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Maize-groundnut intercropping to manage fall armyworm and improved crop productivity in smallholder farming systems

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ABSTRACT

Fall armyworm (*Spodoptera frugiperda*) could cause significant losses in maize production in sub-Saharan Africa, thereby threatening the livelihoods of smallholder farmers. Farming systems such as maize-legume intercropping could reduce fall armyworm (FAW) infestations. However, the impact of maize-groundnut intercropping on fall armyworm infestation and its severity is unknown. We, therefore, assessed the impact of intercropping maize with groundnut planted at different times on fall armyworm infestation while exploring the benefits of groundnut to soil fertility improvement. The study was conducted during the minor 2018 and major cropping season in 2018 and 2019, respectively. Maize-groundnut intercropped treated soils increased the concentrations of Nitrate-N, ammonium, and microbial biomass carbon by 31%, 42%, and 45% respectively, compared with non-groundnut treated soils (control). The treatments had no significant effect on FAW infestation and severity. The number of infected maize plants in Ejura was 68% more than in Fumesua and 88% higher in the minor season than in the major season, irrespective of location. The results also indicated that the severity of FAW infestation determined 30% of the maize grain yield. Major seasons and locations interactively influenced maize grain yield, with the major rainy seasons recording 43% more grain yield than the minor seasons. The study provides further understanding of the mechanisms involved in controlling FAW infestation under maize-groundnut intercropping.

Keywords: Intercropping; groundnut; legume; maize; sustainable intensification
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Introduction

The fall armyworm (*Spodoptera frugiperda*) is a pest to cereals (Kasoma *et al.*, 2021). The worm is native to the Americas and recently an invasive pest in Africa , causing significant reduction in maize production (Goergen *et al.*, 2016). In its native range in southern America, the fall armyworms are known to feed on over 350 plant species (Montezano *et al.*, 2018), however, they do not normally feed on cereals such as maize, rice, sorghum and sugarcane. It has been estimated that fall armyworms could approximately cause US$ 13 billion per annum in crop losses across Sub-

Saharan Africa (Day *et al.*, 2017). Due to the highly destructive activities of the FAW on cereal crops, particularly maize, in smallholder farms, the fall armyworms could have a substantial negative impact on food security. Fall armyworm infestations can result in 20%–53% maize yield reductions (De Groote *et al.*, 2020). The cost of fall armyworm damage in Ghana is estimated to be about GH₵ 29.1 million for maize alone (Yeboah *et al.*, 2021). In effect, FAW threatens to undermine progress on sustainable development goals for millions of poor farmers. The current management of the fall armyworm infestation in maize has been mainly through synthetic insecticides (Baudron *et al.*, 2019; Deshmukh *et al.*, 2020; Sagar *et al.*, 2020), which may have negative impact on the environment.

The management of fall armyworms will require a multi-pronged approach that augments existing pest management strategies. Many potential low-cost control options have been built on local knowledge and ecological principles. Importantly, these are often more relevant to smallholders who lack the financial resources to purchase chemical pesticides (Abate *et al.*, 2000; Grzywacz *et al.*, 2014). Crop diversification and integrated pest management (IPM) strategies with various temporal and spatial arrangements suppress fall armyworm incidence while increasing the population of beneficial arthropods for maize production (Koppenhöfer *et al.*, 2015). Depending on the type of crops included in maize cropping system, reduction in maize losses from pests may be underscored by one or more of the following mechanisms; (1) limiting the pests' ability to locate host plants (Poveda *et al.*, 2008); (2) repelling pests through plant-mediated chemicals (Bakthavatsalam, 2016); or (3) stimulating the abundance and diversity of natural enemies that may control pests (Mailafiya *et al.*, 2011). Several studies have shown that intercropping maize with other crops reduced fall armyworms infestation (Tanyi *et al.*, 2020) and this strategy has a high potential to improve the livelihood of smallholder farmers in Ghana.

However, the cultivation of maize should not reduce the fertility of the soil. Groundnut is one of the widely consumed legumes that could improve soil fertility in a maize cropping system. Groundnuts fix nitrogen in the soil and increase soil organic matter and carbon content if the biomass is incorporated into the soil (Witcombe & Tiemann, 2022). In this study, we hypothesized that the maize-groundnut intercropping system would help reduce fall armyworm infestation and improve soil fertility as well as improve maize productivity compared to sole maize cultivated fields. Hence, this study aimed to reduce fall armyworm infestation by intercropping maize with groundnut while harnessing the benefits of groundnut to the soil. Since the temporal arrangement of the crops is essential, the timing of groundnut planting was varied to determine its impact on fall armyworms infestation and soil fertility improvement.

