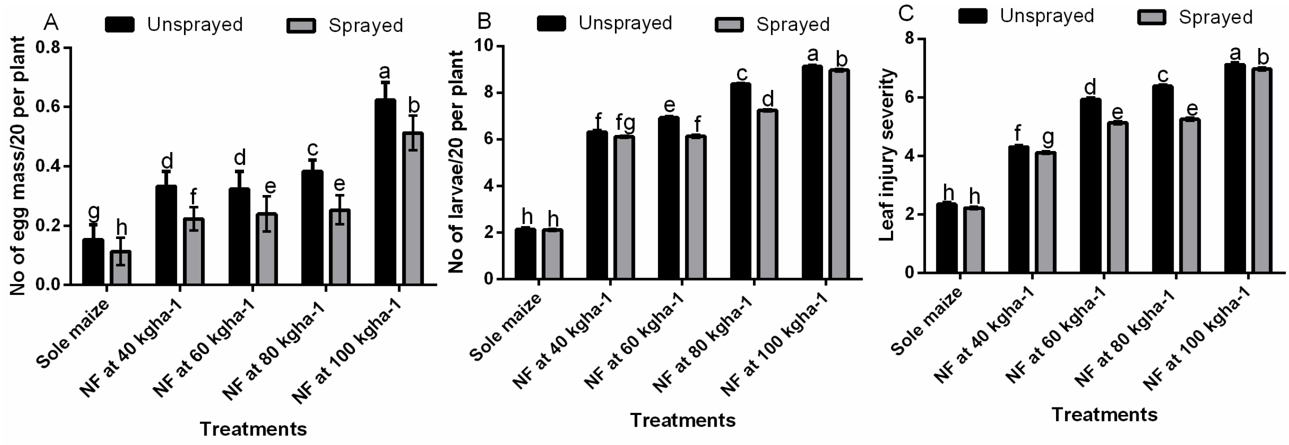

Figure 1. Interaction Effect of nitrogen fertilizer rate and pesticides application on (A) number of egg mass per 20 plants, (B) number of larvae per 20 plants, and (C) leaf injury severity.

compared to the control (Figure 1(A)). However, on the unsprayed plots, number of egg mass did not significantly differ from the 40 kg/ha and 60 kg/ha treatments. Similarly, the number of larvae on unsprayed plots (71.1%) and sprayed plots (59.8%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg/ha, compared to the control (Figure 1(B)). The number of larvae on unsprayed plots (72.2%) and sprayed plots (60.9%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg per/ha, compared to the control (Figure 1(C)). However, on the sprayed, leaf injury severity did not significantly differ from the 40 kg/ha and 60 kg/ha treatments. Thus, among the fertilizer treatments, 100 kg/ha treatment gave the highest number of egg mass, larvae, and leave injury severity with or without insecticide spray, whereas the least occurred on 40 the kg/ha treatment, compared to the control.

3.2. Interaction Effect of Nitrogen Fertilizer and Pesticides Application on Maize Plant Growth Parameters

There was a significant ($p < 0.01$) nitrogen and pesticide application effect on plant height at weeks four, six, and eight (Figure 2). At week four, plant height on unsprayed plots (40.1%) and sprayed plots (45.5%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg per/ha, compared to the control (Figure 2(B)). At week 6, plant height on unsprayed plots (40.1%) and sprayed plots (45.5%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg per/ha, compared to the control (Figure 2(C)). At week 8, plant height on unsprayed plots (44.6%) and sprayed plots (49.3%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg per/ha, compared to the control (Figure 2(D)). Thus, among the fertilizer treatments, 100 kg/ha had the highest plant height across the number of weeks with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control.

There was a significant ($p < 0.01$) nitrogen and pesticide application effect on days to 50% tasselling and silking. However, days to 50% silking did not significantly ($p = 0.06$) differ between the sprayed and the unsprayed treatments (Figure 3).

