Agriculture Development Journal

Volume 18 ISSN: 2091-0738(Print), 2091-0746 (Online) July 2025

Government of Nepal
Ministry of Agriculture and Livestock Development
Agriculture Information and Training Centre
Hariharbhawan, Lalitpur, Nepal
Emall: info@aitc.gov.np, Website: www.aitc.gov.np

Disclaimer	:	The Journal shall not take any responsibility for the views expressed in the contents of articles published in the journal and all such responsibility shall lie with the author/s.
Pubished	:	July, 2025
Available at	:	www.aitc.gov.np / www.nepjol.info/index.php/adj
ISSN	:	2091-0738 (Print), 2091-0746 (Online)

TABLE OF CONTENTS

https://doi.org/10.3126/adj.v18i1.82082

IMPACT OF MAIZE-LEGUME INTERCROPS FOR THE MANAGEMENT OF FALL ARMYWORM, *Spodoptera frugiperda* J. E. SMITH (LEPIDOPTERA; NOCTUIDAE) IN CHITWAN, NEPAL

Chiran Adhikari[1 2,*], Sundar Tiwari[1], Resham Bahadur Thapa[1], and Saraswati Neupane[3]

[1] Department of Entomology, Agriculture and Forestry University, Rampur, Chitwan, Nepal
[2] College of Natural Resource Management (CNRM), Kapilakot, Sindhuli, Nepal
[3] Nepal Agricultural Research Council (NARC), Rampur, Chitwan, Nepal

ABSTRACT

Fall armyworm (Spodoptera frugiperda J. E. Smith, 1797) is an invasive, polyphagous, voracious, and destructive pest that threatens maize production globally, including in Nepal. This study aimed to evaluate suitable maize intercropping systems and assess their impact on fall armyworm damage, the abundance of natural enemies, and maize grain yield. Field experiments were conducted in 2022 on spring maize in Chitwan, Nepal. The study employed a Randomized Complete Block Design (RCBD) with six treatments, each replicated four times. The treatments included maize intercropped with rajma bean (Phaseolus vulgaris L.), mungbean (Vigna radiata L.), cowpea (Vigna unguiculata L.), soybean (Glycine max L.), and black gram (Vigna mungo L.), along with a maize monoculture as the control. Data on fall armyworm damage were collected at 10-day intervals starting from 21 days after maize sowing. Visual observations were made to count the total number of crop stands, infected plants, live larvae, and the number of predators and parasitoids. The results showed that maize-soybean intercropping had the lowest fall armyworm infestation on maize, followed by maize with black gram and maize with mungbean. In contrast, mono-cropped maize had the highest percentage of plant infestation. The abundance of beneficial insects was higher in legume-intercropped maize fields. Additionally, among the intercropping combinations, the yield of maize-mungbean intercropped was higher (8.09 mt/ha) than that of mono-cropped maize (6.24 mt/ha). Therefore, intercropping with legumes could be an effective and sustainable management strategy to control fall armyworm, increase beneficial arthropod diversity, and boost maize yield.

Keywords:

Maize, Fall armyworm, Beneficial insect, Insecticides, Legume intercrops

INTRODUCTION

In Nepal, maize (*Zea mays* L.) is the second most important crop among cereals in terms of area (9,85,565 ha) and production (31,06,397 mt), with a productivity of 3.15 mt/ha, following rice, which occupies almost 29% of the total area and accounts for 27% of the total production of cereal crops in 2022/23 (MoALD, 2023). Since the pest invasion was reported in 2019, maize farmers in Nepal have faced high levels of fall armyworm (*Spodoptera frugiperda* J.

* Corresponding author Email: cadhikari@afu.edu.np

E. Smith) damage, resulting in an estimated yield loss of approximately 25-35% (GC et al., 2019; PQPMC, 2019). Chemical insecticides have been widely used to control fall armyworm (Yang et al., 2021). Excessive use of these chemicals leads to the development of insecticide resistance (Fatoretto et al., 2017), pest resurgence, toxicity to natural enemies (Desneux et al., 2007), and environmental and human health hazards (Tambo et al., 2020). Consequently, cost-effective, environmentally friendly, and sustainable management approaches are essential to controlling the fall armyworm infestations in maize. Under these circumstances, intercropping has been proposed as one of the alternative methods to reduce fall armyworm infestations and is a key component of integrated pest management (IPM) strategies.

Intercropping cereal with legumes is recognized as the most popular agricultural practice in many developing countries (Songa et al., 2007; Kiwia et al., 2019). Maize intercropped with other edible legumes, when integrated with various sustainable management techniques, is an effective strategy for managing *S. frugiperda* (Hailu et al., 2018). This is because certain crop combinations and their arrangements can disrupt pests' host location, serving as repellents or deterrents. Intercropping operates as both a push and pull system, where plants release semio-chemicals that may either attract or repel pests away from the main crop (Khan et al., 2010). The study suggests that intercropping cereals with legumes can maintain maize productivity while enhancing the population of beneficial insects, such as parasitoids, predators, and pollinators, compared to a maize monocropping system. The findings of this research could aid in identifying the most effective intercropping options for pest management and stable yield.

MATERIALS AND METHODS

The experiment was conducted on spring maize (crop variety: Rampur Composite) from March to June 2022 in Rampur, Chitwan, Nepal. The experimental field was located in the inner Terai region (27.6504070 N latitude and 84.3501430 E longitude, at an elevation of 228 meters above sea level), characterized by a humid and subtropical climate, which is ideal for maize cultivation. The experimental design was laid out in a Randomized Complete Block Design (RCBD) with six treatments, including maize sole cropping as a control, replicated four times. The potential intercrops tested are listed in Table 1. To ensure proper establishment, legume crops were sown 15 to 20 days before maize planting. Each plot for each treatment measured 4 m × 3 m and included four rows of maize and three rows of legumes. After the establishment of the legume crops, maize was sown at a spacing of 75 cm × 20 cm. The intercrops were sown between the maize rows, with maize and intercrops planted alternately. All agronomic practices, including fertilization, irrigation, and pest management, adhered to the guidelines set forth by the National Maize Research Program (NMRP) in Rampur, Chitwan, Nepal, ensuring consistency and standardization across treatments.

Table 1: Potential maize legume intercropping as a treatment

S. N.	Treatments (Intercropping)	Legume Plant- Plant space	Scientific Name of Legume Crops	Maize: Legume ratio	Another name for a legume	Legume variety
1	Maize + Rajma bean	15 cm	*Phaseolus vulgaris* L.	1:1	Kidney bean	PDR-14
2	Maize + Mung bean	10 cm	*Vigna radiata* L.	1:1	Green gram, green bean, moong	Pratikshya
3	Maize + Cowpea	15 cm	*Vigna unguiculata* L.	1:1	Black-eye pea, crowder pea	Surya
4	Maize + Soyabean	15 cm	*Glycine max* L.	1:1	Golden bean	Puja
5	Maize + Black gram	10 cm	*Vigna mungo* L.	1:1	Urad bean, mash bean	Khajura Mas- 1
6	Sole crop (Maize only)	-	-	-	-	

The total number of crop stands, infected plants, live larvae, predators and parasitoids was counted from the middle two rows of maize. Predators and parasitoids were counted through visual observation, while soil-dwelling carabids were sampled using pitfall traps (Morris, 1960; Mills, 2005; Kogan and Herzog, 2012). Simple plastic cups were used as traps, placed at ground level and half-filled with water. Data were collected at 10-day intervals, starting 21 days after the maize was sown. The percentage of plant infestation by fall armyworm was calculated using the following formula:

Statistical analysis

The collected data were tabulated and maintained in an Excel spreadsheet. The data on the percentage of plant infestation and the number of fall armyworm larvae underwent a square-root transformation to meet the normality assumption. Data analysis was performed using Analysis of Variance (ANOVA) in R-Studio version 4.1.3. Multiple comparisons among the treatments were conducted using the LSD at 5% and 1% significance levels (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Effects of intercropping on fall armyworm infestation and crop damage

The percentage of plant infestation caused by fall armyworm larvae varied significantly ($p<0.05$) among the tested treatments. Based on the damage symptoms observed on the whorl and the upper four leaves, maize-legume intercropping consistently showed better performance compared to sole maize cropping. In regions such as Africa and the Americas, intercropping maize with legumes like common beans, groundnuts, cowpeas, and lima beans is a traditional practice. This method has gained popularity in modern agroecological farming systems (Pierre et al., 2021; Pierre et al., 2022). Cereal-legume intercropping has reduced specialist pests while providing additional resources for arthropod predators, such as shelter and food (Norris et al., 2018).

Non-significant results were observed when data were collected at 21 days after maize sowing. However, the data collected at 31 days after sowing revealed significant differences among the tested intercrops. Maize intercropped with soybean exhibited the lowest percentage of plant infestation (3.66%), followed by maize intercropped with cowpea (4.03%), mung bean (4.15%), and black gram, which were statistically similar to one another. Higher plant infestation was observed in maize grown alone, with an average infestation of 5.46%. This was followed by maize intercropped with rajma bean, which had a mean plant infestation of 4.68% (Table 2).

Lower infestation levels on maize intercropped with cowpea and beans could be due to natural enemies, as leguminous plants attract predators and parasitoids that may enhance the effectiveness of biological control agents, thereby reducing the pest population, as demonstrated by Hailu et al. (2018), Udayakumar et al. (2021) and Keerthi et al. (2023). Similar results were observed by Kumar et al. (2014) and Reddy et al. (2019), who found that intercropping maize with legumes such as cowpea, soybean, red gram, and green gram enhances the population growth of natural enemies of the fall armyworm, thereby reducing its effectiveness. In Uganda, the damage caused by fall armyworms was significantly reduced when maize was intercropped with legumes, such as *Phaseolus vulgaris* L., *Glycine max* L., and *Vigna unguiculata* L., reported by Hailu et al. (2018).

Observation of *S. frugiperda* at 41 days after sowing revealed significant differences among the intercropping treatments ($F = 33.79$, $p < 0.001$). The lowest crop damage percentage was recorded in maize intercropped with soybean (3.70%) and maize intercropped with mung bean (3.75%), which were statistically similar to maize intercropped with black gram (4.02%) and maize intercropped with cowpea (4.07%). In contrast, the highest plant infestation percentage (5.76%) was observed in maize sole cropping, followed by maize intercropped with rajma bean at 4.27%, with this difference being statistically significant.

The data recorded at 51 days after sowing revealed significant differences among the treatments, with plant infestation percentages ranging from 3.62% to 5.80%. Maize intercropped with soybean showed the lowest infestation (3.62%), providing the most effective protection against *Spodoptera frugiperda*, followed by maize intercropped with black gram (3.84%), which was statistically similar. Maize intercropped with mung bean (4.11%) and cowpea (4.19%) also demonstrated relatively lower infestation levels. In contrast, sole maize cropping exhibited the highest infestation percentage (5.80%), followed by maize intercropped with rajma bean (4.40%). These findings are consistent with previous studies by Hailu et al. (2018), as well as Udayakumar et al. (2021) and Guo et al. (2022).

The observations made at 61 days after sowing indicated that the percentage of plant infestation varied significantly among the plots, ranging from 3.32% to 5.80%. The combination of maize intercropped with soybean showed the lowest percentage of plant infestation (3.32%). This was followed by maize intercropped with mung bean (3.74%), which was statistically similar to maize intercropped with black gram (3.81%) and maize intercropped with cowpea

(4.03%), respectively. A higher percentage of plant infestation (5.80%) was observed in maize sole cropping, statistically similar to maize with rajma bean (4.15%). The percentage of plant infestation and the severity of fall armyworm were greater during the early growth stage of maize, declining as the plants matured across the different treatments. Hailu et al. (2018) noted that intercropping maize with leguminous crops significantly reduced the presence of stem borers and fall armyworm compared to mono-cropped maize, particularly in the early growth stages leading up to tasselling. Tanyi et al. (2020) stated that maize intercropped with beans was better protected from *S. frugiperda* infestation compared to a sole maize monocrop; this finding was similar to the results of this study. The maize intercropped with beans experienced less infestation compared to mono-crop maize because the green leaves of the bean emit green leaf volatiles that may repel *S. frugiperda*, thereby reducing infestation in the maize plants.

Table 2: Plant infestation percentage on maize legume intercropping by fall armyworm larvae in Chitwan, Nepal, 2022

Intercropping	Plant infestation (%)				
	21 DAS	31 DAS	41 DAS	51 DAS	61DAS
Maize + Rajma bean	5.12 (26.34)	4.68 (21.88)[b]	4.27 (18.21)[b]	4.40 (19.41)[b]	4.15 (17.35)[b]
Maize + Mung bean	5.09 (25.96)	4.15 (17.28)[c]	3.75 (14.10)[c]	4.11 (16.96)[bc]	3.74 (14.03)[c]
Maize + Cowpea	4.74 (22.62)	4.03 (16.26)[c]	4.07 (16.60)[bc]	4.19 (17.64)[bc]	4.03 (16.28)[bc]
Maize + Soybean	4.83 (23.57)	3.66 (13.45)[d]	3.70 (13.74)[c]	3.62 (13.11)[d]	3.32 (11.08)[d]
Maize + Blackgram	5.02 (25.69)	4.21 (17.72)[c]	4.02 (16.26)[bc]	3.84 (14.83)[cd]	3.81 (14.74)[bc]
Maize (sole)	4.94 (24.82)	5.46 (29.88)[a]	5.76 (33.23)[a]	5.80 (33.70)[a]	5.80 (33.71)[a]
Grand mean	4.96	4.37	4.26	4.33	4.14
SEm	0.06	0.26	0.31	0.32	0.35
LSD	0.92	0.27	0.40	0.39	0.37
CV %	12.30	4.03	6.17	6.01	5.91
p-value	ns	***	***	***	***
F-value	0.24	51.00	33.79	35.24	49.49

CV: Coefficient of Variation; LSD: Least Significant Difference; SEm: Standard Error of Mean; ***: Significance at < 0.1% ($p<0.001$); ns: Non-significance; DAS: Day After Sowing; Mean values in columns separated by the same letters are not statistically different by LSD at $P \leq 0.05$; figure in parenthesis indicate original values and figure outside parenthesis indicate the square root transformed values.

Effects of intercropping on fall armyworm larval density, beneficial insect abundance, and maize yield

The analysis of variance for fall armyworm larval counts at 61 days after sowing revealed a highly significant difference among the tested intercropping treatments ($p < 0.001$), with an overall mean of 1.41 ± 0.22 larvae per plant. The lowest larval population was observed in the maize intercropped with soybean (0.97 larvae), followed by maize intercropped with cowpea (1.18), maize intercropped with mung bean (1.18), maize intercropped with black gram (1.22), and maize intercropped with rajma bean (1.40), which were statistically at par with each others. Liu et al. (1988) reported that volatile compounds, namely tetradecene and dodecene, emitted by resistant soybean leaves, were the primary components responsible for repelling insect pests. The olfactory response tests showed that soybeans had a strong deterrent effect against fall armyworm adults. Soybean and groundnuts likely emitted semiochemicals that repelled the fall armyworm from maize, as reported by Kusi et al (2024) and Tao et al (2024). In contrast, sole cropping of maize resulted in a higher mean larval population of 2.48. This pattern aligns with the findings of Udayakumar et al (2021). Their study found that the number of fall armyworm larvae decreased when maize was intercropped with soybean, and no significant differences were noted in pest population reduction among the other tested legumes. According to Wink et al (2004), allelochemicals in leguminous crops can reduce pests' oviposition. These legumes contain quinolizidine alkaloids, which have allelopathic effects on fall armyworms in maize fields. Additionally, green leaf volatiles released by companion legume crops help repel fall armyworm larvae from maize plants. Root exudates from beans may also contain novel flavonoid compounds that interfere with the pupation phase of the fall armyworm life cycle in the soil, thereby disrupting the pest's ecological development (Chamberlain et al., 2006; Khan et al., 2010).

During the study period, 26 different predator species and 11 parasitoid species were recorded in the maize experimental field. Among the top beneficial insects, the black ant (2231), ladybird beetle (1185), spider (615), pirate bug (95), parasitic wasp (51), and carabids (23) were observed in the highest numbers. Matova et al (2020) suggest that intercropping generally creates a protective microclimate that enhances the diversity and abundance of beneficial insects. Maize intercropped with soybean showed a higher number of parasitoids compared to other combinations. Research by Andow (1991); Amala and Shivalingaswamy (2018) highlights the role of intercrops in increasing the abundance and diversity of natural enemies, as well as in reducing the population of phytophagous insects. Many researchers reported that legume crops, such as cowpea flowers, provide pollen, nectar, and shelter to natural enemies, encouraging their growth in maize intercropping systems (Dannon et al., 2010; Day et al., 2017; Mudare et al., 2022). Research has shown that natural enemies can detect olfactory cues from intercrops and border crops (Hoballah et al., 2002), which enhances natural parasitism and predation of *S. frugiperda*.

