Research Article

APPLICATION OF BALANCED FERTILIZERS REDUCES THE INCIDENCE OF FALL ARMYWORM IN MAIZE CROP

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ABSTRACT

Fall armyworm (FAW), a selective polyphagous pest, has become the global limiting factor for maize production. Its damaging parameters; percent infestation, percent damage for maize plant leaves, leaf damage score and maize grain yield were evaluated under a long-term fertility assessment plots at Lumle, Kaski, Nepal in 2020 and 2021. The significantly lowest infestation (41.02% in 2020 and 12.45% in 2021), percent damage (20.04 in 2020 and 18.07 in 2021) and the leaf damage score (1.62 in 2020 and 1.10 in 2021) were recorded in plots receiving balanced fertilizers (NPK @ 120:60:40 kg and 2 t FYM /ha). Ultimately, the maize grain yield (3.04 t/ha in 2020 and 3.72 t/ha in 2021) was also the significantly highest in balanced fertilizer (NPK @ 120:60:40 kg and 20 t FYM/ ha) applied plots followed by the FYM only applied plot (2.18 t/ha in 2020 and 2.644 t/ha in 2021). This study suggests to consider the incorporation of organic sources along with chemical fertilizer to reduce the incidence of FAW in maize crop.

Key words : *Spodoptera frugiperda*, chemical fertilizers, FYM, damage scores, grain yield

INTRODUCTION

American Fall armyworm *Spodoptera frugiperda* (J.E. Smith) is a destructive pest native to tropical and sub-tropical regions of Americas (Du Plessis et al., 2018). It is a polyphagous pest but the greatest damage is observed in grasses such as maize and sorghum (main hosts), along with other monoculture crops such as cotton and soybean (Hardke et al., 2015). However, 353 host plant species from 76 plant families, principally Poaceae (106), Asteraceae (31) and Fabaceae (31) have been reported (Montezano et al., 2018). Two genetically and behaviorally distinct strains of *S. frugiperda*; maize strain and rice strain have been identified (Lu & Adang, 1996).

S. frugiperda adults are very strong flier and can fly for a long distance during the summer (Capinera, 2001), can fly up to 500 km before oviposition (Prasanna et al., 2018). It is known for travelling 1600 km from southern U. S. state Mississippi to southern Canada in 30 hours with assistance of proper wind pattern (Rose et al., 1975). The pest was confined to American continents till 2015. For the first time out of American continents, it was reported from Africa in 2016 (Goergen et al., 2016). Nepal reported its first sighting of the pest on 9 May, 2019 from Nawalpur district (Bajracharya et al., 2019).

S. frugiperda larvae are voracious feeder and cause a huge damage by defoliating the host. Young larvae feed on epidermal layer of foliage making hole on them giving characteristic symptom of pest damage (Sisay et al., 2019). Older larvae can cause greater damage and defoliation leaving only ribs and stalk of corn plant giving torn or ragged appearance (Marenco et al., 2017). Yield losses of over 70% have been recorded on corn by Hruska & Gould (1997). It was found that *S. frugiperda* has the potential to cause maize yield losses in a range from 8.3 to 20.6 mt per annum, the value of these potential losses is estimated at between $22,481 million and $6,187 million (Day et al., 2017). In Nepal, the *S. frugiperda* has the potential to cause maize yield losses of 20-25%, which translates to the loss of more than half a million tons of the annual maize production – estimated at around 200 million Nepalese Rupees (Pradhan, 2020).

The common management strategy for the *S. frugiperda* has been the use of insecticide sprays and genetically modified crops (Bt maize). However, most smallholder farmers cannot afford repeated sprays of insecticides and Bt maize is not available everywhere. Furthermore, excessive use of chemical insecticides removes potential natural enemies, negatively impacts human and livestock health, leads to resistance development in target pests and increases crop production costs (Yu, 1991; Prasanna et al., 2018). Difficulties in the control of *S. frugiperda* have been attributed to its wide range of host plants, vast geographical distributions and rapid long distance movement (Knipling, 1980).