Materials and Methods

Study area

Two experimental fields were established at the CSIR-Crops Research Institute, Fumesua, in the forest agro-ecological zone and Ejura in the forest-savannah transition agro-ecological zone during the 2018 and 2019 minor and major cropping season respectively. Both the forest and the transition agro-ecological zones receives a bi-modal rainfall pattern that amounts to about 1500 and 1300 mm of rainfall per annum, respectively (MoFA, 2021). The major and minor season spans from April to July, and September to November, respectively. Fumesua is in the Ejisu Municipality in the Ashanti Region (Latitude 6^{o}43'W; Longitude

1°36'W) at an elevation of 228 m above sea level. The soil is characterized by Ferric acrisols (FAO-UNESCO, 2018) while Ejura is in the Sekyedumasi Municipality in the Ashanti Region (Latitude 7°24'N; Longitude 1°21'W) at an elevation of 225 m above sea level and has Savannah ocrosols soil type. The topsoil consist of greyish brown sandy loam and dark brown to brown fine sandy loam soils, respectively at Fumesua and Ejura (Adjei-Gyapong & Asiamah, 2002). The soils in the study areas are generally sandy and inherently low in fertility and moisture retention capacity attributes. The sandy-loam soil at Fumesua and Ejura has a pH value in 0–30 cm soil layer of ≈4.7; 5.1, soil organic carbon was 1.49%; 1.94%; total nitrogen (N) was 0.17%; 0.53% and phosphorus (P) was 16.37%; 17.63%, respectively (Yeboah *et al.*, 2021). Rainfall data of the study sites were collected from the Ghana Metrological Agency.

Soil sampling and analyses

Pre-planting soils sampling were taken from depth 0–15 cm, bulked and air - dried for both physical and chemical analysis. .Post-harvest soil samples were also taken from each plot at similar depths for the appropriate laboratory analysis as well. Three soil samples were collected from each plot, bulked, and analyzed for soil nitrates (NO_3^-), ammonium (NH_4^+) and microbial biomass carbon (MBC) contents. The indophenol blue method was used to determine the ammonium (Tzollas *et al.*, 2010), while the nitrates were determined by the salicylic acid method (Vendrell & Zupancic, 1990). On the other hand, MBC was determined by the microbial fumigation technique (Baillie *et al.*, 1990).

Experimental design and treatments

The experiments were set up in a Randomized Complete Block Design with three replications and five treatments. The fields were ploughed and harrowed following the standard land preparation practices. The entire field measured 30x17 m^2 with 5x5 m^2 plots size and 1 m alleys between blocks and within plots. The detailed treatments included:

- One row maize; one-row groundnut (planted simultaneously): (MGI1)
- One row maize; one-row groundnut (maize planted one week before groundnut): (MGI2)
- One row of maize; one-row groundnut (maize planted two weeks before groundnuts): (MGI3)
- Sole maize (with Fall Armyworm chemical treatment): (SMC)
- Sole maize (no chemical treatment): (SM)

Planting and crop management

The maize and groundnut seeds were sourced from the CSIR-Crops Research Institute in Ghana. Maize was planted three seeds per hill using the dibbling method and later thinned to two after emergence. Maize was planted at an inter- and intra-row spacing of 80 cm and 40 cm, respectively. The minor season (2018) crop was planted between 1st to 3rd September, and harvested during the second and third week of November every year. The major season (2019) crop was planted between 5th to 8th May, and harvested during the first and second week of August every year. A compound fertilizer, NPK (15-15-15), was applied at 60-60-60 kg/ha as N, P_2O_5 and K_2O as a basal application to all plots at 14 days after planting. Sulphate of ammonium was applied as top-dressing at 30 kg N/ha for 35 days after the basal fertilizer application.