There were significant differences in maize grain yield between maize-legume intercropping and sole maize cropping. The results indicated that intercropping alone can lead to higher yields. These findings are consistent with previous studies by Assefa and Ayalew (2019), Hruska and Gould (1997), and Nboyine et al (2022). The highest grain yield was recorded in the maize intercropped with the mungbean (8.09 mt/ha), followed by maize intercropped with soybean (7.91 mt/ha), likely due to reduced larval incidence and a higher abundance of beneficial insects. However, no differences in maize grain yield were observed among the various legume intercropping combinations. In contrast, the lowest yield occurred in sole maize cropping (6.24 mt/ha) (Figure 1). Intercropping is typically cultivated to maximize the use of space that the main crop does not fully utilize during its early growth stages. Depending on the species and spatial arrangement of the component crops, intercropping can either decrease or increase the yield of the main crop (Ananthi et al., 2017).

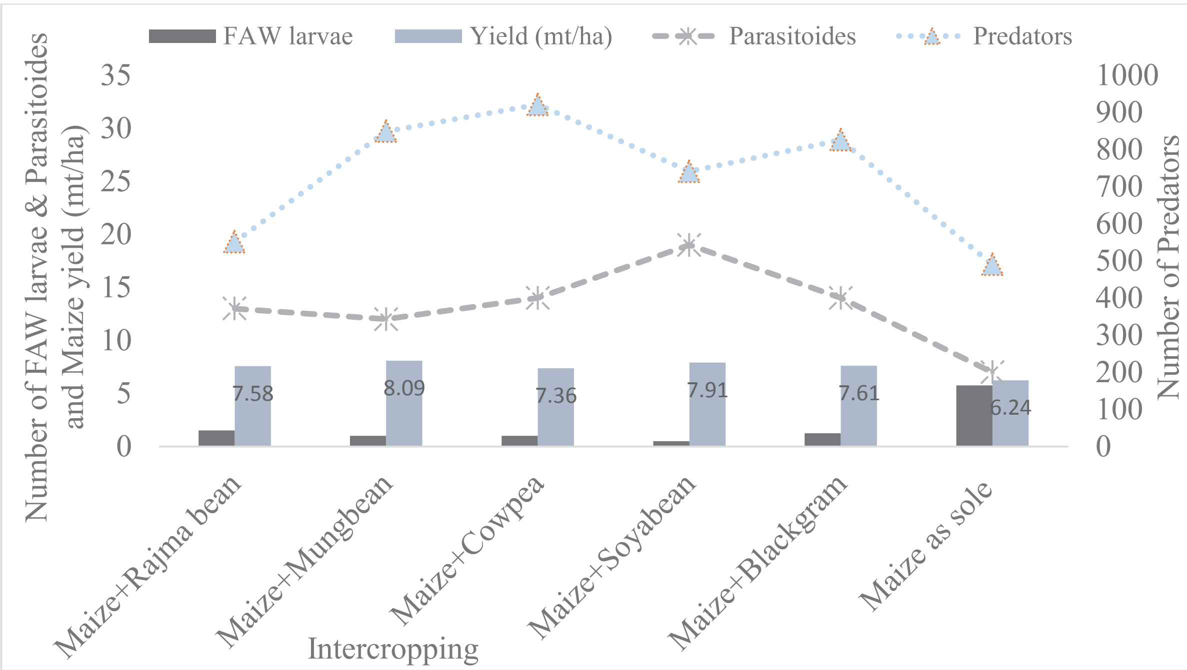


Figure 1: Number of fall armyworm live larvae, predators & parasitoids, and maize grain yield (mt/ha) across the different maize-legume intercropping systems

CONCLUSION

This study revealed that intercropping maize with legumes, particularly pulses like soybean, black gram, mung bean, cowpea, and kidney bean (rajma), significantly reduced the incidence and damage caused by fall armyworm while improving maize yields compared to sole maize cropping. Furthermore, intercropping reduces reliance on synthetic insecticides, provides additional income from legumes, and holds significant potential to enhance the livelihoods of smallholder maize farmers. The maize-legume intercropping system also positively impacts the presence of natural enemies within the crop ecosystem. Overall, it offers a sustainable solution easily adopted by smallholder farmers in Nepal and beyond. However, further research is needed to validate the effectiveness of legume intercropping in managing fall armyworm under diverse agroecological conditions.

DECLARATION

The authors declare no conflict of interests.

ACKNOWLEDGMENTS

The authors are very grateful to the Directorate of Research and Extension (DOREX) of Agriculture and Forestry University, Department of Entomology/AFU, and the National Maize Research Program (NMRP, NARC) for the financial and technical support during the study period.

REFERENCES

Akande, M. O., Oluwatoyinbo, F. I., Kayode, C. O., & Olowokere, F. A. (2006). Response of maize (*Zea mays* L.) and okra (*Abelmoschus esculentus* L.) intercrop relayed with cowpea (*Vigna unguiculata*) to different levels of cow dung amended phosphate rock. *World Journal of Agricultural Sciences*, *2*(1), 119-122.

Amala, U., & Shivalingaswamy, T. M. (2018). Effect of intercrops and border crops on the diversity of parasitoids and predators in agroecosystem. *Egyptian Journal of Biological Pest Control*, *28*(1), 11.

Andow, D. A. (1991). Vegetational diversity arthropod population. *Annual Review of Entomology*, *36*, 561-566.

Assefa, F., & Ayalew, D. (2019). Status and control measures of fall armyworm (*Spodoptera frugiperda*) infestations in maize fields in Ethiopia: A review. *Cogent Food & Agriculture*, *5*(1), 1641902.

Chalka, M. K., & Nepalia, V. (2006). Nutrient uptake appraisal of maize intercropped with legumes and associated weeds under the influence of weed control. *Indian Journal of Agricultural Research*, *40*(2), 86-91.

Desneux, N., Decourtye, A., & Delpuech, J. M. (2007). The sublethal effects of pesticides on beneficial arthropods. *Annual Review of Entomology*, *52*(1), 81-106.

Fatoretto, J. C., Michel, A. P., Silva Filho, M. C., & Silva, N. (2017). The adaptive potential of fall armyworm (Lepidoptera: Noctuidae) limits Bt trait durability in Brazil. *Journal of Integrated Pest Management*, *8*(1), 17.

Gomez, K. A., & Gomez, A. A. (1984). Statistical procedures for agricultural research. John Wiley & Sons. 1-95p.

Guo, J. F., Han, H. L., He, K. L., Bai, S. X., Zhang, T. T., & Wang, Z. Y. (2022). Dispersal of *Spodoptera frugiperda* in maize monoculture and intercropped maize-soybean field. *Plant Protection*, *48*, 110-115.

Hailu, G., Niassy, S., Zeyaur, K. R., Ochatum, N., & Subramanian, S. (2018). Maize–legume intercropping and push-pull for management of fall armyworm, stem borers, and striga in Uganda. *Agronomy Journal*, *110*(6), 2513-2522.

Hruska, A. J., & Gould, F. (1997). Fall armyworm (Lepidoptera: Noctuidae) and *Diatraea lineolata* (Lepidoptera: Pyralidae): Impact of larval population level and temporal occurrence on maize yield in Nicaragua. *Journal of Economic Entomology*, *90*(2), 611-622.

Keerthi, M. C., Mahesha, H. S., Manjunatha, N., Gupta, A., Saini, R. P., Shivakumara, K. T., & Kulkarni, N. S. (2023). Biology and oviposition preference of fall armyworm, *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae) on fodder crops and its natural enemies from Central India. *International Journal of Pest Management*, *69*(3), 215-224.

Khan, Z. R., Hassanali, A., Overholt, W., Khamis, T. M., Hooper, A. M., Pickett, J. A., & Woodcock, C. M. (2002). Control of witchweed Striga hermonthica by intercropping with *Desmodium spp*., and the mechanism defined as allelopathic. *Journal of Chemical Ecology*, *28*, 1871-1885.

Khan, Z. R., Midega, C. A., Bruce, T. J., Hooper, A. M., & Pickett, J. A. (2010). Exploiting phytochemicals for developing a 'push–pull 'crop protection strategy for cereal farmers in Africa. *Journal of Experimental Botany*, *61*(15), 4185-4196.

Kiwia, A., Kimani, D., Harawa, R., Jama, B., & Sileshi, G. W. (2019). Sustainable intensification with cereal-legume intercropping in Eastern and Southern Africa. *Sustainability*, *11*(10), 2891.

Kogan, M., & Herzog, D. C. (Eds.). (2012). Sampling methods in soybean entomology. *Springer Science & Business Media*.

Kumar, P., Sekhar, J. C., Soujanya, P. L., & Kaur, J. (2014). Management of Insect Pests of Maize. *Indian Farming*, *64*(4).

Mills, N. J. (2005). Parasitoids and predators. *Insect sampling in forest ecosystems*, 254-278.

MoALD. (2023). Statistical information on Nepalese agriculture 2078/79 (2021/22). Kathmandu: Ministry of Agriculture, Land Management and Cooperatives.

Morris, R. F. (1960). Sampling insect populations. *Annual Review of Entomology*, *5*(1), 243-264.

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R., & Vanlauwe, B. (2010). A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. *Field Crops Research*, *115*(2), 132-139.

Nboyine, J. A., Asamani, E., Agboyi, L. K., Yahaya, I., Kusi, F., Adazebra, G., & Badii, B. K. (2022). Assessment of the optimal frequency of insecticide sprays required to manage fall armyworm (*Spodoptera frugiperda* J E Smith) in maize (*Zea mays* L.) in Northern Ghana. *CABI Agriculture and Bioscience*, *3*(1), 3.

Norris, S. L., Blackshaw, R. P., Critchley, C. N. R., Dunn, R. M., Smith, K. E., Williams, J., & Murray, P. J. (2018). Intercropping flowering plants in maize systems increase pollinator diversity. *Agricultural and Forest Entomology*, *20*(2), 246-254.

Pierre, J. F., Latournerie-Moreno, L., Garruna, R., Jacobsen, K. L., Laboski, C. A., Us-Santamaria, R., & Ruiz-Sanchez, E. (2022). Effect of maize–legume intercropping on maize physio-agronomic parameters and beneficial insect abundance. *Sustainability*, *14*(19), 12385.

Pierre, J. F., Latournerie-Moreno, L., Garruna-Hernandez, R., Jacobsen, K. L., Laboski, C. A., Salazar-Barrientos, L. D. L., & Ruiz-Sanchez, E. (2021). Farmer perceptions of adopting novel legumes in traditional maize-based farming systems in the Yucatan Peninsula. *Sustainability*, *13*(20), 11503.

Plant Quarantine and Pesticide Management Centre (PQPMC) (2019). American Fall Armyworm and its management [Fact Sheet]. Government of Nepal, Ministry of Agriculture and Livestock Development.

Ranum, P., Pena-Rosas, J. P., & Garcia-Casal, M. N. (2014). Global maize production, utilization, and consumption. *Annals of the New York Academy of Sciences*, *1312*(1), 105 112.

Reddy, L. M., Soujanya, P. L., Sekhar J. C., Sreelatha, D., Bhadru, D., & Anuradha, G. (2019). Management of Insect Pests of Maize.

Songa, J. M., Jiang, N., Schulthess, F., & Omwega, C. (2007). The role of intercropping different cereal species in controlling lepidopteran stem borers on maize in Kenya. *Journal of Applied Entomology*, *131*(1), 40-49.

Tambo, J. A., Kansiime, M. K., Mugambi, I., Rwomushana, I., Kenis, M., Day, R. K., & Lamontagne-Godwin, J. (2020). Understanding smallholders' responses to fall armyworm (*Spodoptera frugiperda*) invasion: evidence from five African countries. *Science of the Total Environment*, *740*, 140015.

Tanyi, C. B., Nkongho, R. N., Okolle, J. N., Tening, A. S., & Ngosong, C. (2020). Effect of intercropping beans with maize and botanical extract on fall armyworm (*Spodoptera frugiperda*) infestation. *International Journal of Agronomy*, *2020*.

Udayakumar, A., Shivalingaswamy, T. M., & Bakthavatsalam, N. (2021). Legume-based intercropping for the management of fall armyworm, *Spodoptera frugiperda* in maize. *Journal of Plant Diseases and Protection*, *128*(3), 775-779.

Yang, X., Wyckhuys, K. A., Jia, X., Nie, F., & Wu, K. (2021). Fall armyworm invasion heightens pesticide expenditure among Chinese smallholder farmers. *Journal of Environmental Management*, *282*, 111949.

https://doi.org/10.3126/adj.v18i1.82083

Agriculture Development Journal, Volume 18 (2025)

MONITORING AND ECO-FRIENDLY MANAGEMENT OF COFFEE WHITE STEM BORER, *Xylotrechus quadripes* CHEVROLAT (COLEOPTERA: CERAMBYCIDAE) IN *Coffea arabica*

Kiran Parajuli[1,*], Manoj Paudel[2] and Sundar Tiwari[3]

[1] Agriculture and Forestry University, Nepal: Currently University of Göttingen, Germany
[2] Agriculture and Forestry University, Nepal: Currently Pennsylvania State University, USA
[3] Department of Entomology, Agriculture and Forestry University, Nepal

ABSTRACT

Coffee, the most widely consumed beverage and important cash crop, is cultivated in more than 70 countries in the world. Coffee white stem borer (CWSB) is one of the major problems in organic arabica coffee production in Nepal. Hence, a study was carried out for eco-friendly management of CWSB by understanding its habitat and ecology. Pest monitoring using CWSB lure in three different locations of Gulmi district showed that late May and early June was the peak emergence period of the beetles. Their population was significantly higher in coffee orchards without shade as compared to shaded coffee orchards. Effects of four different eco-friendly management practices namely red soil plus cow dung, Bordeaux paste, stem scrubbing plus 20% kerosene, stem scrubbing plus 30% neem oil was studied on pest population and plant health. Effect of those treatments on the number of adults, larvae, exit holes and cracks was studied. Stem scrubbing plus 30% neem oil reduced the number of adults, larvae and cracks by 90%, 95% and 31% respectively in late May and early June. Red soil plus cow dung was most effective against exit holes, reducing it by 91% compared to control.

Keywords:

Coffee, coffee white stem borer, eco-friendly, monitoring, shade

1. INTRODUCTION

Coffee is the most important cash crop and popular beverage consumed worldwide because of its pleasant taste, aroma, stimulant effect and health benefits. Coffee beans are grown along the equatorial zone called "The Bean Belt", in over 70 countries. In Nepal, coffee is grown from 700 to 1500 m above sea level (Paudel et al., 2021). It is usually grown by marginalized farmers in upland, and is commercially grown only in 20-22 hilly districts. Nepalese coffee is widely recognized as organic and specialty coffee due to its peculiar aroma and flavor (Paudel & Parajuli, 2020). The specialty coffee of Nepal has high demand in the international market because of its reduced caffeine amount (Tuladhar & Khanal, 2020). Despite high demand for Nepalese coffee in the international market, the country is not in position to meet this demand because of the low national coffee production (Karki, Regmi, & Thapa, 2018). Coffee is a

* Correspondence author Email : parajulikiran10@gmail.com

shade-loving plant. Shade in coffee orchard provides optimum condition for its growth. With proper shade, coffee plants are not exposed to excessive light. Shade providing trees host natural enemies to pests of coffee and shade also delays berries maturation enhancing the coffee quality (Bote & Struik, 2011). In Nepal, multipurpose trees like moringa, banana, guava are grown in coffee orchard to provide shade (K. C., Shrestha, & Dhimal, 2016).