Soil fertilizer management can affect plant quality, which in turn, can affect insect pest abundance and consequent levels of damage (De Groote et al., 2010). Improved soil fertility could cause some plants to become more susceptible to certain insects (Altieri et al., 2005). Inorganic fertilizers incorporation can result in a spike in nitrogen uptake and the production of foliar nitrogen, which is attractive to insect herbivores (Altieri & Nicholls, 2003). The use of nitrogenous chemical fertilizers strengthens maize plant vigor, but these plants become more “desirable” to insect pests such as *S. frugiperda* (Rusch et al., 2013). Higher rates of nitrogen fertilization cause an increase of *S. frugiperda* infestation when compared to other insect pest populations (Van Dusen et al., 1988). In several studies higher nitrogen fertilization has been associated with higher pest population, e.g. Corn stalk borer population increased with increased N fertilizer (Cannon & Alejandro Ortega, 1966). Tanzubil et al. (2004) observed increase in population of stem borer and cotton strainer with increasing N fertilizer in millet. Letourneau (1988) reported the increased number of *Myzus persicae* and *Bravicoryne brassicae* progeny on Brussels sprouts; increased oviposition frequency and growth rate of *Artogeia rapae*, and feeding preference of *Plutella xylostella* on cabbage when soil nitrogen level was increased. Morales et al. (2001) reported the fewer incidence of aphids *Rhopalosiphum maidis* than those in the field treated with synthetic fertilizers. In tomato also, fewer aphid populations in tomatoes grown with organic fertilizers compared to those with synthetic fertilizers was recorded by Yardim & Edwards (2003).

However on *S. frugiperda*, posing a great threat to subsistence and cash crops in large part of the world, correlation between its incidence and soil amendments with fertilizers has not been an explored subject since a long time. This research aims to evaluate the application of fertilizer and its effects on the infestation and damage of *S. frugiperda.*

MATERIALS AND METHODS

Study area and experimental description

Damage assessment was conducted in a long-term fertility trial field of Directorate of Agricultural Research, Lumle (DoAR, Lumle) (1750 m above sea level, 28°17'51" N, 83°49'2" E) (Fig. 1). DoAR, Lumle located in north-western part of Kaski district, Gandaki Province is characterized by a total annual rainfall of 5857 mm and a mean annual temperature of 15.6 °C.

Long-term fertility trial was initiated in 2019 and same treatments were allotted to the plots for three years in a row. Experiment followed maize-rapeseed cropping system and was carried out in randomly completely blocked design consisting of eight treatments (Table 1) with three replications each (Fig. 1). The size of plot was 3 m x 3 m (9 m^2) and seed was sown in a geometry of 75 cm x 25 cm. Chemical sources of Nitrogen, Phosphorous and Potassium were urea, diammonium phosphate (DAP) and muriate of potash (MoP), respectively. Full dose of organic manure, phosphorous, potash and half dose of nitrogen were applied as basal dose and remaining 50% nitrogen was split into two equal halves; one for top dressing at knee height stage and another at tasseling stage. Maize was sown during 3rd week of April and were harvested during the 3rd week of August of both the experimental years. Popular maize variety, Ganesh-2 was used in this experiment. Other inter-cultural operations were carried out following the standard protocol for the cultivation of maize crop.

Table 1. Details of the treatments used in long-term fertility trials at Lumle, Kaski, Nepal

Treatments	$N:P_2O_5:K_2O$ (kg/ ha) :FYM (t/ ha)	Explanations
1	0:0:0:0	Full control
2	120:0:0:0	Full dose of nitrogen
3	120:60:0:0	Full dose of nitrogen and phosphorus
4	120:0:40:0	Full dose of nitrogen and potassium
5	120:60:40:0	Full dose of nitrogen, phosphorus and potassium (AITC, 2023)
6	120:60:40:20	Recommended dose of nitrogen, phosphorus, potassium and FYM (AITC, 2023)
7	60:30:20:10	Half of the recommended doses
8	0:0:0:20	FYM only