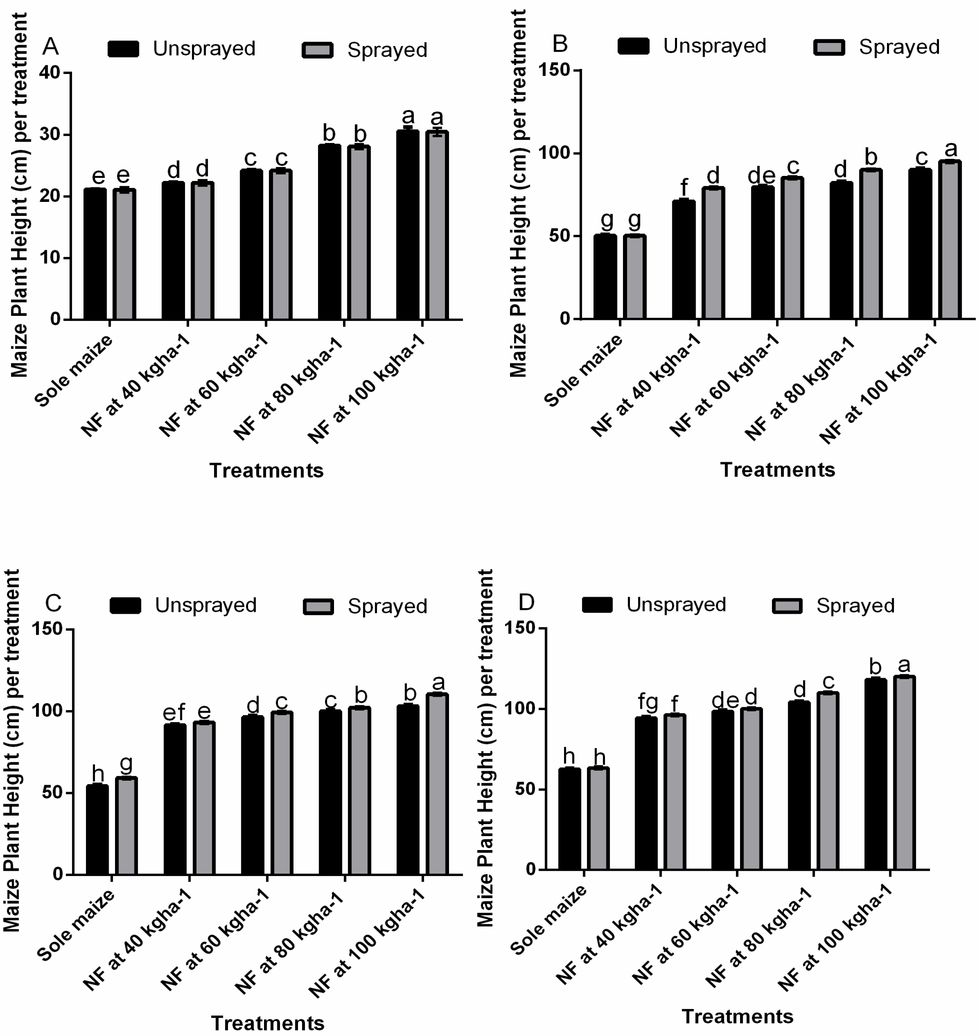

Figure 2. Interaction effect of nitrogen fertilizer and pesticides application on plant height at (A) week one, (B) week four, (C) week six, and (D) week eight after planting.