An increase in coffee white stem borer (CWSB) infestation is questioning the sustainability of coffee production in most of the coffee growing areas of Asia and Africa (Thapa & Lantinga, 2016). Stem borers are the major enemies of coffee. Coffee white stem borer (*Xylotrechus quadripes*) (Coleoptera: Cerambycidae) is native to southeast Asia and is a major constraint for coffee production (Seetharama et al., 2005). It is considered as the major pest of Arabica coffee (Thapa & Lantinga, 2016). It was first recorded in India in 1838 AD and now is a major coffee pest in other Asian countries including Nepal, China, Sri Lanka, Vietnam and Myanmar (Venkatesha & Dinesh, 2012). The female beetle lays eggs on the rough surfaces of the main stem of coffee plant. These eggs hatch into larvae which is the most dangerous stage of the pest. Larva on hatching enters the stem making tunnels that make ridges on the stem of the plant which indicates the infestation (Vega et al., 2006). When larva feeds inside the stem, stem starts swelling (Kumar et al., 2019). The tunnels result in wilting and yellowing of leaves (Cristancho et al., 2016). Larva feeding creates larval galleries which are continuously filled with the larval frass (Rhainds et al., 2009). After completion of larval stage of about 10 months, the larva changes into the resting pupal stage which lasts for about one month. Pupae change to adults, and under favorable environmental conditions, adults emerge out of the stem by cutting an exit hole of about 0.01 m in diameter (Liebig, et al., 2018).

CWSB infestation is the major constraint for the coffee production which fetches a loss up to 70% in Nepal (Bajracharya et al., 2015). Lack of ecofriendly management practices for the control of CWSB is increasing the threat that Nepalese coffee will lose its international organic trade. Therefore, this study was carried out with the objective of understanding the population dynamics of CWSB by regularly monitoring their population in various sites of Gulmi district and evaluating the locally available management practices for CWSB. In this study, we hypothesized that the neem oil application on scrubbed stem will decrease the adult and larval population and the number of exit holes and cracks in the stem.

2. METHODOLOGY

2.1. STUDY SITE:

The research was conducted in Reeptole (1240 masl), Panitanki and Coffee Research Program, Bhandari Dada of Gulmi district, Nepal (Figure 1) from January to July 2020. The field research was conducted in completely randomized block design (RCBD) with five treatments and four replications. Under each treatment, five plants were sampled. So, in total, 100 plants were taken under observation. Healthy, non-border plants in the center of the orchard were randomly selected for the study.

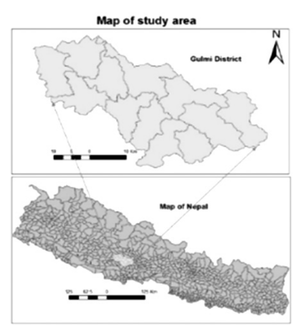


Figure 1: Map of study area.

2.2. CWSB ADULT MONITORING USING CROSS VANE TRAPS

Multi location monitoring of CWSB was carried out by the installation of cross vane pheromone traps in mid-March 2020. The CWSB pheromone lure, 2-hydroxy-3-decanone, which was loaded into a small, sealed vial of 2.5 cm length and 0.75 cm thickness, was used as bait. Five traps were pre-installed at Coffee Research Program, Bhandari Dada, and five traps each was installed at other two locations: Reeptole and Panitanki. Traps were kept for three and half months, and they were monitored at an interval of five days. The beetle collection data from April to June were analyzed.

2.3. DETAILS OF TREATMENTS

Treatments included red soil plus cow dung (T1), Bordeaux paste (T2), stem scrubbing with jute bag and applying kerosene at 20% concentration (T3), stem scrubbing with jute bag and applying neem oil at 30% concentration (T4) and control (T5). Equal amount of red soil and cow dung were mixed properly and then applied to the plant stem. 200ml of kerosene was mixed in 800 ml of water and 300 ml of commercially available neem oil was mixed in 700 ml of water. All treatments were applied 4 times at an interval of 15 days from last week of February to mid-April. Treatments were applied in the main stem and thick branches.

2.4. DATA COLLECTION AND ANALYSIS

Cross vane traps were observed every 5 days and the number of insects trapped was noted down. CWSB infested plants in each experimental unit were observed. Larvae were counted by cutting and longitudinally splitting the stem. This helped us to know the effect of treatment on the larval population. Similarly, other research parameters included were number of exit holes, number of cracked signs and number of adults.

Quantitative and qualitative data obtained from research were analyzed and interpreted by using RStudio and MS-Excel. Count data were square root transformed to normalize the data before conducting analysis of variance (ANOVA). Treatment means were separated by using Duncan's Multiple Range Test (DMRT) at 5% level of significance.

3. RESULTS

3.1. MONITORING OF CWSB AT DIFFERENT LOCATIONS

Cross-vane pheromone traps loaded with lure were installed at the height of 180 cm (average plant height) at different locations for monitoring of beetle population. The monitoring of CWSB was done in three time points: i) April and early May, ii) late May and early June and iii) June 15-30. These three time points were considered to cover pre-monsoon and monsoon season to find the peak beetle emergence time of the year. CWSBs were not recorded in any of traps in any locations for April and early May. A paired t-test was done for the analysis of beetle population in late May and early June and June 15-30. The results showed that in late May and early June, an average of 7.6 adult beetles were found, which was significantly higher as compared to an average of 2.2 adults in June 15-30 (Table 1).

Table 1. Paired t-test between late May plus early June and June 15-30 for monitoring of *Xylotrechus quadripes* in *Coffea arabica* in Gulmi, Nepal, 2020

	Late May and early June	June 15-30
Mean	7.6 ± 0.6	2.2 ± 0.2
Variance	2.74	0.48
P(T<=t) two-tail	0.002**	

** represents level of significance at 1%

For comparing the beetle population between shaded and non-shaded coffee orchard, a paired t-test analysis was done. An average of 13 CWSB adults were found in coffee orchard with no shade providing trees. This value was significantly higher in comparison to the adults' mean of 8.1 in the coffee orchard with shade (Table 2).

Table 2. Paired t-test (between the shaded and non-shaded locations) for monitoring of *Xylotrechus quadripes* in *Coffea arabica* in Gulmi, Nepal, 2020

	Shaded	Non-shaded
Mean	8.1 ± 0.5	13 ± 0.8
Variance	3.68	8.5
P(T<=t) two-tail	0.007**	

** represents level of significance at 1%

3.2. NUMBER OF ADULT COFFEE WHITE STEM BORER

Regardless of the treatments, the maximum number of adults were found in late May and early June compared to the other two sampling periods. After control, maximum adult beetles were found in plants treated with cow dung plus red soil for all the sampling periods. Stem scrubbing plus 30% neem oil was the most effective treatment as significantly low adults were found in plants with this treatment. In major adult emergence period i.e. late May and early June, there were significantly lower adults in plants treated with stem scrubbing plus 30% neem oil with an average of 0.50 beetles than other treatments (Table 3).

Table 3: Effect of different ecofriendly management practices on the mean number of adults *Xylotrechus quadripes* from April to June in *Coffea arabica* in Gulmi, Nepal, 2020.

Treatments	Adult (April and early May)	Adult (late May and early June)	Adult (June 15-30)
Red soil plus cow dung	1.25(1.31)[a]	4.00(2.11)[ab]	1.50(1.40)[ab]
Bordeaux paste	0.75(1.09)[a]	3.00(1.86)[bc]	1.00(1.22)[b]

Stem scrubbing plus 20% kerosene	0.50(0.97)[a]	2.00(1.58)[c]	0.25(0.84)[c]
Stem scrubbing plus 30% neem oil	0.25(0.84)[a]	0.50(0.96)[d]	0.00(0.70)[c]
Control	1.00(1.18)[a]	5.25(2.39)[a]	2.00(1.58)[a]
LSD (α=0.05)	0.46	0.302	0.211
P value	0.243	0.000	0.000

LSD: least significant difference, S: significant, values with same letter on columns are not significantly different at 5% level of significance using DMRT (Duncan's Multiple Range Test) and figure in parenthesis indicate square root transformation (sqrt (x+0.5)).

Stem scrubbing with 20% kerosene also recorded significantly lower adults after neem oil in late May and early June. Bordeaux paste was effective compared to control but was not as effective as neem oil (Table 3).

3.3. NUMBER OF LARVAE OF COFFEE WHITE STEM BORER

All treatments were effective in controlling larval population as compared to control. Within treatments, larval population was significantly lower in stem scrubbing plus 30% neem oil followed by cow dung plus red soil. The average larval population was 0.50, 0.25 and 0.50 for stem scrubbing plus 30% neem oil and 0, 1.75 and 2.25 for cow dung plus red soil in April and early May, late May and early June and June 15-30 respectively (Table 4).

Table 4: Effect of different ecofriendly management practices on the mean number (square root transformed) of larva *Xylotrechus quadripes* from April to June in *Coffea arabica* in Gulmi, Nepal, 2020

Treatments	Larva (April and early May)	Larva (late May and early June)	Larva (June 15-30)
Red soil plus cow dung	0.00(0.96)[b]	1.75(1.47)[c]	2.25(1.64)[d]
Bordeaux paste	0.50(0.96)[b]	2.75(1.77)[b]	3.25(1.92)[c]
Stem scrubbing plus 20% kerosene	0.50(0.96)[b]	3.00(1.87)[b]	4.00(2.11)[b]
Stem scrubbing plus 30% neem oil	0.50(0.71)[b]	0.25(0.84)[d]	0.50(0.97)[e]
Control	1.75(1.49)[a]	5.00(2.35)[a]	6.00(2.55)[a]
LSD (α=0.05)	0.413	0.230	0.177
P value	0.000	0.000	0.000

LSD: least significant difference, S: significant, values with same letter on columns are not significantly different at 5% level of significance using DMRT (Duncan's Multiple Range Test) and figure in parenthesis indicate square root transformation (sqrt(x+0.5).

In late May and early June, Bordeaux paste and kerosene were equally effective against larval population but in June 15-30, the number of larvae was significantly lower in plants treated with Bordeaux paste than with kerosene (Table 4).

3.4. NUMBER OF EXIT HOLES

The exit holes in the main stem and the thick primaries were counted before the application of treatment and up to120 days after the application of treatments (DAT). The result was non-significant up to 60 days after the application of treatment. On 75 DAT, the number of exit holes varied from 0.21 to 1.39 (Table 5), making all the three treatments significantly different from the control plot except for the stem scrubbing plus 20% kerosene. Similar was the case on 90 DAT where the number of exit holes ranged from 0.19 to 1.36 but only red soil plus cow dung and Bordeaux paste was found to be significantly different from the control.

On 105 DAT, the number of exit holes varied from 0.21 to 2.31 and all the four treatments were significantly different from the control. The Bordeaux paste and red soil plus cow dung were found to be the most effective on 105 DAT, but there was no significant difference between these treatments. On 120 DAT, which was almost 4 months after the first application of treatments, the number of exit holes ranged from 0.21 to 2.83 with the lowest number in red soil plus cow dung and the highest in control (Table 5).

Table 5. Effect of different practices on the number of exit holes (square root transformed) of *Xylotrechus quadripes* over 120 days in *Coffea arabica* in Gulmi, Nepal, 2020

Treatments	Before trt application	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
Red soil plus cow dung	0.05 (0.74)[a]	0.06 (0.75)[a]	0.06 (0.75)[a]	0.13 (0.78)[a]	0.13 (0.78)[b]	0.21 (0.84)[b]	0.21 (0.83)[c]	0.21 (0.84)[d]	0.21 (0.84)[e]
Bordeaux paste	0.13 (0.79)[a]	0.19 (0.82)[a]	0.19 (0.82)[a]	0.21 (0.86)[a]	0.25 (0.86)[ab]	0.25 (0.86)[b]	0.25 (0.85)[c]	0.30 (0.89)[d]	0.48 (0.99)[d]
Stem scrubbing plus 20% kerosene	0.08 (0.76)[a]	0.27 (0.86)[a]	0.27 (0.86)[a]	0.45 (0.96)[a]	0.45 (0.96)[ab]	0.68 (1.06)[ab]	0.79 (1.12)[b]	1.70 (1.48)[b]	2.12 (1.62)[b]
Stem scrubbing plus 30% neem oil	0.28 (0.88)[a]	0.20 (0.82)[a]	0.25 (0.86)[a]	0.25 (0.86)[a]	0.78 (0.87)[ab]	0.45 (0.96)[b]	0.48 (0.99)[bc]	0.73 (1.11)[c]	1.15 (1.28)[c]
Control	0.25 (0.86)[a]	0.38 (0.93)[a]	0.60 (1.03)[a]	0.53 (1.00)[a]	0.77 (0.12)[a]	1.39 (1.36)[a]	1.67 (1.47)[a]	2.39 (1.70)[a]	2.83 (1.82)[a]
LSD (α=0.05)	0.196	0.235	0.258	0.245	0.257	0.315	0.228	0.182	0.142
P value	0.528	0.571	0.262	0.323	0.112	0.021	0.000	0.000	0.000

LSD: least significant difference, S: significant, values with same letter on columns are not significantly different at 5% level of significance using DMRT (Duncan's Multiple Range Test) and figure in parenthesis indicate square root transformation (sqrt(x+0.5)). Here DAT is the date after the first application of treatments.

3.5. NUMBER OF CRACKS/ RIDGES

The number of cracks was non-significant for up to 30 DAT. On 45, 60 and 75 DAT, red soil plus cow dung had significantly lower cracks as compared to control. On 90 and 105 DAT, both cow dung plus red soil and stem scrubbing plus 30% neem oil recorded significantly lower cracks. On 120 DAT, the average lowest cracks of 4.50 were found in stem scrubbing plus 30% neem oil followed by 6.00 in red soil plus cow dung. Stem scrubbing plus 20% kerosene was effective only at 120 DAT while Bordeaux paste showed lower cracks from 105 DAT (Table 6).

Table 6. Effect of different practices on the number of cracks (square root transformed) of *Xylotrechus quadripes* over 120 days in *Coffea arabica* in Gulmi, Nepal, 2020

Treatments	Before trt application	15 DAT	30 DAT	45 DAT	60 DAT	75 DAT	90 DAT	105 DAT	120 DAT
Red soil plus cow dung	0.59 (1.02)[b]	0.64 (1.05)[b]	1.14 (1.23)[a]	1.30 (1.30)[b]	1.86 (1.49)[b]	2.68 (1.75)[c]	3.71 (2.04)[b]	3.79 (2.06)[c]	6.00 (2.55)[c]
Bordeaux paste	1.00 (1.21)[ab]	1.00 (1.21)[ab]	1.50 (1.38)[a]	3.60 (1.99)[a]	4.13 (2.14)[a]	5.25 (2.40)[ab]	5.25 (2.40)[a]	5.50 (2.45)[b]	6.88 (2.71)[bc]
Stem scrubbing plus 20% kerosene	1.33 (1.34)[a]	1.33 (1.35)[a]	1.88 (1.54)[a]	3.83 (2.06)[a]	5.35 (2.41)[a]	5.93 (2.53)[a]	6.01 (2.55)[a]	6.45 (2.63)[a]	7.25 (2.78)[b]
Stem scrubbing plus 30% neem oil	1.55 (1.42)[a]	1.60 (1.44)[a]	2.25 (1.65)[a]	2.90 (1.84)[ab]	3.95 (2.10)[a]	3.75 (2.06)[bc]	4.33 (2.20)[b]	4.50 (2.24)[c]	4.50 (2.24)[d]
Control	1.04 (1.21)[ab]	1.16 (1.27)[ab]	1.71 (1.47)[a]	3.25 (1.91)[a]	4.19 (2.13)[a]	4.46 (2.22)[ab]	5.33 (2.41)[a]	6.53 (2.64)[a]	9.13 (3.10)[a]
LSD (α=0.05)	0.258	0.240	0.407	0.552	0.495	0.360	0.163	0.175	0.207
P value	0.049	0.038	0.283	0.072	0.020	0.002	0.000	0.000	0.000

LSD: least significant difference, S: significant, values with same letter on columns are not significantly different at 5% level of significance using DMRT (Duncan's Multiple Range Test) and figure in parenthesis indicate square root transformation (sqrt(x+0.5)). Here DAT is the date after the first application of treatments.

4. DISCUSSION

The maximum adults were seen in late May and early June because of the bright and sunny weather while very few numbers of adults were seen in April and early May and at the end of June. Stem scrubbing plus 30% neem oil and stem scrubbing plus 20 % kerosene were found most effective against adults. Despite having the least exit holes in plants treated with red soil plus cow dung and Bordeaux paste, more adults were observed in the plants treated with red soil and cow dung. Very fewer CWSB adults were observed in the shaded garden because of the shade providing plants. Similar observations were also found in the study done by Thapa and Lantinga (2016).