Foliage damage assessment

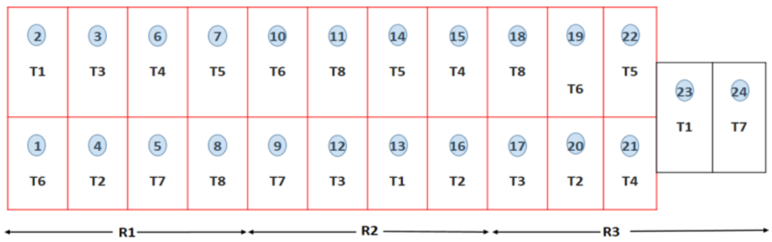

Fig. 1. Layout of long-term fertility experimental plot at Directorate of Agricultural Research (DoAR), Lumle, Kaski, Nepal. Characters encircled represent the plot numbers and T1 to T7 denote the treatment numbers as detailed in Table 1.

Damage assessment survey was conducted during last week of August ahead of tasseling stage when the maize plants stop growing tall. This stage of crop selected for damage assessment to assure the maximum growth attained by the plants and also to assure the damage symptoms clearly visible. Three components were observed for damage assessment; percent *S. frugiperda* infestation, percent damage for maize plant leaves and leaf damage score. Maize grain yield was also recorded after the crop harvest.

Percent *S. frugiperda* infestation: In each surveyed plot, total number of plants and damaged plants were counted and percent infested plants per plot were calculated using the formula given by Sisay et al. (2019):

$$\%\ S. frugiperda \text{ infestation} = \left[\frac{\text{Number of } S. frugiperda \text{ infested plants}}{\text{Total number of plants observed}}\right] \times 100$$

Percent damage for maize plant leaves: For calculation of leaf damage caused by *S. frugiperda*, we randomly selected six plants from each plot and encrypted the data. Percent damage for maize plant leaves were calculated as given by Sisay et al. (2019):

$$\%\text{ damage for maize plant leaves} = \left[\frac{\text{Total number of damaged leaves of single maize plant}}{\text{Total number of leaves assessed per single maize plant}}\right] \times 100$$

Leaf damage score: *S. frugiperda* induced leaf damage was scored by visual observation using the scoring scale of 0-9 (Table 2) as reported by Davis et al. (1992). In each surveyed plot, six plants were randomly selected and upper five leaves were surveyed. Leaf damage scores of individual plants of same treatment were averaged to determine the leaf damage ratings of each treatment.

Table 2 . Visual rating scales for leaf damage assessment (Davis et al., 1992)

Scale	Description
0	No visible leaf damage
1	Only pinhole damage on leaves
2	Pinhole and shot hole damage to leaf
3	Small elongated lesions (5-10 mm) on 1-3 leaves
4	Mid-sized lesions (10-30 mm) on 4-7 leaves
5	Large elongated lesions (>30 mm) or small portions eaten on 3-5 leaves
6	Elongated lesions (>30 mm) and large portions eaten on 3-5 leaves
7	Elongated lesions (>30 mm) and 50% of leaf eaten
8	Elongated lesions (30 cm) and large portions eaten on 70% of leaves
9	Most leaves with long lesions and complete defoliation observed

Assessment of maize yield

All the maize plants of every plots were harvested during first week of September at physiological maturity. Maize cobs were manually threshed by hand, and grains were sun-dried for a few days, and the dry weight (g) was recorded on a scale balance to calculate the total yield.

Statistical analyses

The variation in the treatment means were evaluated by using one-way analysis of variance (ANOVA) after employment of appropriate data transformations. The data of percent infestation and percent leaf damage were subjected to angular transformation, and the leaf damage scores were transformed using square root method. The treatment means were separated by using Tukey's Honest Significant Different (HSD) tests. All the statistical evaluations were carried out by using RSstudio (Version R-4.2.0).

RESULTS

Foliage Damage

Percent *S frugiperda* infestation: The percent maize foliage damage by *S. frugiperda* varied significantly (2020: $F_{7, 16} = 3.24$, $P = 0.03$; 2021: $F_{7, 16} = 4.27$, $P = 0.008$) with the application of different levels of fertilizers (Fig. 2).