The chemical used to control/manage FAW is locally called Attack Botanical Insecticide (Agrimat Limited, Ghana), with emamectin benzoate (1.9% EC) as the active ingredient. The insecticide was applied at a rate of 8.55 g AI/ha between 10–14 days and 26–30 days after planting based on sampling to determine the presence of the insects. The timing of the insecticide application followed the recommendation by Ghana's Ministry of Food and Agriculture (MoFA, 2021).

Data collection

At physiological maturity, the maize plants were manually harvested from the two central rows of each plot. Grains were separated, weighed and extrapolated to grain yield (kg/ha) at 15% moisture on a dry weight basis (Yeboah *et al.*, 2016). Symptoms of fall armyworms larval damage on leaves and whorls (e.g., leaves with holes and ragged edges or skeletonized leaves with partially damaged epidermis giving a windowpane appearance) were used as the basis for infestation assessment. The assessment was carried out on all infested plants in the two central rows of each plot three weeks after planting and at tasselling by using the following formula:

$$\text{Percent infestation (\%)} = \frac{\text{Total number of plants observed}}{\text{Number of plants damaged by FAW}} \times 100$$

The severity of infestation was assessed by visual observation and scored on a scale of 1–9 (Davis *et al.*, 1992; Williams *et al.*, 2006), ranging from 1 = no foliar damage (highly resistant) to 9 = severe foliar damage (totally susceptible). Leaf damage scores of individual plants in the two central rows were averaged to determine the leaf damage ratings of each plot.

Statistical analysis

Statistical analyses were performed with the mixed effect Statistical Package for Social Sciences 22.0 (IBM Corporation, Chicago, IL, USA). It involved analysis of variance (ANOVA) at a probability level of 5% ($p < 0.05$). Data on percent infestation were arcsine transformed to achieve normality. Season and location were considered fixed effects, and replication was considered a random effect. Tukey's Honestly Significant Difference (HSD) test was employed to determine the differences between the means. The regression analyses were performed to determine the relationships between measured parameters.

Results and Discussion

Rainfall data

On average, the amount of rainfall at Fumesua in 2018 was 25% more than that in Ejura, while the amount of rainfall in Fumesua was 20% more than that in Ejura in 2019 (Table 1). Averagely, Fumesua received 26% and 32% more rainfall than Ejura in the major and minor rainy seasons of 2018 and 16% and 25% more rainfall in the major and minor rainy seasons of 2019 than Ejura (Table 1). The major rainy seasons had 18% more rains than the minor rainy seasons.

TABLE 1

Precipitation data recorded during the experimental period (mm)

Months	**Fumesua**		**Ejura**	
	2018	2019	2018	2019
Jan	0	1.4	0	0
Feb	29.8	81.4	40.3	3.8
Mar	228.2	99.6	115.6	123.5
Apr	212.4	177.2	83.4	55.1
May	189.3	134.6	247.4	118.1
Jun	387.6	223.4	187.7	202.6
Jul	143	110.1	172.9	62.3
Aug	91.8	24.8	84.8	106.8
Sep	233.3	158.1	228.6	266.2
Oct	197.1	316.6	117.9	94.8
Nov	10.1	8.8	23.4	3.5
Dec	6.5	41.8	0	59.7
Total	**1729.1**	**1377.8**	**1302.0**	**1096.4**

Treatment effect on soil parameters after the two seasons of maize harvest

Maize-groundnut intercropping treatments (MGI1, MGI2, MGI3) increased the concentrations of NO_3^- ($p < 0.01$), NH_4^+ ($p < 0.01$) and MBC ($p < 0.01$) by 31, 42 and 45% compared with sole maize treatments (SMC and SM) respectively (Fig. 1). On average, Fumesua had 21 and 33% more soil ammonium and microbial biomass carbon concentrations than Ejura (Table 2). The location by treatment interactions had no significant effect on soil nitrates and microbial biomass carbon. However, the interaction significantly influenced soil ammonium concentrations ($p < 0.01$), with MGI1 affecting concentrations between 20% and 48% more than other treatments in Ejura and MGI1 affecting concentrations between 15% and 54% more than other treatments in Fumesua (Fig. 2).