Stem scrubbing controlled the oviposition of coffee white stem borers. Smoothening of the stem of the plant removed the crevices and cracks in stem which were the major egg laying sites for CWSB. As a result, insects did not prefer those scrubbed plants and hence less adults were seen in the scrubbed plants. The result goes in line with the findings of Venkatesha and Dinesh (2012). Scrubbing would have been even more effective if it was done during the egg laying period or before the larvae bore into the stem. As the number of larva increases, the more cracks or ridges appear in the stem. Since the larval population was lower in stem scrubbing plus 30% neem oil and cow dung plus red soil, the lower cracks in those treatments were obvious. Among the scrubbed plants, less adults were seen in neem oil treated plants than kerosene treated plants. Neem, being a very effective bio-pesticide (Panthi, 2015), the extract of its seeds and leaves were found effective against CWSB. The effect of Neem was long-lasting than kerosene. The more the application of neem oil, the more the repellency against feeding and oviposition (Jilani & Saxena, 1990) and hence very few adults were seen in the neem oil treated plants.

The adult of CWSB lays eggs in the batches of 1-10 and the white creamy eggs hatch and change to larva after 8-15 days (NTCDB, 2018b). Larval stage lasts for about 10 months in which larvae go through five instars. Very few larvae were seen in April and early May which might be because larva from previous season had already changed into pupal stage and the eggs laid on studied year were not ready to hatch and bore into the stem. Similarly, the maximum number of larvae was seen on June 15-30 which explains that eggs laid on that year changed into larvae and were boring inside the stem. Despite having fewer adults in plants scrubbed and treated with 20% kerosene, the larval population was found more. This may be due to the short-term repellent effect of kerosene. Its volatile nature couldn't resist oviposition which resulted in even small number of hatched larvae to easily bore inside the stem. The larval population in plants treated with red soil plus cow dung was also found less in number. This was because the clay in soil helped in sticking cow dung to the plant stem and the stems treated with cow dung somehow might have increased the width of stem (NTCDB, 2018). The newly hatched larvae could not bore into the thicker stem and hence larvae inside the plant were less. While cutting the stem of plant scrubbed and treated with neem oil, some of the larvae were found dead which indicated that neem oil had inhibitory action against the larva of insect pests (Isman et al., 1990).

Exit holes are the emergence holes through which the adult borers come out of the stem during flight season (Rhainds et al., 2009). Fifth instar larva make exit holes before pupating so to ease the adult to emerge through the holes. Different treatments were applied from February when the borer inside the stem was almost at the end of the larval period. The least number of exit holes was observed with the paste of red soil plus cow dung followed by Bordeaux paste. This might be because these treatments were long-lasting and remained in stem for a longer time.

Soil in mid hills of Nepal is haplustalfs and rhodustalfs which contain clay in different proportions (Gurung S.B., 2020; Soil survey staff, 2014). The porous property of clay helps in the evaporative cooling (Katsuki et al., 2018). Agricultural residues made with 40% of cow dung have the lowest thermal conductivity (Onjefu et al., 2019). The evaporative cooling character of clay and thermal insulating behavior of cow dung might be the possible reason behind the minimum exit holes in the plant treated with the red soil plus cow dung. Clay evaporated the hot water in the mixture and red soil insulated the flow of heat from outside to inside of the stem. This might have prevented the adults from emerging through exit holes. The dead adults seen inside the stem also indicated that adults couldn't come out, which ultimately lowered the number of exit holes.

5. CONCLUSION

Based on the field visit, farmer's response, literature review and research conducted from among all the constraints for coffee production, coffee white stem borer was found to be the major problem for arabica coffee cultivation in Nepal. Since Nepalese coffee is popular as organic coffee, the use of any chemical pesticides is forbidden which directly demands the need of eco-friendly management practices for the pest control. The research conducted showed that coffee, being shade-loving plant, the provision of shade in coffee orchard proved to be the most effective against adult population of CWSB even in the peak emergence period i.e., late May and early June. Very few adults were found in scrubbed plants because of the absence of egg laying crevices. Stem scrubbing was very effective in itself to reduce the pest and application of any biopesticide having the repellent action like neem oil provided the synergistic result. Stem scrubbing plus 30% neem oil was found to be very effective against the larval population of coffee white stem borer that automatically resulted to a smaller number of cracks. The treatments like cow dung and red soil, stem scrubbing, and neem oil are locally available and affordable. Although these eco-friendly management practices might not have a quick effect on the pests, the adoption of these practices could control the pest slowly without causing any harm to the environment and human health. Therefore, these are affordable, accessible and environmentally friendly practices which can be easily adopted by farmers at a local level. Repetition of the experiment in different geographical locations in multiple years might provide clearer picture on the behavior of CWSB and effectiveness of treatments. Likewise, weather parameters like rainfall and temperature directly influence beetle behavior and hence, incorporating these data in future studies could enhance the robustness of the study.

DECLARATION

The authors declare no conflict of interests.

ACKNOWLEDGEMENT

The research was carried out under Prime Minister Agriculture Modernization Project (PMAMP). So, authors would like to acknowledge Coffee Superzone, Project Implementation Unit Gulmi, Nepal and Coffee Research Center, Bhandarida Gulmi for the technical support.

REFERENCES

Bajracharya, A., Giri, Y., Bista, S., & Mainali, R. (2015). *Coffee promotion strategies focusing on white stem borer management in Nepal.* Lumle: Entomology Division, NARC.

Bote, A. D., & Struik, P. C. (2011). Effects of shade on growth, production and quality of coffee (Coffea arabica) in Ethiopia. *Journal of Horticulture and Forestry*, 3(11), 336–341.

Cristancho, M. A., Caicedo, B. L. C., & Rivillas, C. A. (2016). Compendium of Coffee Diseases and Pests. *Compendium of Coffee Diseases and Pests.* https://doi.org/10.1094/9780890544723

Gurung, S. B. (2020). Soil distribution in Nepal. *NUTA Journal*, 7(1-2), 79-89.

Isman, M., Koul, O., Luczynski, A., & Kaminiski, J. (1990). Insecticidal and Antifeedant Bioactivities of Neem Oils and Their Relationship to Azadirachtin Content. *J. Agric. Food Chem., 38*, 1406-1411.

Jilani, G., & Saxena, R. (1990). Repellent and Feeding Deterrent Effects of Turmeric Oil, Sweetflag Oil, Neem Oil, and a Neem-Based Insecticide Against Lesser Grain Borer (Coleoptera: Bostrychidae). *Journal of Economic Entomology, 83*(2), 629-634. doi:https://doi.org/10.1093/jee/83.2.629

Karki, Y., Regmi, P., & Thapa, R. (2018). Coffee Production in Kavre and Lalitpur Districts, Nepal. *Journal of Nepal Agricultural Research Council, 4*, 72-78. doi:Coffee Production in Kavre and Lalitpur Districts, Nepal

Katsuki, H., Choi, E. K., Lee, W. J., Hwang, K. T., Cho, W. S., & Komarneni, S. (2018). Effect of porous properties on self-cooling of fired clay plate by evaporation of absorbed water. *Journal of Porous Materials*, 25(3), 643–648. https://doi.org/10.1007/s10934-017-0476-0

K. C., R.B., Shrestha, B. K., & Dhimal, S. (2016). Coffee as a niche crop for mid-hills of nepal. *Six Decades of Horticulture Development in Nepal,* 186.

Kumar, A. R., Gopinandhan, T. N., Reddy, P. K., Uma, M. S., Reddy, G. V. M., & Seetharama, H. G. (2019). Assessment of crop loss in Arabica coffee due to white stem borer , Xylotrechus quadripes Chevrolat (Coleoptera : Cerambycidae) infestation. *Journal of Plantation Crops,* 47(3), 140–144. https://doi.org/10.25081/jpc.2019.v47.i3.6041

Liebig, T., Babin, R., Ribeyre, F., Van Astern, P., Poehling, H., Jassogne, L., Avelino, J. (2018). Local and regional drivers of the African coffee white stem borer (Monochamus leuconotus) in Uganda. *Agricultural and Forest Entomology, 20*(4), 514-522. doi:https://doi.org/10.1111/afe.12284

NTCDB. (2018). Coffee Production Technology. Nepal Tea and Coffee Development Board (NTCDB).

NTCDB, N. T. and C. D. B. (2018b). Coffee production technology.

Onjefu , L., Kamara, V., Chisale, P., Kgabi, N., & Zulu, A. (2019). Thermal efficient isolating materials from agricultural residues to improve energy efficiency in buildings. *International Journal of Civil Engineering and Technology, 10*(2), 2067-2074.

Panthi, B. (2015). Small scale Coffee Farmer's Response towards Management of Coffee Pest through Field Level Techniques. *Journal of Institute of Science and Technology, 19*(2), 37-44. doi:https://doi.org/10.3126/jist.v19i2.13850

Pattan, F., & Khan, H. (2017). Intermittent Mating and Egg Laying by Coffee White Stem Borer , Xylotrechus quadripes Chevrolat (Coleoptera : Cerambycidae). *Mysore Journal of Agricultural Sciences, 51*(2), 240-243.

Paudel, M., & Parajuli, K. (2020). Constraints and Determinants of Coffee Processing Methods in Gulmi District, Nepal. *International Journal of Applied Sciences and Biotechnology, 8*(3), 368-373. doi:https://doi.org/10.3126/ijasbt.v8i3.31565

Paudel, M., Parajuli, K., Regmi, S., & Budhathoki, S. (2021). Effect of altitude and shade on production and physical attributesof Coffee in Gulmi, Syangja and Palpa districts of Nepal. *Journal of Agriculture and Natural Resources, 4*(1), 222-238. doi:https://doi.org/10.3126/janr.v4i1.33275

Rhainds, M., Lan, C. C., Zhen, M. L., & Gries, G. (2009). Incidence, Symptoms, and Intensity of Damage by Three Coffee Stem Borers (Coleoptera: Cerambycidae) in South Yunan, China. *Journal of Economic Entomology*, 95(1), 106–112. https://doi.org/10.1603/0022-0493-95.1.106

Seetharama, H., Vasudev, V., Vinod Kumar, P., & Sreedharan, K. (2005). Biology of coffee white stem borer Xylotrechus quadripes Chev (Coleoptera: Cerambycidae. *J. Coffee Res.*, 98-107.

Soil Survey Staff. (2014). Illustrated guide to soil taxonomy. U.S. Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center.

Thapa, S., & Lantinga, E. (2016). Infestation by Coffee White Stem Borer, Xylotrechus quadripes , in Relation to Soil and Plant Nutrient Content and Associated Quality Aspects. *Southwestern Entomologist, 41*(2), 331-336. doi:https://doi.org/10.3958/059.041.0209

Tuladhar, A., & Khanal, D. (2020). Coffee production in Nepal – A brief review. *Acta Horticulturae, 1274*, 161-166. doi:https://doi.org/10.17660/ActaHortic.2020.1274.21

Vega, F. E., Posada, F., & Infante, F. (2006). Coffee Insects: Ecology and Control. *Encyclopedia of Pest Management,* 1–4. https://doi.org/10.1081/E-EPM-120042132

Venkatesha, M., & Dinesh, A. (2012). The coffee white stemborer Xylotrechus quadripes (Coleoptera: Cerambycidae): bioecology, status and management. *International Journal of Tropical Insect Science, 32*(4), 177-188. doi:https://doi.org/10.1017/S1742758412000331

https://doi.org/10.3126/adj.v18i1.82086

MORPHOLOGICAL CHARACTERISTICS OF *Bipolaris sorokiniana* CAUSING SPOT BLOTCH OF WHEAT AND ITS IN VITRO MANAGEMENT USING DIFFERENT BOTANICALS

Hemanta Kumar Pandey[1] and Pratistha Adhikari[1,*]

[1] Agriculture and Forestry University, Rampur, Chitwan

ABSTRACT

Spot blotch disease of wheat caused by Bipolaris sorokiniana is one of the most concerning diseases of wheat, significantly constraining production over the last four decades. An estimated 25 million hectares of wheat grain are affected by spot blotch, particularly in humid and high-temperature regions. The study was conducted at Agriculture and Forestry University, Rampur, Chitwan, in 2023 with the objective to characterize the morphological traits of B. sorokiniana and manage the disease using botanicals under laboratory conditions. The research included a field survey of ten locations in Chitwan to identify the severity of spot blotch disease using double-digit scoring, morphological variations of B. sorokiniana conidia isolated from those locations, and in vitro management of the pathogen using botanical extracts (at 15 % concentration). The study revealed that the disease was most severe at Bijaynagar, Bharatpur-16, which recorded the highest number of spots per leaf (23) and the largest spot area (0.170 cm²). Isolate of B. sorokiniana from Bijaynagar has highest radial mycelium growth (8.62 cm). Among nine botanical extracts, garlic clove and neem extract effectively inhibited pathogen mycelial growth by 63.22% and 61.15 %, respectively. The study helped to identify severely affected locations in the Chitwan district along with potential efficient management options of B. sorokiniana.

Keywords:

Bipolaris sorokiniana, Botanical extracts, Disease severity, Morphological variability, Spot blotch disease

1. INTRODUCTION

Wheat occupies a third place after rice and maize in Nepal in terms of area under cultivation and production (MoALD, 2024). In Nepal, the majority of wheat cultivation is done in the Terai where the climate is warm and humid. As of 2022/23, the cultivated area, production, and productivity of wheat in Nepal were recorded at 697,762 hectares, 2,098,462 metric tons, and 3.01 tons per hectare, respectively (MoALD, 2024). Various diseases pose serious threats to wheat yields, among them is the foliar blight complex, being one of the most destructive fungal diseases in humid and high-temperature regions (Manandhar et al., 2016; Al-Sadi, 2021; Basnet et al., 2022). The fungus has a worldwide distribution and is aggressive under high relative humidity, elevated temperatures, and low soil fertility conditions prevalent in Nepal (Basnet et

* Corresponding author Email: adhikari_pk@yahoo.com

al., 2022). This pathogen is a causal agent of seedling blight, foliar blight/ spot blotch, common root rot, and black point of wheat, barley, and other small cereal grains and grasses (Al-Sadi, 2021). The pathogen can survive in infected crop residues and saprophytically on dead plant material (Tembo et al., 2018). Seedling infections often lead to blight, causing pre- or post-emergence seedling death (Manandhar et al., 2016; Al-Sadi, 2021). The disease becomes most severe when the crop's late post-anthesis stage coincides with periods of high relative humidity and elevated temperatures. Globally, spot blotch affects an estimated 25 million hectares of wheat fields (Gupta et al., 2022).

Considering the high yield loss due to this pathogen, knowledge of genetic diversity within the pathogen population is necessary for developing effective management strategies. *B. sorokiniana* exhibits high morphological and pathogenic variability, which complicates its identification and hampers effective disease management (Basak et al., 2024). Characterizing its morphological traits, such as colony color, growth habit, conidial size, shape, and septation, is important for accurate identification to develop effective management strategies for specific pathogen populations. Similarly, understanding the variability in disease severity in different locations can guide region-specific disease forecasting and management. In recent years, plant-based antifungal agents (botanicals) have garnered attention as eco-friendly alternatives due to their biodegradability, lower toxicity, and potential to inhibit a broad range of pathogens. However, there is limited information on the efficacy of these botanicals against *B. sorokiniana*. This study aims to investigate the morphological characteristics of *B. sorokiniana* isolated from different locations of Chitwan district, and to evaluate the potential botanical extracts for in vitro disease management.

2. MATERIALS AND METHODS

2.1 Field survey

A field survey was conducted in major wheat-growing regions of Chitwan, Nepal, during the wheat-growing season of 2023 to assess the prevalence and severity of spot blotch disease caused by *Bipolaris sorokiniana*. The survey covered a total of 10 randomly selected wheat fields of Chitwan (Table 1, Figure 1).