The lowest level of damage (41.02 ± 2.97 and 12.45 ± 2.40%, respectively in 2020 and 2021) was recorded for the balanced application of nutrients (120:60:40 kg NPK and 20 ton FYM in a hectare) followed by the use of FYM (20 t/ha) only (46.74 ± 2.085 and 30.58 ± 7.62%, respectively in 2020 and 2021).

However, the infestation per plot (22.86 ± 3.81 and 25.73 ± 7.75, respectively) when applied with the fertilizer doses of 120:0:40:0 and 120:60:40:0 in 2021 were at par with those of the FYM only used plots. The highest level of the infestation (80.06 ± 8.18%) in 2020 was found in the imbalanced fertilizer (120:60:0 kg NPK and 0 t FYM/ha) where the part of organic matter and potassium was lacking which was followed by the other imbalanced applications of fertilizers (Fig. 2). However, in 2021, the highest infestation (55.63 ± 6.68%) was observed in the plots receiving nitrogenous fertilizer (120:0:0:0) only.

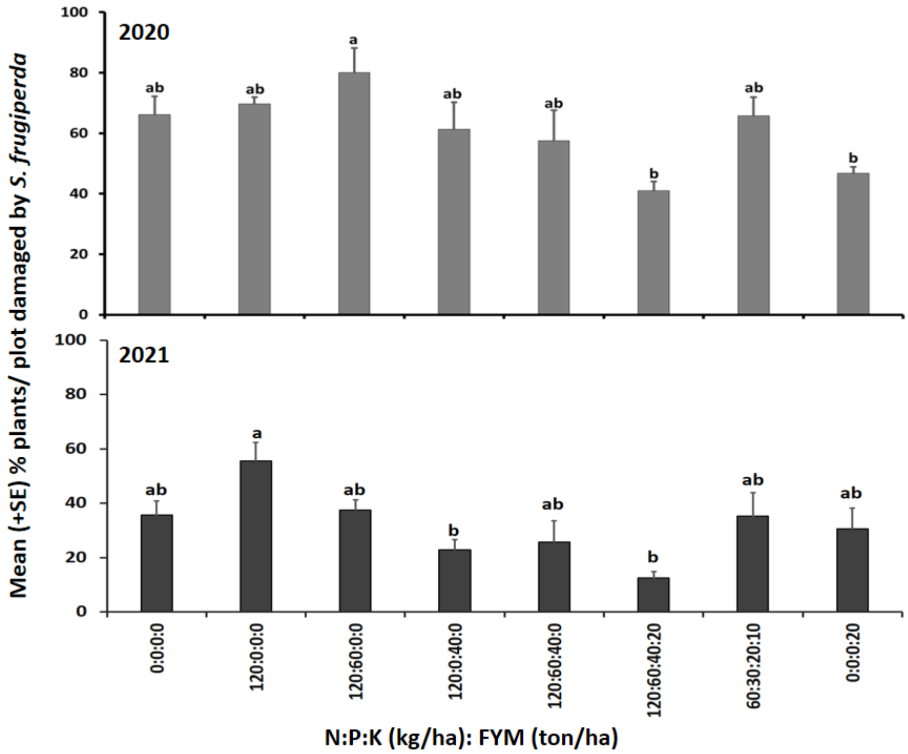

Fig. 2. Percent *S. frugiperda* infestation on maize plants sown under a long-term fertility assessment trial at Directorate of Agricultural Research (DoAR), Lumle, Kaski, Nepal during the experiment years 2020 and 2021. The small cases above Mean (+SE) bars represent the differences in the treatments as separated by Tukey's Honest Significant Difference (HSD) tests at 5% level of significance.

Percent damage for maize plant leaves: In 2020, the percent damage for maize plant leaves didn't vary significantly ($F_{7, 16}$ = 1.98, P = 0.1217) with the application of different levels of fertilizers, but distinct level of differences could be observed in damage level between balanced and imbalanced application of fertilizers.