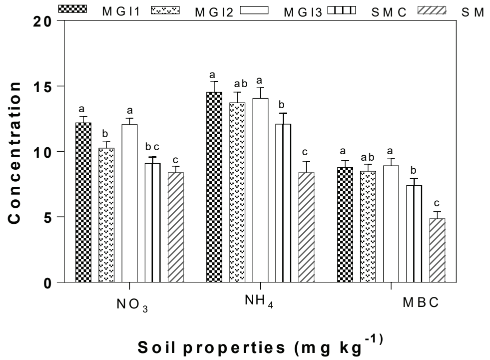

Fig. 1: Soil nitrates, ammonium and microbial biomass carbon concentrations in Ejura and Fumesua in 2018 and 2019. Error bars represent the standard error of the treatment means; Different lower-case letters show the differences in treatment means

TABLE 2

Location effects of soil parameters after the two growing seasons

Location	Ammonium nitrate	Microbial biomass carbon
	------------- mg kg^{-1}	---------------
Ejura	11 ± 0.29^b	6 ± 0.36^b
Fumesua	14 ± 0.70^a	9 ± 0.39^a

Lower case letters show differences in the treatment means

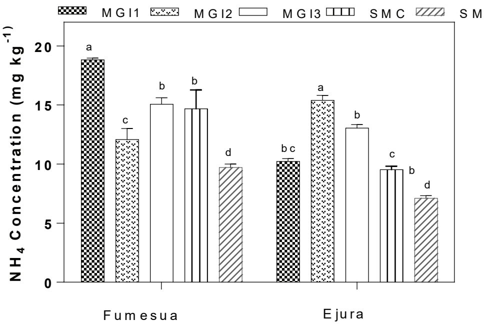

Fig. 2: Location and treatment interaction effects on soil ammonium concentration in the two growing seasons. Error bars represent the standard error of the treatment means; Different letters represent differences in the treatment means in the locations Fall armyworm infestation and severity

The two main treatments (groundnut and chemical fall armyworm plots) had no significant effect ($p > 0.80$) on the number of infested maize plants (Fig. 3). However, individually, locations, seasons and their interactions significantly affected ($p < 0.01$) the number of infested maize plants. On average, the number of infested maize plants at Ejura was 68% more than at Fumesua. In Ejura, there were 90% more infested maize plants in the minor season than in the major season.

In Fumesua, 98% more infested maize plants in the minor season than in the major season (Fig. 4A). The severity of fall armyworms infestation followed a similar trend. There was a significant interaction effect between the locations and rain seasons ($p < 0.02$).

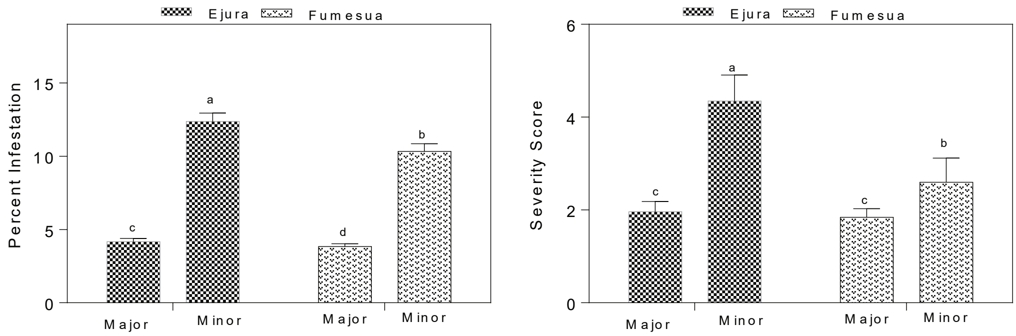

Fig. 3: Percent FAW infestation and severity score observed during the experimental period. Error bars represent the standard error of the differences between the treatment means; Different letters represent differences in the location and rain season means

Maize grain yield and yield components

The treatments and their interactions with the season, and location had no significant effects on plant height, cob number, cob weight and stover weight of maize (Table 3). However, the seasons, locations and years individually significantly affected these parameters. On average, maize plants in Fumesua were 13% taller than plants in Ejura ($p < 0.01$). On average, in the major rainy season, the maize had 28% more cobs than in the minor season ($p < 0.01$), while maize had 1.2% fewer cobs in 2018 compared to 2019 ($p < 0.01$). The weight of the cobs in Fumesua was 43% more than the weight of cobs in Ejura ($p < 0.01$) and 47% more in 2018 than in 2019 ($p < 0.04$). Stover weight was 51% more in the major rainy seasons than the minor rainy seasons ($p < 0.01$); 47% more in Fumesua than Ejura ($p < 0.01$) and 48% more in 2018 than 2019 ($p < 0.01$) (Table 3).