Location	Ward Number
Meghauli	Bharatpur-28
Jutpani	Kalika-11
Patihani	Bharatpur-22
Bhojad	Bharatpur-11
Bhimnagar	Bharatpur-10
Ratnagar	Ratnanagar-15
Rampur	Bharatpur-15
Shivaghat	Bharatpur-14
Tandi	Ratnanagar-2

Location	Ward Number
Bijaynagar	Bharatpur-16

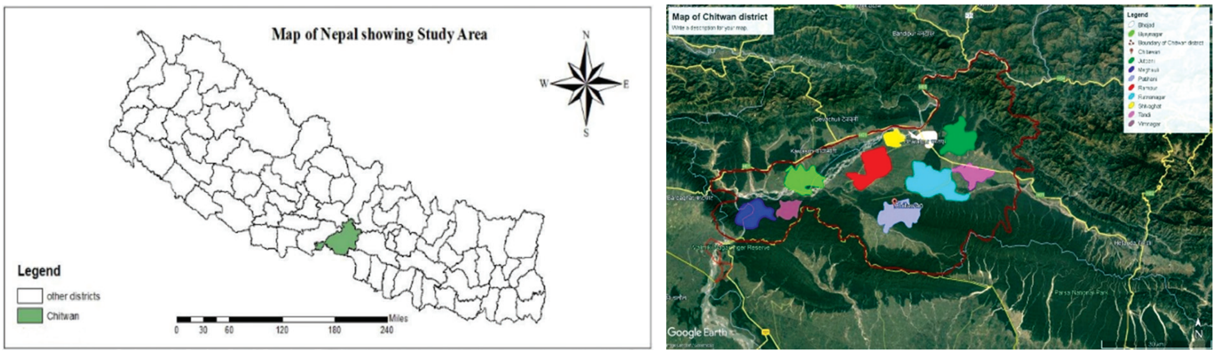


Figure 1. Map of the study site

2.1.1 Disease scoring and severity assessment

The double digits scale (00 to 99), developed by the modification of Saari & Prescott, 1975 was used to measures foliar infection based on two digit, where; the first digit (D1) indicates disease progress in canopy height from the ground level, and the second digit (D2) refers to severity of the disease based on diseased leaf area

Disease Severity (%) = (D1/9) × (D2/9) × 100

Where, D1 = First digit / height of infection

D2 = second digit / severity of infection

2.1.2 Number of lesions

The number of lesions was recorded from 10 penultimate leaves sampled from each location. The total number of spots per leaf was noted, and the average number of lesions was calculated for the sampled leaves.

2.1.3 Measurement of the Area of spot

The size of the necrotic spots was measured in centimeters using ImageJ software. The length and width of the lesions were recorded from 10 penultimate leaves sampled per field. For each leaf, the five largest spots were selected for measurement.

2.2 Collection of Diseased Samples

Wheat leaves exhibiting typical symptoms of spot blotch, such as dark brown lesions with chlorotic margins, were collected from surveyed wheat fields in Chitwan. The samples were placed in sterilized polyethylene bags, labeled, and transported to the laboratory for further study.

2.3 Isolation and Identification of Pathogen

Small sections (about 5 mm) were cut from the edges of the diseased leaf lesions. These sections were surface-sterilized by immersing them in 1% sodium hypochlorite solution for one minute, followed by rinsing three times with sterile distilled water. The sterilized sections were then placed on water agar plates and incubated at 25 ± 2°C for 7 days. Single spore culture was prepared by picking up single conidia of *B sorokiniana* from water agar plates and transferred to potato dextrose Agar (PDA) plates (Duveiller & Altamirano, 2000) and incubated at 25 ± 2 ºC. Emerging fungal colonies were sub-cultured to obtain pure cultures. Morphological characteristics of the isolates, including colony growth and color of 30 conidia, were observed and recorded after seven days of incubation.

2.4 Evaluation of botanical extract against spot blotch

2.4.1 Preparation of Botanical Extracts

Botanical extracts were prepared from locally available nine plants known for their antimicrobial properties, such as Neem *(Azadirachta indica)*, Mehendi (*Lawosina inermis*), Titepati (*Artemisia vulgaris*), Asuro (*Justicia adhatoda*), Abhijalo (*Drymaria diandra),* Bakaino (*Melia azedarach*), Jamun *(Syngium cumini*), Eucalyptus (*Eucalyptus globulus*), and Garlic (*Allium sativum*) (Figure 2). Fresh plant materials were washed, shade dried for three days, and ground into a paste. Extracts were obtained by homogenizing the paste with sterile distilled water (1:1 w/v) and filtering it through muslin cloth (Magar et al., 2020).

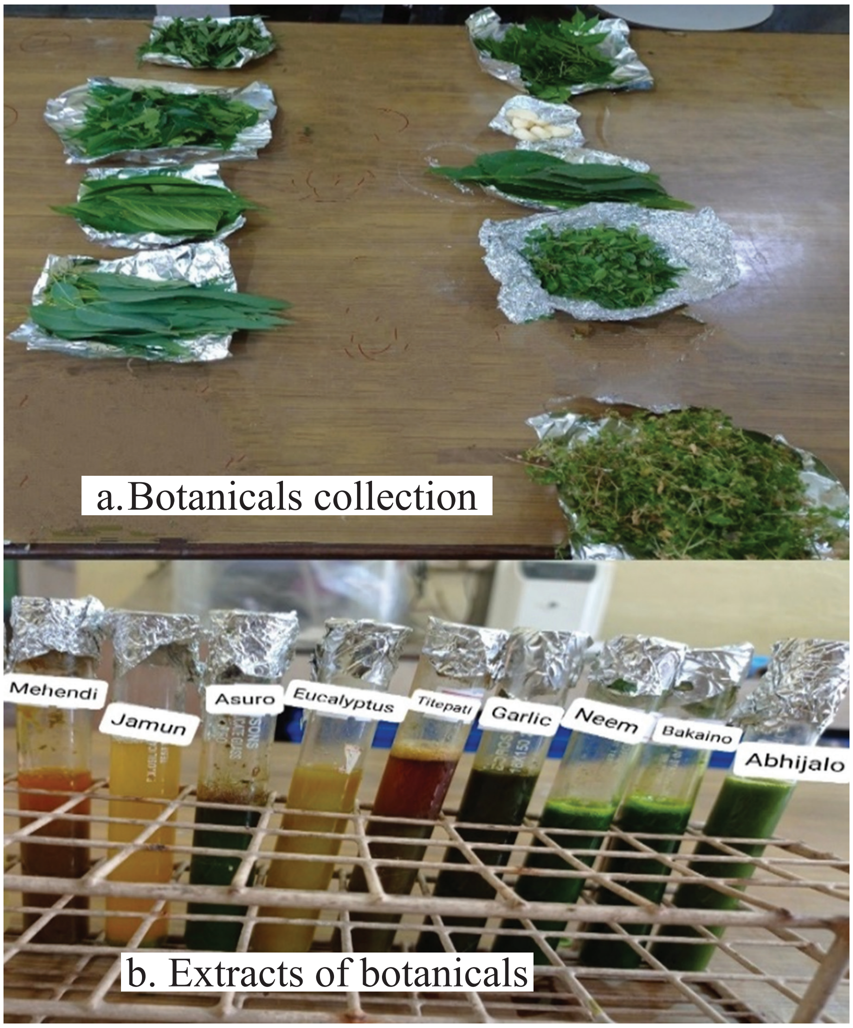


Figure 2. Preparation of botanical extract

2.4.2 In vitro Efficacy of Botanical Extracts

In order to evaluate the efficacy of botanical extracts against *B. sorokiniana* poisoned food technique was used. For this experiment, *B. sorokiniana* isolated from Bijayanagar was used. Botanical extracts at a concentration of 15% were added to the PDA medium and then poured into sterilized petri plates. The experiment was carried out in a completely randomized design (CRD). A 5 mm diameter mycelial plug from a 7-days-old pure culture was cut out with the help of cork borer and placed at the center of each plate. Plates without botanical extracts was used as a control treatment. All treatments were replicated three times, and the plates were incubated at 25 ± 2°C for 7 days. Colony growth diameter was measured, and the percentage inhibition of radial growth (PIRG) was calculated using the following formula:

$$PIRG = (C-T/C) \times 100$$

Where, C = Colony diameter in the control, T = Colony diameter in the treatment

2.5 Statistical Analysis

All the data recorded were entered in MS excel and *in vitro* data were subjected to analysis of variance (ANOVA), and mean differences were compared using Duncan's Multiple Range Test (DMRT) at a 5% level of significance. Statistical analysis was performed using R studio.

3. RESULTS

3.1 Field survey

From the field survey, it was observed that the number of spots per leaf and disease scoring was found highest at Bijaynagar (23) and (77) respectively, while the number of spots and disease scoring was lowest at Bhimnagar (9.4) and (51) respectively (Table 2).

Table 2. Average number of spots per leaf and disease scoring of spot blotch disease at different locations in Chitwan, 2023

Location	Average no of spots/leaf	Double digit scoring	Growth stage
Meghauli	19.8	73	Maturity
Patihani	12.7	74	Maturity
Bhimnagar	9.4	51	Dough
Rampur	20.2	71	Maturity
Tandi	15.1	53	Flowering
Jutpani	20.2	76	Maturity
Bhojad	10.2	72	Dough
Ratnanagar	14.2	75	Maturity
Shivaghat	15.2	73	Dough
Bijaynagar	23	77	Maturity

Length of the spot was found to be highest on Bijaynagar (1.097 cm) and lowest on Tandi (0.554 cm). Breadth of spot was observed highest on Bhojad (0.164 cm) and lowest on Ratnanagar

(0.099 cm). Total area covered by spot was observed highest at Bijaynagar (0.170 cm^2) and lowest at Bhimnagar (0.056 cm^2) (Table 3).

Table 3. Average length, breadth, and area of spot blotch lesions at different locations in Chitwan, 2023

Location	Spot length (cm)	Spot breadth (cm)	Spot area (cm^2)
Meghauli	0.914	0.157	0.148
Patihani	0.855	0.153	0.131
Bhimnagar	0.557	0.101	0.056
Rampur	0.556	0.102	0.057
Tandi	0.554	0.107	0.059
Jutpani	0.724	0.119	0.086
Bhojad	0.937	0.164	0.154
Ratnanagar	0.596	0.099	0.059
Shivaghat	0.754	0.122	0.091
Bijaynagar	1.097	0.155	0.170

3.2 Morphology of *Bipolaris sorokiniana*

There was a difference in the morphology of isolated *B. sorokiniana* from different locations. The longest length of conidia was found in isolate of *B. sorokiniana* from Bhimnagar (21.083 µm) and the shortest from Bijaynagar (16.83 µm). While conidia breath was found to be almost the same for all places (Table 4).

Table 4. Average length and breadth of conidia of *B. sorokiniana* isolated from different locations of Chitwan, 2023

B. sorokiniana Isolate	Conidia	
	Length (µm)	Breadth (µm)
Meghauli	18.583	4.790
Patihani	20.333	4.750
Bhimnagar	21.083	5.000
Rampur	20.330	5.000
Tandi	19.167	5.000
Jutpani	19.333	5.000
Bhojad	21.000	5.000
Ratnanagar	20.750	5.000
Shivaghat	20.330	5.000
Bijaynagar	16.830	5.000

Four distinct cultural groups of *B. sorokiniana* were observed on PDA medium: Effuse Black Regular (EBR), Effuse Blackish White Regular (EBWR), Velvety Blackish White Regular (VBWR), and Effuse Whitish Regular (EWR) (Table 5 and Figure 3). The colonies varied in color, ranging from light brown to deep brown and dark brown to black.

Table 5. Cultural characteristics of *B. sorokiniana* in PDA isolated from different location of Chitwan, 2023

Location	Cultural characteristics of *B. sorokiniana*
Meghauli	Effuse Black Regular (EBR)
Patihani	Effuse Blackish White Regular (EBWR)
Bhimnagar	Effuse Whitish Regular (EWR)
Rampur	Effuse Blackish White Regular (EBWR)
Tandi	Effuse Black Regular (EBR)
Jutpani	Effuse Black Regular (EBR)
Bhojad	Velvety Blackish White Regular (VBWR)
Ratnanagar	Effuse Whitish Regular (EWR)
Shivaghat	Effuse Black Regular (EBR)
Bijaynagar	Velvety Blackish White Regular (VBWR)

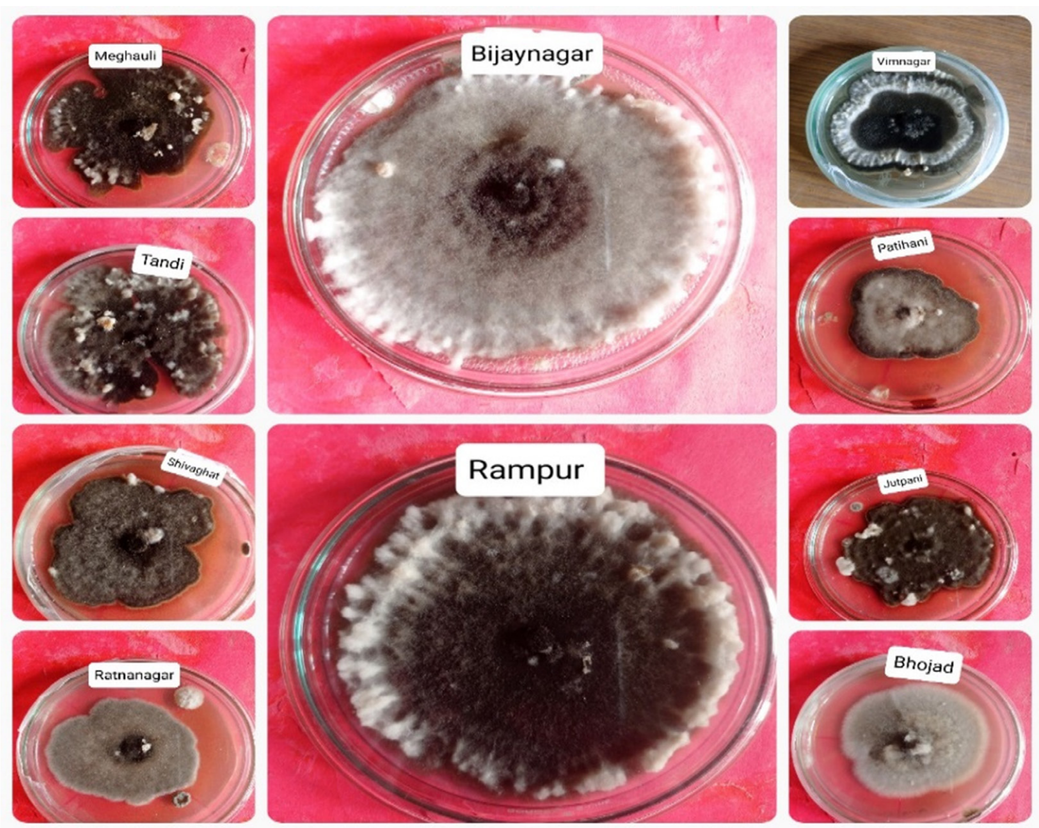


Figure 3. Cultural characteristics of *B. sorokiniana* of ten different places at Chitwan on 2023

3.3 Radial mycelium growth

A significant difference in the growth rate of different isolates of *B. sorokiniana* (Figure 4). The highest growth rate was observed in the Rampur isolate (1.62 cm) on the first day of culture. But from the second day highest mycelial growth was observed in the Bijaynagar isolate (2.82 cm), reaching 8.62 cm on the eighth day. The lowest growth on all days was observed in the Bhimnagar isolate, which achieved only 5.32 cm on the eighth day.

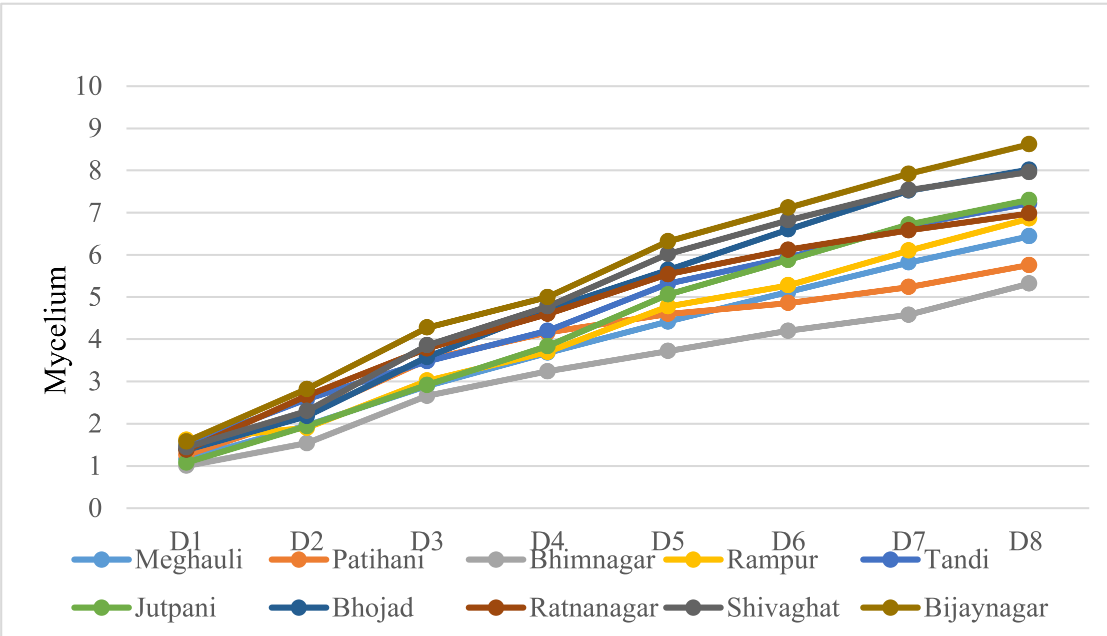


Figure 4. Radial mycelium growth of *B. sorokiniana* isolated from different location of Chitwan, 2023

3.4 Bioassay of botanicals against *Bipolaris sorokiniana*

The effectiveness of botanicals in inhibiting the mycelial growth of *B. sorokiniana* varied significantly. Garlic clove extract showed the highest inhibition percentage (63.22%) which was at par with neem (61.15%) and mehendi (57.93%) as shown in table 6. Garlic's efficacy can be attributed to allicin, which disintegrates cytoplasmic components and collapses fungal hyphae at a concentration of 15%, garlic clove extract completely inhibited mycelial growth (Figure 5).