The lowest level of damage i.e. 20.04 ± 4.35% was recorded for the balanced application of nutrients (120:60:40 kg NPK and 20 ton FYM in a hectare) whereas the highest level of leaf damage i.e. 57.29 ± 6.03% was recorded in the imbalanced fertilizer (120:60:0 kg NPK and 0 ton FYM/ha) applied plots (Fig. 3).

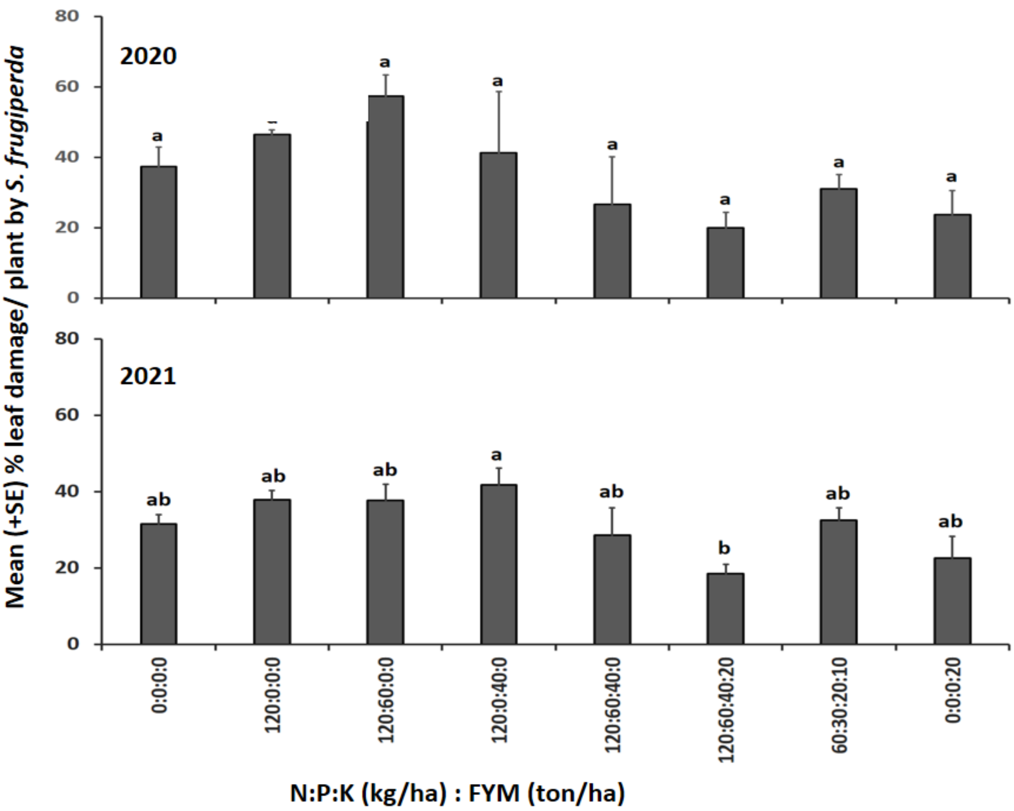

Fig. 3. Percent *S. frugiperda* damage for maize plant leaves under a long-term fertility assessment trial at Directorate of Agricultural Research (DoAR), Lumle, Kaski, Nepal during the experimental years 2020 and 2021. The differences in lower cases above Mean (+SE) bars represent the significant differences in the effect of fertilizer treatments on percent leaf damage per plant by *S. frugiperda* as separated by Tukey's Honest Significant Difference (HSD) test at 5% level of significance.

In contrast in 2021, percent maize plants damage was significantly influenced by the application of different doses of fertilizers ($F_{7,\ 16}$ = 3.38, P = 0.0206). The highest damage (41.72 ± 4.40%) was observed in the plots receiving unbalanced fertilizer (120:0:40 kg NPK in a hectare) and the lowest damage (18.60 ± 2.36%) was recorded again in the plots receiving balanced doses of fertilizers (120:60:40 kg NPK and 20 t FYM in a hectare) followed by those plots applied with FYM only (22.57 ± 5.66%) (Fig. 3).