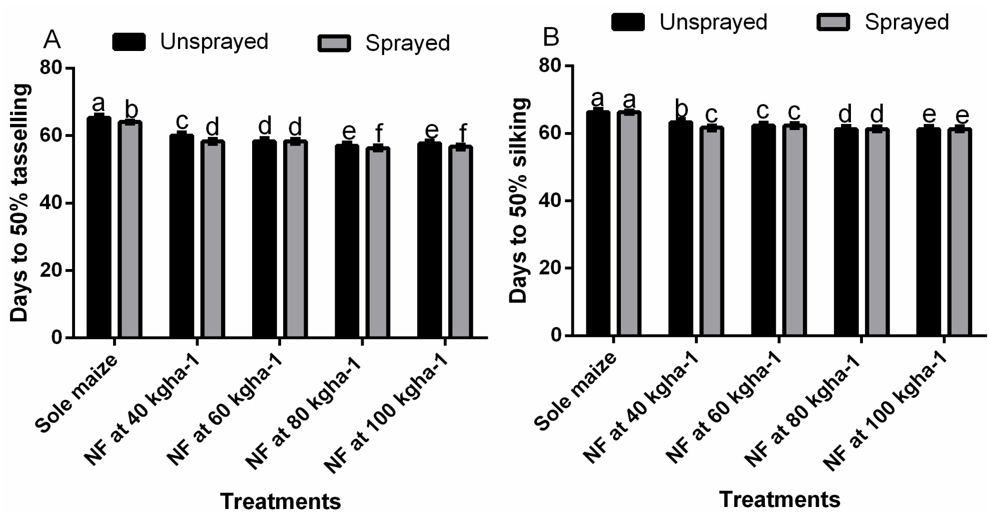

Figure 3. Interaction effect of nitrogen fertilizer and pesticides application on (A) days to 50% tasselling (B) days to 50% silking after planting.

Days to 50% tasselling on unsprayed plots (24.1%) and sprayed plots (16.6%) were highest on nitrogen fertilizer at 40 kg/ha and least on 100 kg per/ha, compared to the control (**Figure 3(A)**). Days to 50% silking on unsprayed plots (91.3%) and sprayed plots (18.9%) were highest on nitrogen fertilizer at 40 kg/ha and least on 100 kg per/ha, compared to the control (16.9% and 15.7%) (**Figure 3(B)**). Thus, among the fertilizer treatments, 40 kg/ha had the highest tasselling and silking with or without insecticides spray, whereas the least occurred on 100 kg per/ha treatment, compared to the control.

3.3. Interaction Effect of Nitrogen Fertilizer and Pesticides Application on Maize Plant Biomass

There was a significant ($p < 0.01$) nitrogen fertilizer and pesticide application effect on dry shoot biomass and total dry biomass (**Figure 4**). Comparatively, dry shoot biomass on unsprayed plots (44.2%) and sprayed plots (46.5%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg per/ha, compared to the control (**Figure 4(A)**). Total dry biomass on unsprayed plots (53.4%) and sprayed plots (56.8%) were highest on nitrogen fertilizer at 100 kg/ha and least on 40 kg per/ha, compared to the control (**Figure 4(B)**). Thus, among the fertilizer treatments, 100 kg/ha had the highest dry shoot biomass and total dry biomass with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control.

3.4. Combine Effect of Nitrogen Fertilizer and Pesticides Application on Maize Grain Yield

There was a significant ($p < 0.01$) nitrogen fertilizer and pesticide application effect on grain yield, hundred seed weight, stover dry weight. Grain yield, hundred seed weight, and stover dry weight were significantly ($p < 0.01$) higher on sprayed plots, compared to unsprayed plots (**Figure 5**). Generally, grain yield, hundred seed weight, stover dry weight did not significantly differ between the