The treatments ($p > 0.68$), locations ($p > 0.69$) and years ($p > 0.09$) alone had no significant effects on maize grain yield in any of the experimental sites (Fig. 4). However, the different rain seasons ($p < 0.01$) and their interactions with the location ($p < 0.01$) had significant effects on the maize grain yield (Fig. 4). The major rainy seasons, on average, had 43% more grain yield than the minor rainy seasons from both locations.

TABLE 3

Individual effects of the rain season, location and year on maize plant parameters

Season	**Plant height (cm)**	**Cob number**	**Cob weight (kg)**	**Stover weight (kg)**
Major	166 ± 2.59^{a}	31291 ± 891.23^{a}	4.17 ± 0.52^{a}	7.49 ± 0.23^{a}
Minor	161 ± 3.17^{b}	22563 ± 1091.53^{b}	3.98 ± 0.61^{a}	3.70 ± 0.41^{b}
Location				
Ejura	155 ± 3.11^{a}	3065 ± 1458.07^{a}	3.78 ± 0.40^{a}	4.41 ± 0.41^{a}
Fumesua	178 ± 2.85^{b}	3274.92 ± 786.34^{a}	6.67 ± 0.32^{b}	8.32 ± 0.33^{b}
Year				
2018	156 ± 3.27^{a}	27729 ± 771.83^{b}	5.44 ± 0.29^{a}	6.61 ± 0.29^{a}
2019	152 ± 3.54^{a}	28083 ± 1543.65^{a}	2.90 ± 0.57^{b}	3.41 ± 0.58^{b}

Lower case letters show differences in the treatment means. NS means not significant

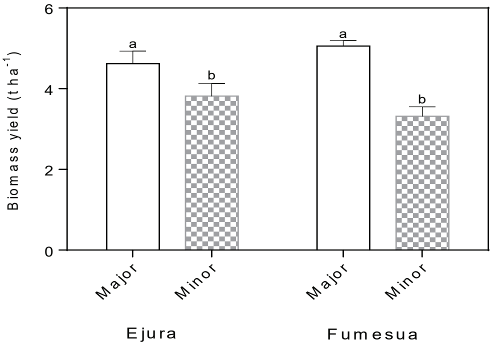

Fig. 4: Maize grain yield (t ha $^{-1}$) as influenced by location and rain season interactions. Error bars represent the standard error of the treatment means; Different letters represent differences in the treatment means Groundnut biomass yield

The individual treatments ($p > 0.59$), locations ($p > 0.42$) and season ($p > 0.11$) alone had no significant effects on groundnut biomass yield (data not shown). The results also showed that seasons ($p < 0.034$) and their interactions with the location ($p < 0.026$) had significant effects on the groundnut biomass yield (Fig. 5). On average, the major rainy seasons recorded 36% more groundnut biomass yield than the minor rainy seasons. The highest yields were observed at Fumesua in the major season.

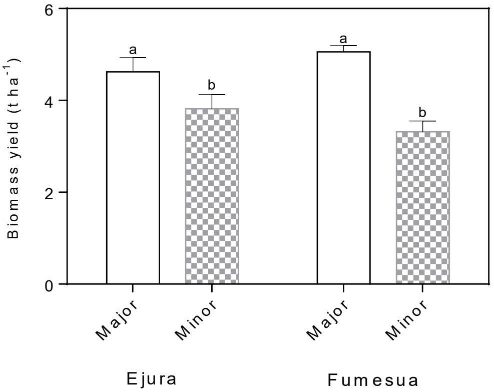

Fig. 5: Groundnut biomass yield (t ha $^{-1}$) as influenced by location and season interactions. Error bars represent the standard error of the treatment means; Different letters represent differences in the treatment means

Relationship between parameters

An increase in the number of groundnut stands/ population had no significant effect ($p > 0.88$) on the change in the number of infested maize plants (Fig. 6A) and had no relationship with the severity of fall armyworms infestation (Fig. 6B). However, there was a positive relationship ($p < 0.03$) between the severity of fall armyworms infestation and maize grain yield, such that an increase in severity determined about 30% of the increase in maize grain yield (Fig. 7B). The number of infested plants had no relationship with maize grain yield (Fig. 7A).