Leaf damage score: Average maize leaf damage score ranged from 1.62 ± 0.84 to 3.117 ± 0.25 in 2020 and 1.10 ± 0.06 - 3.00 ± 0.35 in 2021. Damage scores varied significantly between different experimental plots (2020: $F_{7,\ 16}$ = 6.60, P = 0.002; 2021: $F_{7,\ 16}$ = 2.90, P = 0.04). The highest was scored in plots fertilized with imbalanced fertilizer (120:0:40 kg NPK/ha applied plot in 2020 and 120:0:0kg NPK/ha applied plot in 2021) whereas, lowest score was obtained in plots fertilized with optimum dose of N:P:K and FYM in both the years (Fig. 4). The plots fertilized only with FYM @ 20 t/ha were also least infested by the pest in both the study years.

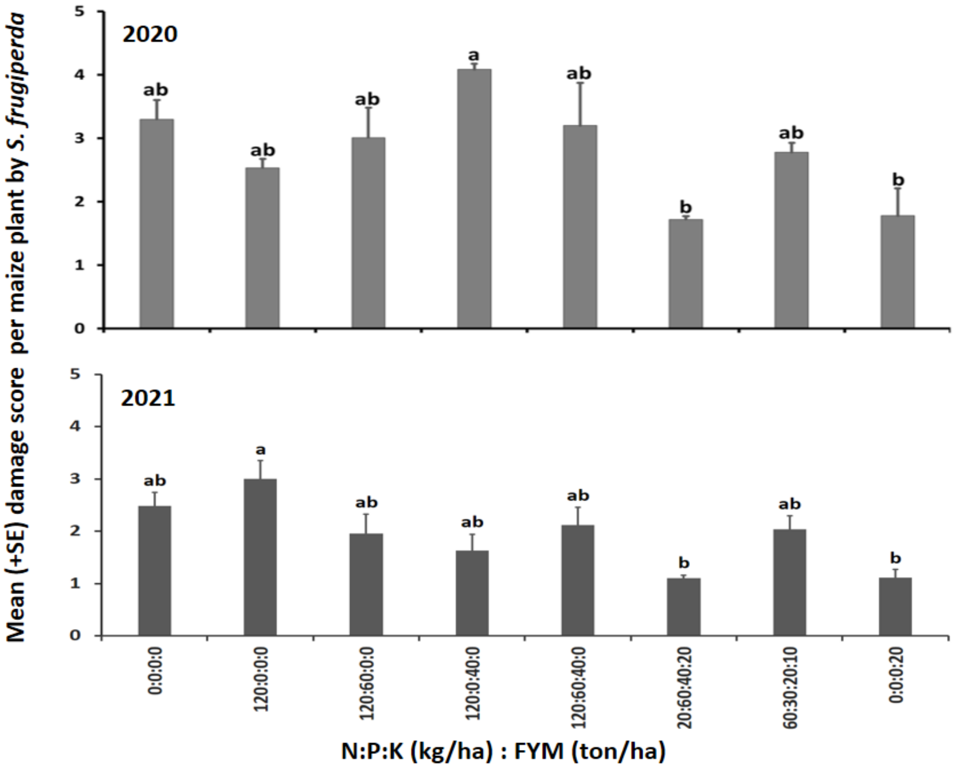

Fig. 4. Leaf damage score per maize plant by *S. frugiperda* during 2020 and 2021 maize crop seasons sown under a long term fertility assessment trial at Directorate of Agricultural Research (DoAR), Lumle, Kaski, Nepal. The differences in small cases above Mean (+SE) bars are for the significant differences in the treatment effects on the maize plant damage score by *S. frugiperda* when means were separated by the Tukey's Honest Signficant Difference (HSD) test at 5% level of significance.