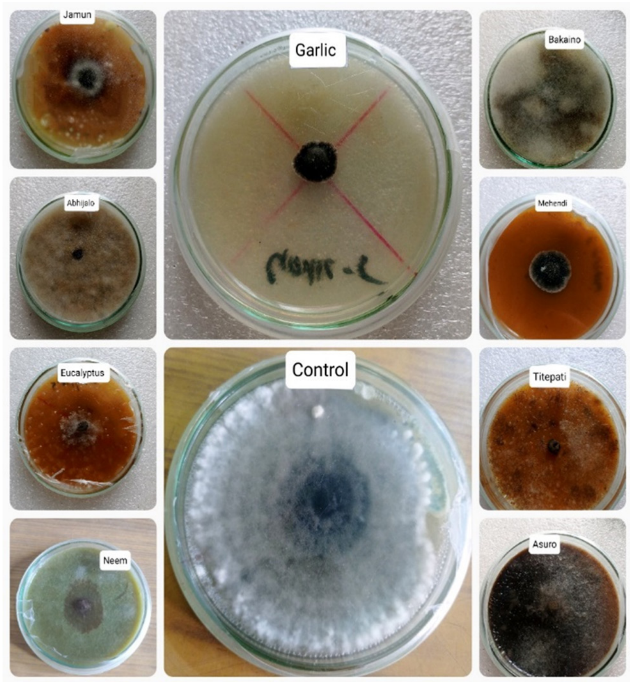


Figure 5. Radial mycelium growth of *B. sorokiniana* on PDA media containing different botanical extracts

Table 6. Effect of botanical extracts on percentage growth inhibition of the *Bipolaris sorokiniana* under the *in-vitro* conditions, 2023

Botanical extracts/Concentration	Percentage growth inhibition over control
Asuro	8.28^{d} (17.67)
Abhijalo	11.03^{d} (18.47)
Bakaino	2.07^{d} (12.21)
Eucalyptus	47.82^{b} (43.55)
Garlic	63.22^{a} (52.66)
Jamun	27.36^{c} (30.89)
Mehendi	57.93^{ab} (49.53)
Neem	61.15^{ab} (51.37)
Titepati	5.29^{d} (13.09)
Grand Mean	32.16
F value	***
LSD	8.36
CV (%)	20.28

Note: CV: Coefficient of variation, LSD: Least significant differences, mean followed by same letter in the column are not significantly different by Duncan's Multiple Range Test. *** significant at 0.1% $p<0.001$.

4. DISCUSSION

The field survey revealed significant variability in spot blotch severity across the surveyed locations, with Bijaynagar exhibiting the highest disease severity in terms of spot number, spot area and disease scoring. In Bijayanagar, local genotype of wheat was sown in a particular field and was at the maturity stage, this genotype might be susceptible to spot blotch. While lower spot blotch severity was observed in Bhimnagar, where variety Vijaya was sown in the field and was at the dough stage. However, varieties sown in other locations were unknown. The variations in spot blotch severity might be attributed to differences in local environmental conditions, such as temperature, humidity, and crop management practices, such as the use of resistant or susceptible varieties. Previous studies have demonstrated that warmer temperatures and high relative humidity favor the proliferation and spread of *B. sorokiniana* (Duveiller et al., 2005). This observation is in line with earlier studies that have reported increased disease susceptibility as the crop approaches physiological maturity (Duveiller et al., 2005). Hooi et al. (2023) and Chakraborty et al. (2024) identified host-pathogen interactions as major determinants of disease development in wheat-*B. sorokiniana* interactions. According to Bock et al. (2010), spot length and breadth are crucial indicators of disease severity as they reflect pathogen virulence and host susceptibility. The observed variability in spot dimensions suggests differences in pathogen aggressiveness across locations.

The isolates of *B. sorokiniana* exhibited notable variability in conidial morphology and cultural characteristics. Bhimnagar isolates had the longest conidia, while Bijaynagar isolates had the shortest. Such differences may indicate genetic diversity within *B. sorokiniana* populations. Variations in cultural traits like colony texture and color are consistent with findings by Devi et al. (2021), who observed colony color of dark brown to black and highlighted morphological diversity among *B. sorokiniana* isolates. Similarly, Mahto et al. (2012) have reported the similar observation of morphological variation among 48 isolates of Nepal and then grouped them into three categories (dark grey, light grey and white). Devi et al. (2021) also reported twelve different morphological groups of *B. sorokiniana* with conidial dimensions ranging from 125 to72 µm x 57 to25 µm (length x breadth). Singh et al (2021) and Aminuzzaman and Hossain (2005) also observed the color of pure culture to be light brown to deep brown. Significant differences in radial mycelial growth among isolates were observed highlighting the pathogenic variability of *B. sorokiniana*. The rapid growth observed in the Bijaynagar isolate might indicate a highly virulent strain. Growth trends observed over the incubation period are consistent with reports by Biswas & Das (2018) and Singh et al. (2021). The isolates having high growth rates show relatively high percent disease indices (PDIs) under controlled conditions. The rapid growth rate of *B. sorokiniana* enables them to invade host cell fast, accelerating infection and resulting in greater disease (Chakraborty et al., 2024).

The bioassay demonstrated the remarkable efficacy of garlic clove extract in inhibiting the growth of *B. sorokiniana*. This aligns with the findings of Magar et al. (2020). They observed that the highest mycelial growth inhibition percentage was recorded with the application of garlic clove extract (52.85%) at 15% concentration. The result is attributed to the inhibitory action of allicin, a compound with antifungal properties. The ability of garlic to disintegrate fungal cytoplasmic structures and cell walls underscores its potential as an eco-friendly alternative to chemical fungicides (Aala et al., 2014; Karnwal & Malik, 2024). Neem, eucalyptus, and mehendi extracts also exhibited inhibitory effects, although less potent than garlic, suggesting their supplementary role in integrated disease management strategies.

5. CONCLUSION

The study revealed significant variability in the occurrence, morphology, and cultural characteristics of *Bipolaris sorokiniana* isolated from different locations of Chitwan. Isolate Bijaynagar exhibited the highest disease severity, spot number, and radial mycelial growth, emerging as an important source for spot blotch infection. Morphological observations exhibited variation in conidial size and cultural characteristics of *B. sorokiniana*. Among the botanicals tested, garlic clove extract demonstrated the highest antifungal efficacy, providing a sustainable alternative for disease management.

DECLARATION

The authors declare no conflict of interests.

6. REFERENCES

Aala, F., Yusuf, U. K., Nulit, R., & Rezaie, S. (2014). Inhibitory effect of allicin and garlic extracts on growth of cultured hyphae. *Iranian Journal of Basic Medical Sciences, 17*(3), 150.

Al-Sadi, A. M. (2021). *Bipolaris sorokiniana*-induced black point, common root rot, and spot blotch diseases of wheat: A review. *Frontiers in cellular and infection microbiology, 11*, 584899.

Aminuzzaman, F. M., & Hossain, I. (2005). Pathotype variation of *Bipolaris sorokiniana* on wheat. *Bangladesh Journal of Plant Pathology, 21*(1/2), 81–88.

Basak, P., Gurjar, M. S., Kashyap, N., Kumar, T. P. J., Khokhar, M. K., Jha, S., & Saharan, M. S. (2024). Morphological, pathogenic and molecular analysis of Bipolaris sorokiniana inciting spot blotch of barley in India. *Indian Phytopathology*, *77*(1), 93-102.

Basnet, R., Shrestha, S. M., & Bhandari, D. (2022). Field based assessment of spot blotch (*Bipolaris Sorokiniana*) disease of wheat (*Triticum aestivum* L.). *International Journal of Research and Review, 9*(8), 872–879. https://doi.org/10.52403/ijrr.20220876

Biswas, A., & Das, S. (2018). Morphological characterization of *Bipolaris sorokiniana* infecting. *International Journal of Current Microbiology and Applied Sciences, 7*(08), 225–248. https://doi.org/10.20546/ijcmas.2018.708.029

Bock, C. H., Poole, G. H., Parker, P. E., & Gottwald, T. R. (2010). Plant disease severity estimated visually, by digital photography and image analysis, and by hyperspectral imaging. *Critical reviews in plant sciences, 29*(2), 59-107.

Chakraborty, S., Mahapatra, S., Hooi, A., Bhushan, B. T., Almansour, M. I., Ansari, M. J., & Hossain, A. (2024). Survey, isolation and characterization of *Bipolaris sorokiniana* (Shoem.) causing spot blotch disease in wheat under the climatic conditions of the Indo–Gangetic plains of India. Heliyon.

Devi, H. M., Das, T., Das, S., & Mahapatra, S. (2021). Variability among *Bipolaris sorokiniana* isolates of wheat from north-eastern plain zones of India. *Journal of Crop and Weed, 17*(3), 118-129.

Duveiller, E., & Altamirano, I. G. (2000). Pathogenicity of *Bipolaris sorokiniana* isolates from wheat roots, leaves and grains in Mexico. *Plant Pathology, 49*(2), 235–242. https://doi.org/10.1046/j.1365-3059.2000.00443.x

Duveiller, E., Kandel, Y. R., Sharma, R. C., & Shrestha, S. M. (2005). Epidemiology of foliar blights (spot blotch and tan spot) of wheat in the plains bordering the Himalayas. *Phytopathology, 95*(3), 248–256. https://doi.org/10.1094/PHYTO-95-0248

Gupta, P. K., Chand, R., Vasistha, N. K., Pandey, S. P., Kumar, U., Mishra, V. K., & Joshi, A. K. (2018). Spot blotch disease of wheat: the current status of research on genetics and breeding. *Plant Pathology, 67*(3), 508–531. https://doi.org/10.1111/ppa.12781

Hooi, A., Mahapatra, S., Chakraborty, S., Mukherjee, D., & Maji, A. (2023). Disease scenario and virulence pattern of major wheat pathogens occurring in indo-gangetic plains of West Bengal, India. *Indian Journal of Ecology, 50*(6), 2088-2095.

Karnwal, A., & Malik, T. (2024). Exploring the untapped potential of naturally occurring antimicrobial compounds: novel advancements in food preservation for enhanced safety and sustainability. *Frontiers in Sustainable Food Systems, 8*, 1307210.

Magar, P. B., Baidya, S., Koju, R., & Adhikary, S. In-vitro evaluation of botanicals and fungicides against *Bipolaris Sorokiniana*, causing spot blotch of wheat. *Journal of Agriculture and Natural Resources, 3*(2), 296-305.

Mahto, B. N., Gurung, S., Nepal, A., & Adhikari, T. B. (2012). Morphological, pathological and genetic variations among isolates of *Cochliobolus sativus* from Nepal. *European Journal of Plant Pathology, 133*, 405–417.

Manandhar, H. K., Timila, R. D., Sharma, S., Joshi, S., Manandhar, S., Gurung, S. B., Sthapit, S., Palikhey, E., Pandey, A., Joshi, B., Manandhar, G., Gauchan, D., Jarvis, D. I., & Sthapit, B. R. (2016). *A field guide for identification and scoring methods of diseases in the mountain crops of Nepal.* In Bioversity International.

MoALD, 2024. (2024). Statistical Information on Nepalese Agriculture (2077/78). Publicatons of the Nepal in Data Portal, 73, 274.

Saari, E., & Prescott, J. M. (1975). A scale for appraising the foliar intensity of wheat diseases. *In Plant Disease Reporter 59(*5), 377-380.

Singh, R., Singh, R. V., Mishra, L. K., & Chauhan, A. (2021). Analysis of cultural and pathogenic diversity in *Bipolaris sorokiniana* causing spot blotch of bread wheat in north India. *International Research Journal of Pure and Applied Chemistry, 22*(4), 12-22.

Tembo, B., Sibiya, J., & Tongoona, P. (2018). Genetic variability among wheat (*Triticum aestivum* L.) germplasm for resistance to spot blotch disease. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 119*(1), 85–93.

https://doi.org/10.3126/adj.v18i1.82087

EFFECTS OF DIFFERENT TILLAGE AND NITROGEN MANAGEMENT PRACTICES ON MAIZE YIELD PARAMETERS, AND SOIL PROPERTIES IN MID HILLS OF NEPAL

Pushpa Pandey[1], Aakriti Khatri[1], Akangksha Lamichhane[1], Ram Kumar Shrestha[1] and Dipak Khanal[1]

[1] Institute of Agriculture and Animal Science, Tribhuvan University, Nepal

ABSTRACT

A field experiment was conducted in March 2022 at Lamjung Campus, Sundarbazar, Nepal, to study the effects of tillage and nitrogen management practices on soil properties, yield, and yield attributes of the Posilo Makai-1 variety of maize. Two tillage systems (ZT-zero tillage and CT-conventional tillage) and four nitrogen management approaches (N1-traditional farmer's practice, N2-recommended dose of NPK fertilizer (RDF), N3-50% RDN from urea+50% from FYM (farmyard manure) + recommended dose of phosphorous and potassium, and N4-leaf color chart (LCC)-based application of nitrogen + recommended dose of phosphorus and potassium) as main-plot and sub-plot factors were replicated thrice in a split-plot design. Research results revealed that nitrogen management practices significantly affected yield attributes and yield of the maize. LCC-based nitrogen application produced the highest cob length (15.2 cm), cob diameter (40.70 cm), grains per row (29.7), ear weight (89.0 g), grains per cob (420.03), 100-grain weight (20.70 g), and grain yield (4913.89 kg/ha), while the lowest values for yield attributes and yield were reported from farmer's practice with the lowest yield (3227.47 kg/ha). Although statistically similar, LCC-managed plots had higher residual soil nitrogen (0.15%), organic matter (2.83%), soil available phosphorus (11.97 kg/ha), and available potassium (142.44 kg/ha), with reduced soil acidity (pH 5.35). However, tillage systems showed no statistically significant effect on yield parameters, yield, and soil parameters. These findings suggest that LCC-based nitrogen management could be a better practice for sustainable soil management and resource conservation in the long run.

Keywords:

LCC, Nutrient management, Soil properties, Tillage, Yield

INTRODUCTION

Maize is one of the most important cereal crops in the world, ranking first in productivity (5872.8 kg/ha), followed by rice (4744.4 kg/ha) and wheat (3505.9 kg/ha) (FAOSTAT, 2021). In Nepal, maize is the second most cultivated cereal after rice, with an average national productivity of 3.06 tons/ha (MoALD, 2022). It is used extensively for food, feed, and industrial purposes (Goodla et al., 2012). Nearly two-thirds of Nepal's total maize production comes from the mid-

* Corresponding author Email: dreampuspa33@gmail.com

hill regions, where farming is predominantly maize-based (Devkota et al., 2015). However, existing soil and nutrient management practices fall short of realizing the potential yield of maize, resulting in a substantial yield gap of 2.9 t/ha (Basukala & Rasche, 2022). Addressing this gap requires sustainable soil and nutrient management practices tailored to the region's complex topography, soil constraints, and limited resource access (Devkota et al., 2015).

The conventional tillage system governs the tillage practices in maize cropping in mid-hills, including the use of animal ploughs, mini-tractors, or tractors for primary tillage operations (Bajaracharya, 2001). These intensive practices disrupt soil structure, increase nitrogen losses, and deteriorate the soil quality, ultimately affecting maize yields (Atreya et al., 2006). Since tillage practices influence nutrient dynamics through runoff, erosion, and leaching and affect the crop yield, adoption of sustainable tillage methods that promise minimal soil disturbance is essential to optimize maize productivity (Sharma et al.,2021). In this regard, conservation tillage, which involves multiple tillage operations, including zero and minimum tillage, might be a potential measure to reduce soil structure deterioration, minimize nutrient losses, and increase maize yields (Atreya et al., 2006; Khan et al., 2021).