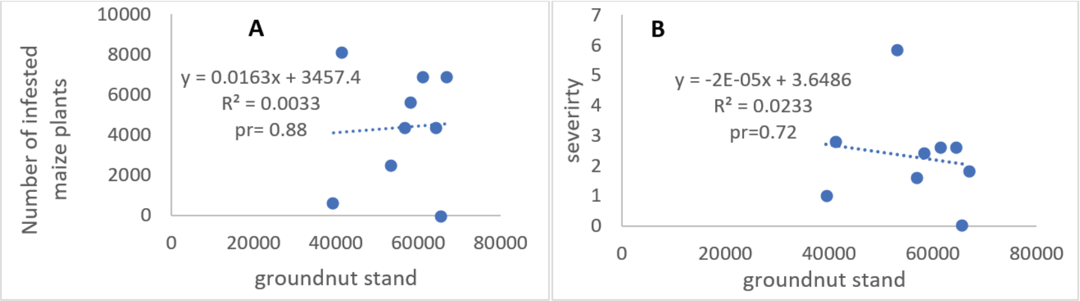

Fig. 6: Relationship between the number of infested maize plants (number/ha) and groundnut stand (A) and the relationship between the severity of fall armyworms infestation and groundnut stand (B)

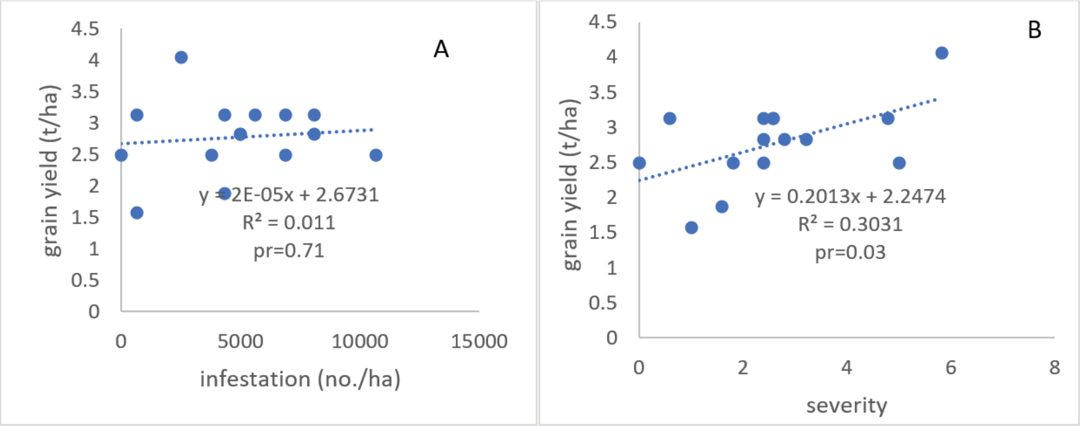

Fig. 7: Relationship between the number of infested maize plants (number/ha), and severity and the grain yield (tha^{-1}) of maize

The higher levels of NH_4^+ and NO_3^- in the groundnut-treated plots compared with non-groundnut plots may be attributed to the nitrogen-fixing potential of groundnut (Gabasawa *et al.*, 2016). Native Rhizobia in groundnut fixed nitrogen in the form of NH_4^+ to the plants, some of which was released to the soil as nodules decomposed or returned to the soil through groundnut residue (Kebede, 2021). In this study, the groundnut biomass was returned to the plots after harvesting. Since NH_4^+ is oxidized to NO_3^- in well-aerated soils (Barth *et al.*, 2020; Peng *et al.*, 2015) like that of the current research sites, it is not surprising that the levels of NO_3^- affected by the treatments follow the same trend as that of NH_4^+ and that NH_4^+ on the average is more than NO_3^-. The single row maize and groundnut planted at two weeks intervals had less soil NH_4^+ and NO_3^- levels compared to the other groundnut plots, probably because the two weeks interval caused maize to out-grow and shade the groundnut, limiting the physiology of groundnut such as nitrogen fixation.