Maize yield assessment

The maize yield (t/ ha) varied significantly among the treatments (Year 2020: $F_{7,\ 16} = 17.56$, $P < 0.001$; Year 2021: $F_{7,\ 16} = 7.25$, $P < 0.001$) (Fig. 5). In both the experiment years, the highest yield (3.04 ± 0.30 and 3.72 ± 0.19 t/ha, respectively in 2020 and 2021) were recorded in the plots receiving the balanced doses of fertilizers.

Interestingly, the yield in the plots receiving FYM only also was at par with those of the balanced fertilizers yielding an average yield of 2.18 ± 0.22 and 2.64 ± 0.84 t/ha, respectively in 2020 and 2021. The lowest yield (0.15 ± 0.05 and 0.23 ± 0.11 t/ha, respectively in 2020 and 2021) was recorded in control (non-fertilized) plots.

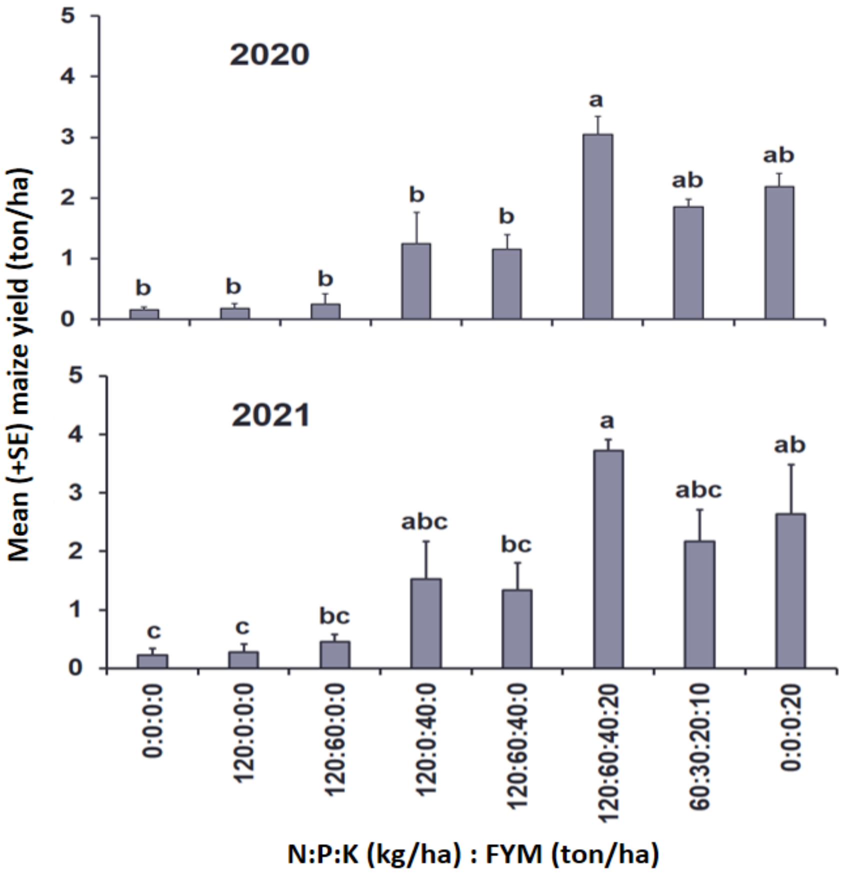

Fig. 5. Maize grain yield (ton/ha) in 2020 and 2021 in a long term-fertility assessment trial plot at Directorate of Agricultural Research (DoAR), Lumle, Kaski, Nepal. The differences in small cases above Mean (+SE) bars represent the statistical differences among the treatments as separated by Tukey's Honest Significant Different (HSD) test at 5% level of significance.