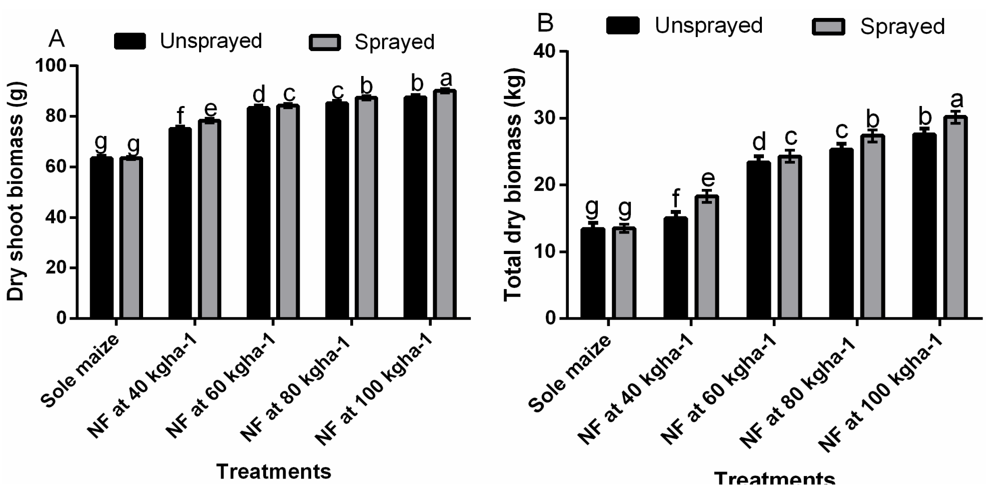

Figure 4. Interaction effect of nitrogen fertilizer and pesticides application on (A) dry shoot biomass and total dry biomass after harvest.

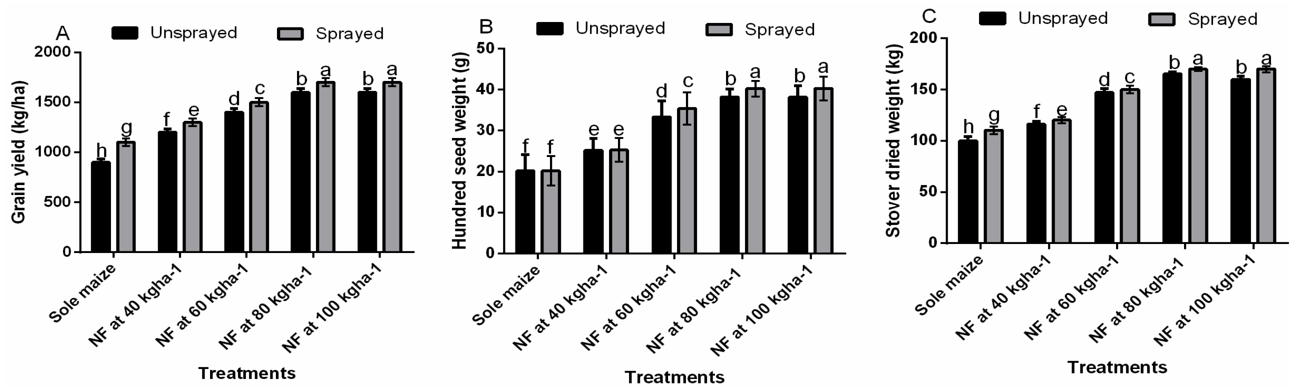

Figure 5. Interaction Effect of nitrogen fertilizer and pesticides application on (A) grain yield, (B) hundred seed weight, and (C) stover dried weight after harvest.

80 kg/ha and 100 kg/ha, with or without pesticides. Comparatively, grain yield on unsprayed plots (55.5%) and sprayed plots (59.7%) were highest on nitrogen fertilizer at 80 and 100 kg/ha and least on 40 kg per/ha, compared to the control (**Figure 5(A)**). Hundred seed weight on unsprayed plots (65.1%) and sprayed plots (69.9%) were highest on nitrogen fertilizer at 80 and 100 kg/ha and least on 40 kg per/ha, compared to the control (**Figure 5(B)**). Stover dry weight on unsprayed plots (45.4%) and sprayed plots (49.9%) were highest on nitrogen fertilizer at 80 and 100 kg/ha and least on 40 kg per/ha, compared to the control (**Figure 5(C)**). Thus, among the fertilizer treatments, 80 and 100 kg/ha had the highest grain yield, hundred seed weight, and stover dry weight with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control.