Besides tillage practices, nitrogen (N) management is another critical factor limiting maize productivity (Thapa, 2021). Most of the farmers in the mid-hills of Nepal often apply urea and FYM without regard to crop demand or optimal timing (Vista et al., 2022), leading to nutrient losses and degradation of soil quality through leaching losses, volatilization losses, and reduced nitrogen use efficiency (Khadka, 2017). Minimizing such nutrient loss problems is a challenge for effective soil and plant nitrogen management. The concept of demand-based nutrient management is arising at present, where plants or soil are assessed for the amount and application timing of fertilizers. Demand-based N management strategies, such as the use of a Leaf Color Chart (LCC), can help synchronize fertilizer application with crop needs, thereby minimizing nitrogen losses and improving crop yields (Ladha et al., 2007). This budget-friendly, low-cost decision-making tool might be an efficient technology for many small-scale farmers of Nepal for N-management in cereal crops, including maize. Despite its cost-effectiveness and ease of use, the effectiveness of LCC as a tool to manage nitrogen and increase crop yield remains under-researched in Nepalese maize-based farming systems.

This study, thus, addresses a critical knowledge gap by experimentally evaluating the combined effects of tillage and nitrogen management practices on maize yield performance and soil nutrient status under mid-hill conditions in Nepal. The primary objective was to assess whether resource-conserving approaches specifically, zero tillage and real-time nitrogen application using the Leaf Color Chart (LCC) could enhance yield attributes, improve crop productivity of maize, and maintain soil fertility. It was hypothesized that the integration of zero tillage with LCC-based nitrogen management would result in significantly higher maize yields and improved soil nutrient status compared to conventional tillage and traditional nitrogen application methods. Findings from this research may provide accessible, low-cost solutions for smallholder farmers in Nepal's mid-hills, supporting more sustainable and efficient maize production systems.

MATERIALS AND METHODS

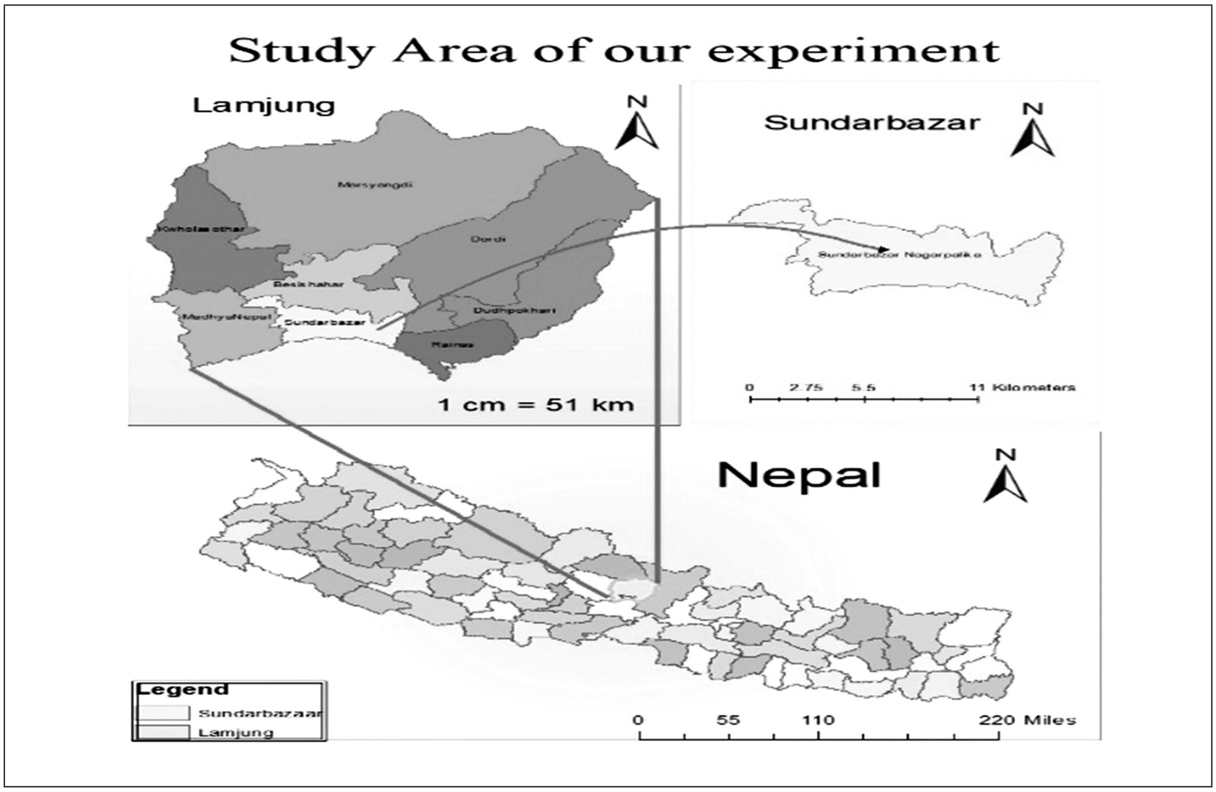


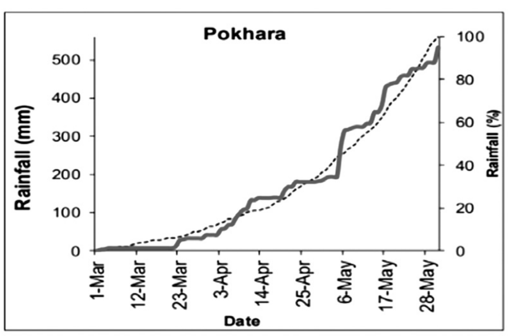
Figure 1: Map showing the experimental site.

Description of the experimental site

The experiment was carried out from March 2022 to July 2022 in the field of Lamjung Campus, Sundarbazar municipality, Lamjung district of Nepal. The site represents the mid-hill region and is situated at 28⁰ 7' N latitude and 84⁰ 25' E longitude and at an elevation of 857 masl (Figure 1). The mid-hill agro-ecological zone of Nepal ranges from approximately 600 to 1800 masl (NARC). Laboratory work was conducted in the Soil and Fertilizer testing laboratory, Kaski.

Details of climate and soil properties

The mean rainfall of the nearest meteorological station (Kaski) during the experimental months is shown in the figure 2:



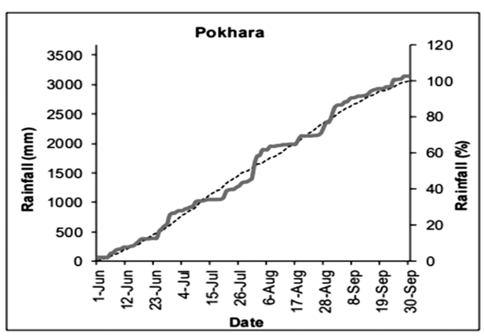


Figure 2: Mean rainfall(mm) in Pokhara during experimental months of 2022
Source: DHM reports,2022

(- - - -): Daily accumulated normal precipitation during the Pre-Monsoon (March to May) and Monsoon Season (June to September)

(**------**): Daily accumulated precipitation of the Pre-Monsoon and Monsoon Seasons of the experimental year 2022.

The soil characteristics of the field before conducting the study is given below in the table 1.

Table 1: Soil characteristics before sowing

pH	OM (%)	Total N (%)	P_2O_5(kg/ha)	K_2O(kg/ha)	Soil texture
6.7	4.49	0.22	17.06	204	Clay loam

Experimental design and treatments

A two-factor factorial experiment in a split-plot design with three replications was carried out, in which **tillage** was the main plot factor and **nitrogen management** was the subplot factor. The main plot factor consisted of two treatment levels: zero tillage (ZT) and conventional tillage (CT). Conventional tillage followed farmers' practice of tilling the soil to a depth of 15–20 cm using a hand tractor, while zero tillage involved surface seeding of maize without disturbing the soil.

The subplot factor included four nitrogen management treatments: **(N1)** Farmer's practice, **(N2)** Recommended dose of fertilizers (RDF)**, (N3)** 50% Recommended dose of Nitrogen (RDN) through urea + 50% RDN through farmyard manure (FYM)+ Recommended dose of Phosphorous and Potassium**,** and **(N4)** Leaf Color Chart (LCC)-based nitrogen management+Recommended dose of Phosphorous and Potassium.

In N1, the farmer's practice involved applying FYM at 7 kg per plot (equivalent to approximately 13.67 tons/ha), along with DAP (67 g per plot/ 130.43kg/ha) before sowing and applying the full dose of urea (80 g per plot/15.63kg/ha) at the time of first weeding or 25 DAS.

For N2 (RDF), the recommended dose of fertilizer 120:60:40 kg/ha $N:P_2O_5:K_2O$ with 10 tons/ha FYM was used. Based on the 5.12 m^2 plot size, each plot received approximately 134 g of urea (~260.87 kg/ha), 67 g of DAP (~130.43 kg/ha), and 34 g of MOP (~66.67 kg/ha). The full amount of DAP and MOP, along with half of the total urea (~67 g), was applied as a basal dose during sowing. The remaining half of urea (~67 g) was top-dressed at around 25–30 DAS, to meet the plant's peak nitrogen demand. Notably, the fertilizer treatments did not include micronutrients like zinc and boron. Their omission may limit potential yield and soil enrichment, especially in micronutrient-deficient soils. Future studies should incorporate these elements to ensure more comprehensive nutrient management. In N3, 60 kg/ha of nitrogen was supplied through urea (~67 g per plot), while the remaining 60 kg N/ha was supplemented using well-decomposed FYM at 20 tons/ha (equivalent to ~14 kg/plot). Phosphorus and potassium sources (DAP and MOP) were supplied in amounts similar to the RDF treatment.

In N4, nitrogen was managed using a six-panel Leaf Color Chart (LCC) following ICAR guidelines, allowing real-time, demand-based urea application. Phosphorus and potassium sources (DAP and MOP) were supplied in amounts similar to the RDF treatment.

There were 24 experimental units, each with a plot size of 5.12 m² (3.2 m × 1.6 m). A spacing of 1 m was maintained between blocks and 0.5 m between plots. Row-to-row and plant-to-plant spacing were maintained at 75 cm and 25 cm, respectively.

Variety of maize

Posilo makai-1 variety of maize was selected since it is a recommended variety for mid-hill regions of Nepal.

Agronomic practices.

In all experiment plots, two seeds per hill were planted and thinned to a single plant per hill after the first weeding. The recommended dose of fertilizer is 120:60:40 kg/ha N: P_2O_5:K_2O respectively. All the adjustments regarding the treatment combinations were done accordingly. Cultivation practices were carried out as recommended by the National Maize Research Program, Rampur, Chitwan. Two hand-weeding was carried out at 25 DAS and 45 DAS respectively.

Data collection

Various agronomic data were recorded from five random sample plants per plot to analyze yield and yield attributing characters. Pre-crop soil samples were collected from soil depth 0-20cm and analyzed for soil physical, and chemical properties one month prior to land preparation. Post-crop soil samples from soil depths 0-20 cm were taken from 24 experimental units and analyzed for soil physical and chemical properties.

Data Analysis

Data collected was tabulated in MS Excel and analyzed using R-studio software at a 5% level of significance.

The following parameters were observed and recorded during the study period (Table 2):

Table 2: Observed yield and soil parameters

	Observed Parameters	**Method**
YIELD PARAMETERS	Grains/row	Manual Counting
	No. of grains/cob	Manual Counting
	Cob length	Measuring scale
	Cob diameter	Vernier calipers
	Ear weight	Weighing balance
SOIL PARAMETRS	Residual Soil OM	Walkley-Black method
	Residual Total Soil N	Kjeldahl Distillation method
	pH	pH Meter
	Residual soil P_2O_5	Modified Olsen's bicarbonate method
	Residual Soil K_2O	Using Flame Photometer

Grain yield is calculated using the formula=

[Grain Weight×10×(100 – Moisture content)]/ [(100 − Adjusted moisture content) × Plot Area)]

RESULT AND DISCUSSION

Effect of nitrogen management and tillage methods on soil properties

Post-harvest laboratory analysis of soil samples revealed that plots managed with LCC-based nitrogen management (N4) had no significant influence on soil parameters i.e. residual soil total, organic matter, available phosphorus, available potassium, and soil pH, although consistently reported the highest values for residual soil total N (0.146%), organic matter (OM; 2.83%), available phosphorus (P_2O_5; 11.97 kg/ha), and available potassium (K_2O; 142.44 kg/ha), along with the highest soil pH (5.35). Conversely, plots under farmers' practice (N1) reported the lowest values across all these parameters, with soil pH value at 4.92. Krishnakumar and Haefele (2013) reported similar results of soil parameters with use of LCC in irrigated transplanted rice. The higher residual N in LCC-managed plots could be attributed to demand-based fertilizer application, reducing nitrogen losses through leaching and volatilization. This increase in residual nitrogen content likely contributed to improved OM levels, as the C:N ratio in soil remains relatively stable (~10:1), and greater N availability enhances microbial decomposition of organic residues (Brady and Weil, 2008).

Although not statistically significant, conventional tillage (CT) showed slightly higher soil nutrient values than zero tillage (ZT), likely due to better initial mixing of fertilizers and improved nutrient availability in the short term. However, this advantage may diminish or reverse over multiple seasons, as zero tillage has been associated with gradual improvements in soil structure, organic matter buildup, and moisture retention, which collectively enhance soil health and long-term productivity (Bhattacharyya et al.,2012). Additionally, the short duration of the experiment (one season) may not have been sufficient to capture the long-term benefits of zero tillage, which often manifest over time through improved soil structure and moisture conservation, as noted by Bhattacharyya et al. (2012). Similar findings were reported by Bhattarai et al. (2016) in the western mid-hills of Nepal and Sharma et al. (2021) in the eastern hill region, both observing enhanced organic matter and nutrient conservation over multiple cropping seasons under conservation tillage systems.

Table 3: Effect of tillage and nitrogen management treatments on soil properties at Lamjung campus, Sundarbazar in 2022

Treatment	pH	Residual Soil N (%)	Residual SOM (%)	Residual Soil P_2O_5 (kg/ha)	Residual Soil K_2O(kg/ha)
Tillage treatments					
ZT	5.01	0.129	2.49	9.71	127.54
CT	5.22	0.135	2.60	10.09	128.63
LSD	NS	NS	NS	NS	NS
N treatments					
Farmers practice (N1)	4.92	0.126	2.43	7.81	119.05
RDF (N2)	5.08	0.127	2.45	11.18	129.13
½ RDN + ½ FYM (N3)	5.11	0.129	2.48	8.64	121.71
LCC (N4)	5.35	0.146	2.83	11.97	142.44
LSD	NS	NS	NS	NS	NS

Effect of nitrogen management and tillage methods on grain yield and yield attributes of maize

1.Cob length, cob diameter, and ear weight

Significant effects ($p < 0.05$) of nitrogen management were observed on cob length, cob diameter, and ear weight, with the highest values recorded in LCC-based N management (N4) and the lowest in farmer's practice (N1). Tillage did not show a significant impact on these parameters (Table 4). Enhanced nitrogen availability under LCC likely improved nutrient uptake and increased nutrient assimilation ,with increased supply of photosynthates for cob development and biomass (Morales et al.,2000). These results agree with those of Sapkota et al. (2020), who also observed increased cob traits in maize using LCC under similar hill environments.

2.Grains row^{-1}, Grains cob^{-1}, and 100-grain weight

LCC based nitrogen management (N4) also led to significantly higher grains row^{-1} and grains cob^{-1} compared to other nitrogen management treatments, whereas 100-grain weight did not differ significantly among treatments (Table 4). Likewise, tillage had no significant effect on 100-grain weight, grains row^{-1} and, grains cob^{-1} The lack of tillage effect on these traits suggests that short-term tillage variations may not be sufficient to influence reproductive growth in maize.