DISCUSSION

Soil fertility management can directly reduce plant susceptibility to pests, by mediating plant health (Phelan et al., 1995). Several studies also document that farming practices that cause nutrition imbalances in plants can lower pest resistance (Magdoff & Van Es, 2021). In reviewing 50 years of research relating to crop nutrition and insect attack, Scriber (1984) found 135 studies showing increased damage and/or growth of leaf-chewing insects or mites in N-fertilized crops, versus fewer than 50 studies in which herbivore damage was reduced. In our research we found that *S. frugiperda* preferred the plots fertilized with nitrogen alone and combination of nitrogen and phosphorus as infestation percent was higher in those plots. This result is similar to the result obtained by Wiseman et al. (1973) where, *S. frugiperda* larva preferred corn foliage fertilized with nitrogen and combinations of nitrogen rather than unfertilized and combinations of phosphorous and potassium. A conclusion by Wang et al. (2013) in their review, K-deficient plants tend to be more susceptible to infection than those with an adequate supply of K was found to be true as comparatively lower level of infestation was observed in combinations with K. Experimental plot treated with optimum fertilizer dose (full dose) and FYM showed lower level of damage when compared to unfertilized check and other unbalanced combinations fertilizer. Same results were obtained by (Figueroa-Brito et al., 2013) where loss due *S. frugipeda* damage was higher in plant fertilized with urea whereas, plants treated with vermicompost showed less damage.

It was interesting to witness the reduced level of *S. frugiperda* incidence on the maize crops grown in FYM only applied plots leading into the comparable yield to the plots receiving balanced fertilizer. Though not reported for *S. frugiperda*, there are reports on other insect pests, the incidence of which were greatly affected by the application of organic sources of fertilizers like FYM. Yardim & Edwards (2003) in a 2-year experiment illustrated the lower population of aphids on tomatoes grown in composted cattle manure applied plots than in the synthetic fertilizer only applied plots, suggesting the potential to reduce pest attack in long term by applying organic sources of fertilizers. In a review report by Rowen et al. (2019), they emphasized on two ways how the animal waste fertilizers influence pest control. Firstly, they affect prey suppression from the bottom up by changing macro- and micro-nutrient concentrations in the plants, which are null in the inorganic sources of fertilizers, by shaping the rhizosphere community, by increasing the release of defensive chemicals and by altering the herbivore induced plant volatiles. Secondly, the animal waste fertilizer, i.e. FYM can affect conservation bio-control by improving soil-surface habitat for predators through altered soil tilth, organic matter, water retention and by supporting decomposers' communities. Similarly, Eigenbrode & Pimentel (1988) reported the reduced incidence of flea beetle, imported cabbage worm and diamond back moth on collards when fertilized with dairy manure than with chemical fertilizers.

Organic fertilization has pronounced positive impacts on the soil health and on the induction of beneficial physiological activities on plants. Chandramani et al. (2010) demonstrated an induced level of silica content in paddy rice after organic amendment in soil, and a negative correlation between silica and insect infestation; -0.789 for leaf folder, -0.930 for stem borer and -0.958 for gall midge, with an accompanying higher grain yield on a par with balanced NPK applied plots. So, the conclusion was that the application of organic sources of nutrition reduced the incidence of major rice insect pests. However, due attention should be paid on using well decomposed FYM as there are reports on the hike on incidence of stem borer in maize plants when used with fresh FYM (Elsayed et al., 2023).

CONCLUSIONS

Balanced use of fertilizers is crucial for plant growth and development thereby to enhance proper nutrient management in intensive agriculture for plant production. Plants respond quickly to available nutrients for the quick absorption, increased photosynthesis, vegetative growth and eventually for the higher yield. Though the mechanisms involved remained obscure, this study clearly demonstrated the resistance of maize crop to *S. frugiperda* when the growing field was fertilized with balanced doses of fertilizer in combination with the organic source of fertilizer like FYM. Comparable maize grain production in FYM only applied plots to those of balanced fertilizer application plots suggests to always use organic sources of fertilizers in harnessing the mechanism that reduces the *S. frugiperda* burden in maize crop.

Declaration of competing interests

The authors declare no competing interests. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpr etation of data; in the writing of the manuscript; and in the decision to publish the results.

Author's contribution

KC and ST designed the study and managed the fund, carried out the study, analyzed the data and drafted the manuscript; KS, ES, SD and SD carried out the field experiments. All authors finalized the manuscript and accepted to submit for scientific publication.

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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