4. Discussion

Insect pests pose one of the major threats to agricultural productivity. They decrease crop yield, quality, and aesthetic value of non-edible plants. The nutritional quality of plant tissue is one of the main characteristics of host plant selection by phytophagous insects [9]. Fall armyworm is one of the most important maize pests, and insecticides are proposed as an important option for their management [1]. In the present study, fall armyworm number of egg mass, larvae, and mean crop damage were higher on the unsprayed plots, compared to the sprayed plots. The efficacy of newer compounds with active ingredients such as: Chlorantraniliprole, cyantraniliprole, flubendiamide, and novaluron showed a greater insecticidal effect on the performance of fall armyworm [10]. This was demonstrated when spinetoram, chlorantraniliprole, spinosad, and lambda-cyhalothrin were applied against fall armyworm [11]. This is an indication that the strategic utilization of pesticide treatment could play a major role in fall armyworm management. The present study showed that among the nitrogen fertilizer treatments, 100 kg/ha had the highest number of egg mass, larvae, and leaf injury severity with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control. However, on the unsprayed plots, number of egg masses did not significantly differ between 40 kg/ha and 60 kg/ha treatments. Nitrogen is the major nutrient required by insects and in most cases the main limiting factor for optimal growth of insects [12]. Application of nitrogen fertilizer normally increases herbivore feeding preference, food consumption, survival, growth, reproduction, and population density except in a few instances where nitrogen fertilizer reduces the herbivore performance. Excessive dose of nitrogen fertilizer produces lush green plants, which will attract pests. An increase in nitrogen increases the biosynthesis or accumulation of proteins, free amino acids and sugars that might have attracted insects [13]. This suggests that maize plants under 100 kg/ha fertilizer rate accumulated higher nitrogen concentration which possibly attracted the fall armyworm. Nitrogen fertilizer increases plant growth and yield parameters such as plant height, biomass as observed in this experiment. It is reported that Whitefly females aggregated, and laid more eggs, on leaves and on plants with the highest nitrogen and water content. *Aphis gossypii* also showed lower mean generation time, highest finite rate of increase when fed on chrysanthemum fertilized at a 150% fertilizer level [13]. It appears that the most critical way to increase yield and develop sustainable agriculture in modern crop production is sufficient fertilizer application. However, an increase in the nitrogen content of plants may correlate positively to pest population growth. For instance, in the present study, maize plants under 100 kg/ha nitrogen fertilizer treatment, which had higher nitrogen content also demonstrated higher fall armyworm infestation. Conversely, the 40 kg/ha fertilizer treatment, which had comparably lower nitrogen content also demonstrated lower fall armyworm infestation. It is reported that the nitrogen content of plants was directly related to the level of nitrogen fertilization, and that it affected among and within plant distribution of *Trialeurodes vaporariorum* adults on tomato (*Lycopersicon esculentum*) [14].

Cogger, *et al.*, [15] observed that availability of nutrient in the rhizosphere of soil can easily be accessed by plants roots which enhances growth. Inorganic fertilizer was observed to release nutrients more readily as these plants were taller. In the present study, increase in nitrogen fertilizer increased plant height across all treatments. Comparatively, 100 kg/ha nitrogen fertilizer treatment had the highest plant height across the number of weeks with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control. Moreover, 40 kg/ha had the highest days of tasselling and silking with or without insecticides spray, whereas the least occurred on 100 kg per/ha treatment, compared to the control. Adeniyan and Ojeniyi, [16] and Larney, *et al.*, [17] reported that inorganic fertilizer supply nutrients more readily than compost at the early growth phases but by the latter stages of development, combination of compost and N fertilizer treated plants grew more rapidly over the N fertilizer alone plots. This is an indication that 100 kg/ha nitrogen fertilizer treated plants grew rapidly possibly due to readily greater available nitrogen in the soil rhizosphere.