Fujita *et al.* (1993) also found reductions in biological nitrogen fixation of legumes due to mutual shading by cereals. The sole maize treatment had no legume to at least return some of the nutrients to the soil to influence ammonium concentrations. Hence the lowest soil NH_4^+ concentration. Microbial biomass carbon was higher in groundnut included plots because the supply of nitrogen and organic carbon by these legumes enhanced Rhizobium and other microbial densities and diversities and consequent higher carbon return to the soil upon their lysis. This confirms the reports of Shah *et al.*, (2010), who observed a 1.70, 3.36, and 1.46 times increase in microbial biomass carbon by growing legumes in the fallow phase of a rice-wheat system. Virk *et al.*, (2022) also reported increases in soil organic carbon due to increased microbial activity with legumes. Since Fumesua contains more organic carbon (matter) and clay than Ejura soils (Yeboah *et al.*, 2021), they could hold up more of the ammonium made available by biological nitrogen fixation, hence the more of it retained in the soil. Higher soil organic matter content has been linked with increased nutrient holding capacities of soil (Lal, 2020). The greatest soil nutrient content in the groundnut treated plots observed in this study could be due to increased soil organic matter and its rate of mineralization (Urbatzka *et al.*, 2009).

It has been reported that N from legumes such as groundnut mineralizes slowly with relatively low loss and high synchrony with crops needs (Hoffman *et al.*, 2014). This implies that the slow rate of mineralization of N from legumes such as groundnut and or the higher organic matter returned to the soil would result in high N in groundnut treatments than the sole maize plots. The increased N content in those treatments as reported in this study could translate to higher productivity of the crop and therefore improve the livelihood of smallholder farmers.

Contrary to the report of Khan *et al.* (1997) that intercropping legumes with maize reduce fall armyworm infestation, this study showed that legumes other than groundnut should be considered for such purpose because the inclusion of groundnuts did not affect fall armyworm infestation or severity.

Baudron *et al.* (2019) collected data on 791 smallholder farms for fall armyworm damage in eastern Zimbabwe. They found that aside from Desmodium spp, legumes like groundnuts, cowpea and common bean were ineffective at reducing fall armyworms infestation. Though maize yield losses ranging from 22 to 67% have been associated with fall armyworms infestation in Ghana (Day *et al.*, 2017), it is common to find that infestation does not correlate with yield loss, as demonstrated in our study. Upon similar findings, Baudron *et al.* (2019) concluded that the effect of fall armyworm infestation might have been overestimated since the introduction of the pest on the continent and that farmers must pay attention to other factors affecting maize yield.

In our study, infestation and severity were higher during the minor season than the major season, irrespective of location. Heavy downpours have been reported to harm fall armyworm population build-up (Niassy *et al.*, 2021; Timilsena *et al.*, 2022). These authors demonstrated that egg dislodgement was more frequent in the rainy seasons than during the dry seasons, causing reduced infestation potential. Given the influence of moisture on fall armyworm infestation and severity, a consideration for climate information services in fall armyworm management is critical. More effort is therefore needed to determine the relationship between rainfall and fall armyworm population fluctuations in different agro-ecologies.

Irrespective of the amount of rainfall received in a place, rainfall distribution was an essential determinant of maize yield in this study. Since the grain filling stage is crucially moisture dependent (Omoyo *et al.*, 2015), it is for this reason that the higher moisture supplies at the tail ends of the major seasons, especially in June during the grain filling period of the maize caused higher maize yield in the major season of this study. Precipitation was found to be very low around November in the minor season during which grain filling was active. This must have led to the low yields in the minor season as found in this study. Technologies such as what we explored in this study, that seek to alleviate biotic and abiotic constraints to efficient production of maize have the primary goal of unlocking the crops' potential to increase grain yields, as this is often the immediate benefit of farmers.

Conclusion and Recommendation

This paper investigated the effect of maize-groundnut intercropping on fall armyworm infestation, soil and maize productivity in different agro-ecologies. Maize-groundnut intercrop improved soil fertility through nitrate nitrogen, ammonium and microbial biomass carbon enhancement. In this study, both fall armyworm infestation and the severity of infestation were not influenced by maize-groundnut intercropping. Infestation and severity were higher in the minor season than in the major season. The results also revealed a positive relationship between the severity of fall armyworm infestation and maize grain yield, indicating the dependent of fall armyworm severity on maize grain yield. The findings of this study are relevant to smallholder agriculture in improving soil and maize productivity.

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