Nitrogen is the highest determinant nutrient for plant growth and the most vital nutrient reducing maize yield in various parts of the world [18]. Maize required a lot of N [19]. Total biomass of maize was higher in treatment combination of organic and inorganic fertilizer. Kibunja, *et al.* [20] observed that total biomass of maize was higher when manure and chemical fertilizers were used. The present study showed that, among the fertilizer treatments, 100 kg/ha had the highest dry shoot biomass and total dry biomass with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control. The application of nitrogen fertilizer increased plant biomass in maize [21]. This suggests that the high nitrogen absorption by plants was equally translated into yield and vegetative growth.

Dogra [22] described fertilizer as substances added to soil to improve growth of plants, as well as their yield. The three primary plant nutrients are nitrogen, phosphorus and potassium. In related studies using maize and wheat N fertilizer produced yield with much higher percentage than either compost used alone [23]. Integrated supply of plant nutrients by organic and inorganic fertilizer increased the fertility of the soil and crop productivity Chand, *et al.* [24]. In the present experiment, among the fertilizer treatments, 80 and 100 kg/ha had the highest grain yield, hundred seed weight, and stover dry weight with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control. Fertilizer is an essential input contributing to crop production because it increases productivity and improves yield quantity and quality [16]. This suggests that 80 and 100 kg/ha had the maximum yield due to the nitrogen content level, compared to the other treatments. Moreover, the grain yield was observed to be higher with the higher rate of nitrogen fertilizer application. The major nutrients required by maize for optimum growth include: Nitrogen (N) required for obtaining maximum yield and quality [25].

It is reported that less dose of Nitrogen increase the chlorogenic acid which acts as a resistance factor in plants against insect pest [26]. In contrast, in the present study, maize plants which had less dose of Nitrogen fertilizer showed higher susceptibility to the fall armyworm, compared to those under high dose. This was confirmed by the drastic reduction in yield on 40 kg per/ha treatment, compared with the 80 and 100 kg per/ha treatments. It was found that application of only nitrogen or higher dosage of nitrogen increased the pest population while application of phosphorus and potash with or without combination of nitrogen reduced the population build up. However, application of 120 $kg \cdot ha^{-1}$ nitrogen increased the yield despite higher population [27]. Higher nitrogen fertilization appears to confer pest tolerance or resistance in maize plants. Although, the higher population of fall armyworm infestation may have caused significant tissue injury to the plants, yield increased regardless of the level of pest infestation. This could be due to the plant's high nutrient levels, which repair or replace the tissues injuries caused by these pests. However, the insignificant yield level between 80 and 100 kg per/ha treatments indicates that nitrogen fertilization may require a certain threshold level. Excessive application may only increase farmers input cost rather that maximizing their marginal returns.

5. Conclusion

The present study has shown that fall armyworm number of egg mass, larvae, and leave injury severity were higher on the unsprayed plots, compared to the sprayed plots. Relatively, 100 kg/ha nitrogen fertilizer rate had the highest number of egg mass, larvae, and leave injury severity with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control. Moreover, among the fertilizer treatments, 80 and 100 kg/ha had the highest grain yield, hundred seed weight, stover dry weight with or without insecticides spray, whereas the least occurred on 40 kg per/ha treatment, compared to the control. Maize plants that had a higher dose of nitrogen fertilizer showed higher susceptibility to the fall armyworm, compared to those under less dose. We therefore recommend that farmers apply 80 kg/ha nitrogen fertilizer for maize production in areas with incidence of fall armyworm.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Capinera, J.L. (2000) Fall Armyworm, *Spodoptera frugiperda* (J.E. Smith) (Insecta: Lepidoptera: Noctuidae). The University of Florida, Institute of Food and Agricultural Sciences. (UF/IFAS), Gainesville.

[2] Day, R., *et al*. (2017) Fall Armyworm: Impacts and Implications for Africa. *Outlooks on Pest Management*, **28**, 196-201. https://doi.org/10.1564/v28_oct_02

[3] Aber, J.D., Goodlae, C.L., Ollinger, S.V., Smith, M.L., Mahill, A.H., Martin, M.E., *et al*. (2003) Is Nitrogen Deposition Altering the Nitrogen Status of Northeastern Forest? *BioScience*, **53**, 375-389. https://doi.org/10.1641/0006-3568(2003)053[0375:INDATN]2.0.CO;2

[4] Rashid, M.M., Jahan, M. and Islam, K.S. (2016) Impact of Nitrogen, Phosphorus and Potassium on Brown Planthopper and Tolerance of Its Host Rice Plants. *Rice Science*, **23**, 119-131. https://doi.org/10.1016/j.rsci.2016.04.001

[5] Cairns, J.E. Hellin, J., Sonder, K., *et al*. (2013) Adapting Maize Production to Climate Change in Sub-Saharan Africa. *Food Security*, **5**, 345-360. https://doi.org/10.1007/s12571-013-0256-x

[6] Tavares, W.S., Costa, M.A., Cruz, I., Silveira, R.D., Serrão, J.E. and Zanuncio, J.C. (2010) Selective Effects of Natural and Synthetic Insecticides on Mortality of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and Its Predator *Eriopis connexa* (Coleoptera: Coccinellidae). *Journal of Environmental Science and Health*, *Part B*, **45**, 557-561. https://doi.org/10.1080/03601234.2010.493493

[7] Tambo, J.A., Day, R.K., Lamontagne-Godwin, J., Silvestri, S., Beseh, P.K., Oppong-Mensah, B., Phiri, N.A. and Matimelo, M. (2019) Tackling Fall Armyworm (*Spodoptera frugiperda*) Outbreak in Africa: An Analysis of Farmers' Control Actions. *International Journal of Pest Management*, **66**, 298-310. https://doi.org/10.1080/09670874.2019.1646942

[8] Harrison, R.D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner,

U. and van den Berg, J. (2019) Agro-Ecological Options for Fall Armyworm (*Spodoptera frugiperda* JE Smith) Management: Providing Low-Cost, Smallholder Friendly Solutions to an Invasive Pest. *Journal of Environmental Management*, **243**, 318-330. https://doi.org/10.1016/j.jenvman.2019.05.011

[9] Bernays, E.A. and Chapman, R.F. (1994) Host-Plant Selection by Phytophagous Insects. Chapman & Hall, New York, 95-165. https://doi.org/10.1007/b102508

[10] Hardke, J.T., Temple, J.H., Leonard, B.R. and Jackson, R.E. (2011) Laboratory Toxicity and Field Efficacy of Selected Insecticides against Fall Armyworm (Lepidoptera: Noctuidae). *Florida Entomologist*, **94**, 272-278. https://doi.org/10.1653/024.094.0221

[11] Sisay, B., Tefera, T., Wakgari, M., Ayalew, G. and Mendesil, E. (2019) The Efficacy of Selected Synthetic Insecticides and Botanicals against Fall Armyworm, *Spodoptera frugiperda*, in Maize. *Insects*, **10**, Article 45. https://doi.org/10.3390/insects10020045

[12] Boswell, A.M., Provin, T. and Behmer, S.T. (2008) The Relationship between Body Mass and Elemental Composition in Nymphs of the Grasshopper *Schistocerca americana*. *Journal of Orthoptera Research*, **17**, 307-313. https://doi.org/10.1665/1082-6467-17.2.307

[13] Rostami, M., Zamani, A.A., Goldastech, S., Shoushtari, R.V. and Kheradmand, K. (2016) Influence of Nitrogen Fertilization on Biology of *Aphis gossypii*. *Journal of Plant Protection Research*, **52**, 118-121.

[14] Godfery, L.D., Keillor, K., Hutmacher, R.B. and Cisneros, J.J. (1999) Interaction of Cotton Aphid Population Dynamics and Cotton Fertilization Regime in California. *Proceedings of the Beltwide Cotton Conference*, **2**, 1008-1011.

[15] Coogger, C., Hummel, R., Hart, J. and Bary, A. (2008) Soil and Redosier Dogwood Response to Incorporated and Surface-Applied Compost. *Journal of Horticultural Science*, **43**, 2143-2150. https://doi.org/10.21273/HORTSCI.43.7.2143

[16] Adeniyan, O.N. and Ojeniyi S.O. (2003) Comparative Effectiveness of Different Levels of Poultry Manure with NPK Fertilizer on Residual Soil Fertility, Nutrient Uptake and Yield of Maize. *Moor Journal of Agricultural Research*, **4**, 191-197. https://doi.org/10.4314/mjar.v4i2.31775

[17] Larney, E.J., Olson, A.F., Miller, J.J., DeMaere, P.R., Zvomuya, F. and McAllister, T.A. (2008) Physical and Chemical Changes during Composting of Wood Chip—Bedded and Straw-Bedded Beef Cattle Feedlot Manure. *Journal of Environmental Quality*, **37**, 725-735. https://doi.org/10.2134/jeq2007.0351

[18] Miao, Y., Mull, D.J., Hernandez, J.A., Wiebers, M. and Robert, P.C. (2007) Potential Impact of Precision Nitrogen Management on Corn Yield, Protein Content and Test Weight. *Soil Science Society of America Journal*, **7**, 1490-1499. https://doi.org/10.2136/sssaj2005.0396

[19] Onwueme, I.C. and Sinha, T.D. (1991) Field Crop Production in Tropical Africa. Technical Centre for Agricultural and Rural Co-Operation (CTA), Ede, Wageningen.

[20] Kibunja, C.N., Mwaura, F.B., Mugendi, D.N., Kitonyo, E.M. and Salema, M.P. (2010) Nitrogen (N) Use Efficiency under Continuous Maize-Bean Cropping System in Semi-Humid Highlands of Kenya. *East African Agricultural and Forestry Journal*, **76**, 115-120.

[21] Du-Plessis, J. (2003) Maize Production. Agricultural Information Service, Department of Agriculture, Pretoria, South Africa. https://Fastonline.org/CD3WD40/LSTOCK/001/SAIinfoPaks/docs/maizeproduction

[22] Dogra, D. (2010) Biochemical Evaluation of Buckwheat (*Fagopyrumes culentum Moench*) Genotypes. Ph.D. Thesis, Department of Chemistry and Biochemistry, CSK Himachal Pradesh KrishiVishvavidyalaya, Palampur.

[23] Gitari, J.N. and Friesen, D.K. (2001) The Use of Organic/Inorganic Soil Amendments for Enhanced Maize Production in the Central Highlands of Kenya. *Seventh Eastern and Southern Africa Regional Maize Conference*, Kenya, 11-15 February 2001, 367-371.

[24] Chand, S., Anwar, M. and Patra, D.D. (2006) Influence of Long-Term Application of Organic and Inorganic Fertilizer to Build up Soil Fertility and Nutrient Uptake in Mint Mustard Cropping Sequence. *Communications in Soil Science and Plant Analysis*, **37**, 63-76. https://doi.org/10.1080/00103620500408704

[25] Nutall, W.T., Moulin, A.P. and Townley-Smith, L.J. (1992) Yield Response to Canola to Nitrogen, Phosphorus Precipitation, and Temperature. *Journal of Agronomy*, **84**, 765-768. https://doi.org/10.2134/agronj1992.00021962008400050001x

[26] Chatterjee, R., Choudhuri, P. and Laska, N. (2013) Influence of Nutrient Management Practices for Minimizing Whitefly (*Bemisia tabaci* Genn.) Population in Tomato (*Lycopersicon esculentum* Mill.). *International Journal of Science*, *Environment and Technology*, **2**, 956-962.

[27] Jauset, A.M., Sarasúa, M.J., Avila, J. and Albajes, R. (1998) The Impact of Nitrogen Fertilization on Feeding Site Selection and Oviposition by *Trialeurodes vaporariorum*. *Entomologia Experimentalis et Applicata*, **86**, 175-182. https://doi.org/10.1046/j.1570-7458.1998.00278.x