Table 4: Effect of tillage and nitrogen management treatments on yield attributes of maize at Lamjung campus, Sundarbazar in 2022

Treatment	Grains / row	Grains / cob	Cob length(cm)	Cob diameter(mm)	100- grain weight	Ear weight (gm)
Tillage treatments						
ZT	25.26	357.77	13.28	37.91	18.96	69.91
CT	26.61	371.64	14.23	37.59	19.25	67.99
LSD	NS	NS	NS	NS	NS	NS
N treatments						
Farmers practice (N1)	22.25^{c}	320.65	12.61^{b}	36.31^{b}	17.91	56.07^{b}
RDF (N2)	26.82^{ab}	361.02	14.13^{ab}	37.70^{b}	20.71	72.21^{ab}
½ RDN + ½ FYM (N3)	24.98^{bc}	357.12	13.05^{b}	36.29^{b}	17.08	58.50^{b}
LCC (N4)	29.70^{a}	420.03	15.22^{a}	40.70^{a}	20.70	89.02^{a}
LSD	4.47	NS	2.97	2.81	NS	27.72
p-value	0.022	NS	0.028	0.016	NS	0.012

NS= non-significant

3. Grain yield

Grain yield was significantly influenced by nitrogen management but not by tillage. The highest grain yield (4913.89 kg/ha) was obtained from LCC-based nitrogen managed plots, which was significantly higher than other nitrogen treatments (Table 5). This can be attributed to improved synchronization of nitrogen supply with plant demand, leading to enhanced grain formation and filling. The yield superiority of LCC over RDF, FYM, and farmer's practice aligns with earlier studies in similar agro-ecological settings (Bashyal et al., 2020; Gautam et al., 2022). In line with our findings, Kharel et al. (2019) reported a 25–30% yield advantage under LCC-based management in mid-hill maize compared to traditional urea broadcasting.

Although LCC (N4) showed the highest performance in grain yield and yield attributing parameters, RDF (N2) also performed well, with yield and yield attributes statistically similar to N4 for several traits such as cob length and ear weight. This suggests RDF could be a practical option where LCC use is limited due to labor or knowledge constraints. Additionally, the N3 treatment (½ RDN + ½ FYM) showed promising result in maintaining soil organic matter, likely due to the gradual nutrient release from FYM. Its benefits might become more evident in long-term trials, as organic inputs typically take time to fully integrate into soil nutrient cycles.

Table 5: Effect of tillage and nitrogen management treatments on grain yield of maize at Lamjung Campus, Sundarbazar in 2022

Treatment	**Grain yield(kg/ha)**
Tillage treatments	
ZT	3905.91
CT	4053.6
LSD	NS
N treatments	
Farmers practice (N1)	3227.47^{b}
RDF (N2)	4363.86^{ab}
½ RDN + ½ FYM (N3)	3413.8^{b}
LCC (N4)	4913.8^{a}
LSD	1164.9
p-value	0.025

CONCLUSION

In conclusion, LCC-based nitrogen management significantly improved yield-attributing characters and grain yield of maize over other nitrogen management treatments. Significant effects on soil parameters were not reported. Also, yield attributes, grain yield, and soil parameters did not vary significantly among different tillage practices. Thus, the research results revealed the potentiality of incorporating LCC-based nitrogen management in maize over farmers' practice to increase its productivity, which assists in synchronizing nitrogen supply with the crop demand. RDF also demonstrated comparable results in yield traits and grain yield and could serve as a feasible option, particularly in less technology-intensive environments where frequent monitoring and decision-making required by LCC are challenging under resource-limited conditions. Moreover, the ½ RDN + ½ FYM treatment contributed positively to soil OM and could offer long-term benefits through sustained nutrient release. Although tillage effects were not statistically significant in this study, their long-term impact warrants further investigation through multi-season trials. These findings highlight practical, low-cost options for smallholder farmers and support future policy directions aiming to enhance input use efficiency and soil health in mid-hill agriculture by synchronizing N supply with crop demand. Moreover, long-term studies along with integration of zero-tillage practice and LCC-based nitrogen management in different agro-ecological belts are suggested to assess the impact of tillage and nutrient management practices on yield attributes, soil quality parameters, and grain yield of maize.

DECLARATION

The authors declare no conflict of interests.

REFERENCES

Atreya, K., Sharma, S., Bajracharya, R. M., & Rajbhandari, N. P. (2006). Applications of reduced tillage in hills of central Nepal. *Soil and tillage research*, *88*(1-2), 16-29. https://doi.org/10.1016/j.still.2005.04.003

Bajaracharya, R. M. (2001). Land preparation: an integral part of farming systems in the mid-hills of Nepal. *Nepal Journal of Science and Technology*, *3*(1).

Bashyal, S., Poudel, P. B., Magar, J. B., Dhakal, L., Chad, S., Khadka, B., & Bohara, S. L. (2020). Effect of nutrient management on two varieties (hybrid and local) of maize in western inner terai of Nepal. *International Journal of Applied Sciences and Biotechnology*, *8*(2), 191-198. https://doi.org/10.3126/ijasbt.v8i2.29586

Basukala, A. K., & Rasche, L. (2022). Model-Based Yield Gap Assessment in Nepal's Diverse Agricultural Landscape. *Land*, *11*(8). https://doi.org/10.3390/land11081355

Bhattacharyya, R., Kundu, S., Pandey, S. C., Singh, K. P., & Gupta, H. S. (2008). Tillage and irrigation effects on crop yields and soil properties under the rice–wheat system in the Indian Himalayas. *Agricultural water management*, *95*(9), 993-1002. https://doi.org/10.1016/j.agwat.2008.03.007

Bhattarai, R., Subedi, S., & Paudel, M. N. (2016). Effects of conservation tillage on soil quality indicators in mid-hill maize systems. *Nepalese Journal of Agricultural Sciences*, *14*, 95–103.

Brady, N. C., & Weil, R. R. (2008). *The nature and properties of soils* (13th ed., pp. 662–710). Prentice Hall.

Devkota, K. P., McDonald, A. J., Khadka, A., Khadka, L., Paudel, G., & Devkota, M. (2015). Decomposing maize yield gaps differentiates entry points for intensification in the rainfed mid-hills of Nepal. *Field Crops Research*, *179*, 81-94. https://doi.org/10.1016/j.fcr.2015.04.013

Gautam, S., Tiwari, U., Sapkota, B., Sharma, B., Parajuli, S., Pandit, N. R., ... & Dhakal, K. (2022). Field evaluation of slow-release nitrogen fertilizers and real-time nitrogen management tools to improve grain yield and nitrogen use efficiency of spring maize in Nepal. *Heliyon*, *8*(6). https://doi.org/10.1016/j.heliyon.2022.e09566

Goodla, L., Reddy, E., & Panda, A. (2012). Maize Production and its Utilization as Food, Feed and Biofuel. In *Maize in Poultry Nutrition* (Chapter 6). Project Directorate on Poultry, National Agricultural Innovation Project.

Khadka, J. (2017). Best Practices of Integrated Plant Nutrition System in Nepal. *Best Practices of Integrated Plant Nutrition System in SAARC Countries*, 92.

Khan, N. U., Khan, A. A., Goheer, M. A., Shafique, I., Hussain, S., Hussain, S., ... & Siddiqui, M. H. (2021). Effect of zero and minimum tillage on cotton productivity and soil characteristics under different nitrogen application rates. *Sustainability*, *13*(24), 13753. https://doi.org/10.3390/su132413753

Kharel, M., Devkota, M., & Thapa, R. B. (2019). Use of leaf color chart for efficient nitrogen management in maize in mid-hills. *Journal of Maize Research and Development*, *5*(1), 77–84.

Krishnakumar, S., & Haefele, S. M. (2013). Integrated nutrient management and LCC based nitrogen management on soil fertility and yield of rice (*Oryza sativa* L.). *Scientific Research and Essays, 8*(41), 2059–2067. https://doi.org/10.5897/SRE2013.5643

Ladha, J. K., Bains, J. S., Gupta, R. K., & Balasubramanian, V. (2007). On-farm evaluation of leaf color chart for need-based nitrogen management in irrigated transplanted rice in northwestern India. *Nutrient cycling in agroecosystems*, *78*, 167-176. https://doi.org/10.1007/s10705-006-9082-2

Morales, A. C., Agustin, E. O., Lucas, M. P., Marcos, T. F., & Chlanay, D. A. (2000). Comparative efficiency of N management practices on the performance of upland rice. *Oryza*, *29*, 234–239.

Sapkota, S., Adhikari, K., & Aryal, J. P. (2020). LCC-based nitrogen management in maize: An approach towards improving NUE in hill farming systems. *Nepal Journal of Agricultural Research*, *4*(2), 45–53.

Sharma, R. P., Acharya, S., & Bhatta, M. R. (2021). Comparative evaluation of tillage and nutrient management practices in maize under eastern hills of Nepal. *Agronomy Journal of Nepal*, *9*, 17–29.

Thapa, R. (2021). A detail review on status and prospect of maize production in Nepal. *Food and Agri Economics Review*, *1*(1), 52-56.

Vista, S. P., Devkota, S., Shrestha, S., Kandel, S., Rawal, N., Amgain, R., ... & Timilsina, S. (2022). Fertilizers in Nepal. *National Agriculture Research Institute, National Soil Science Research Centre, Khumaltar, Lalitpur, Nepal*.

https://doi.org/10.3126/adj.v18i1.82088

Agriculture Development Journal, Volume 18 (2025)

GROWTH AND YIELD RESPONSE OF SPRING MAIZE TO ZINC AND BORON COMBINED WITH NPK IN BANKE DISTRICT, NEPAL

Mahendra Acharya[1, *], Swastika Chhetri[2], Padma Acharya[2] and Ravi Kiran Adhikari[3]

[1] Institute of Agriculture and Animal Science, Tribhuvan University, Kathmandu, Nepal
[2] Agriculture and Forestry University, Rampur, Chitwan, Nepal
[3] Department of Agriculture, Harihar Bhawan, Nepal

ABSTRACT

The experiment was carried out to evaluate the effect of zinc and boron along with nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) on growth and yield of spring maize in Duduwa-6, Banke from March to July 2023.The study was conducted in Randomized complete block design including 4 replications and 5 treatments: a) Farmer's practice 100:50 ($N:P_2O_5$) kgha^{-1}, b) Recommended dose 160:60:40($N:P_2O_5:K_2O$) kgha^{-1}, c) Recommended $N:P_2O_5:K_2O$ + 15kgha^{-1} zinc, d) Recommended $N:P_2O_5:K_2O$ + 2kgha^{-1} boron and e) Recommended $N:P_2O_5:K_2O$ + 15kgha^{-1} zinc + 2kgha^{-1} boron. Rampur hybrid-10 variety of maize was sown on sandy loam, neutral soil with medium in organic matter. The field data on phenology, crop growth, yield attributes, yield and economic of crop production were collected. The study revealed that grain yield of maize was significantly higher in fertilization rate of 160:60:40 ($N:P_2O_5:K_2O$) kgha^{-1}, together with the application of Zn 15kg ha^{-1} and B 2kgha^{-1}. The study has also revealed that use of micronutrients such as Zn and B is beneficial to enhance growth and yield of hybrid maize. The plant height was the highest with Recommended $N:P_2O_5:K_2O$ + Zn + B at earlier stage of crop growth but was statistically similar among different treatments at later stage of crop growth. The highest grain yield, harvest index and benefit cost ratio were recorded with the Recommended $N:P_2O_5:K_2O$ + Zn + B while these parameters were the lowest with the farmer's practice. Therefore, highest grain yield and maximum profit were obtained when fertilization rate of 160:60:40 ($N:P_2O_5:K_2O$) kg ha^{-1}, together with the application of Zn 15kgha^{-1} and B 2kgha^{-1}.

Key words:

Benefit Cost ratio, Correlation, Harvest index, Micronutrient, Randomized Complete Block Design

1. INTRODUCTION

Maize (Zea mays L.) is a cereal crop which is referred as "queen of cereals" and is a "non-tillering plant". It is an important cereal grown throughout the world for its grain and greenfodder. It is used as food for human and feed for animals. It is adopted in all the soil types (except in sandy soil) and different seasons; Kharif, Rabi, and Zaid. Being a photo insensitive crop, maize

*Corresponding author Email: mahendra.ext2024@gmail.com

is cultivated in all most all seasons and in different agro-climatic zones, with crop duration ranging from <90-130 days. In Nepal, the contribution of cereal crops to Agriculture Gross Domestic Product (AGDP) is about 49.41% whereas maize alone contribute 25.02% of total cereal production to AGDP, 6.88% in AGDP and 3.15% in GDP (Pandey & Basnet, 2018). It is second most important staple crop after rice in terms of area and production(Kandel, 2021). At present, the maize sown area in Nepal is 979,776 ha with a total production of 2,997,733 metric tons and productivity of 3.05 t ha^{-1} (MoALD, 2022). It occupies about 70% area of total cultivated area in the hills & 20.4% in terai region of Nepal (Craufurd, 2021). Hybrid maize covers about 10% of total maize production in terai and mid hills (Adhikari et al., 2018).

Plant nutrients are chemical elements and compounds necessary for plant growth and reproduction, plant metabolism and their external supply. Plant nutrients, comprising 17 essential elements, are indispensable for growth, metabolism, and reproduction, with macronutrients such as nitrogen, phosphorus, and potassium required in substantial quantities, while micronutrients like zinc and boron are necessary in minimal amounts, necessitating both adequate supply and appropriate ratios (Adnan, 2020). Nitrogen (N) is an essential macronutrient that critically influences maize yield, constituting 1-4% of plant dry matter and serving as a fundamental element of proteins and nucleic acids, with its deficiency leading to impaired growth. Its availability in sufficient quantity throughout the growing season is essential for optimum maize growth. It also mediates the utilization of phosphorus, potassium, and other elements in plants. Optimal amount of these elements in the soil cannot be utilized efficiently if nitrogen is deficient in plants. Therefore, nitrogen deficiency or excess can result in reducing maize yields (Humtsoe et al., 2018)basal application of Boron (5 kg ha-1. Yield and yield components like leaf area per plant, number of grains per cub, 1000 grain weight is found to be positively impacted by the increased dose of phosphorus in maize plant (Alias et al., 2008). Potassium plays a crucial role in maize growth and yield, particularly under drought stress conditions. Studies have shown that potassium application significantly improves various growth parameters, including plant height, leaf area index, and root development (Ali et al., 2020). The combined effect of zinc and boron has resulted in the increased plant dry weight, highest plant height, more numbers of cob per plant, numbers of seed per row, stover yield and grain yield (Sankadiya and Sanodiya, 2021).

Micronutrients play crucial role in plant growth and development. Various physiological as well as phenological activities such as Plant metabolism, nutrition management, chlorophyll synthesis, reproductive growth, flower retention, and fruit and seed development are all performed by micronutrients (Monib et al., 2023). Zinc and boron play crucial roles in maize growth, development, and yield. Zinc is involved in over 300 plant enzymes and has several important functions in plants, including major roles in enzyme reactions, photosynthesis, DNA transcription and auxin activity (Shabaz et al., 2015). Boron is vital for root development, leaf expansion, and cob formation, with deficiency leading to reduced chlorophyll content and compromised plant health (Cruz et al., 2022). Boron plays a key role in cell wall formation and stability, maintenance of structural and functional integrity of biological membranes, movement of sugar or energy into growing parts of plants, and pollination and seed set (Lordkaew et al., 2011). Zn and B play an important role in the basic plant functions like photosynthesis, protein and chlorophyll synthesis (Cakmak, 2008). These nutrients (Zn and B) are also involved in root growth, synthesis of proteins and carbohydrates, increase flower setting (Moeinian et al., 2011) and reduce kernel abortion especially (Wahid et al., 2011).

Maize crop is sensitive to zinc supply as indicated by its high content in grain, as compared to other micronutrients (Losak et al., 2011) (Maňásek et al., 2013). Deficiency of Zn in soil causes deficiency in crops and altogether this has become a problem all over the world with acute zinc deficiency ranges in arid to semi-arid regions of the world (Savithri et al., 2004). Lack of zinc (Zn) is a common micro-deficiency in arid and semiarid areas of the World. Its deficiency is common in cereals, especially in calcareous soils of arid semi-deserts. It is stated that approximately 50 % of the land used for the production of cereals in the world are deficient in Zn (Martens & Westermann, 2018). Maize has been previously considered to have a relatively low boron (B) requirement compared with other cereals (Martens & Westermann, 2018).Yield increases of more than 10% were observed in response to B application (Woodruf et al., 1987). Boron deficiencies are usually apparent on the new leaves of maize since it is during the development of new tissue that nutrients are most required (Reid et al., 2004). In B-deficient maize, poor grain-setting can result in barren cobs, and this was attributed by to the silks being non-receptive (Lordkaew et al., 2011). Boron deficiency inhibits root elongation through limiting of cell enlargement and cell division in the growth zone of root tips and that in severe boron deficiency cases, root growth ceases due to the death of root tips (Dell & Huang, 1997).

Though the role of micronutrients, like Zn and B, application in improving maize performance is well documented; however very little is known about the effect of combined application of B and Zn through different methods on maize performance and growth (Aref, 2011). The objective of the study is to evaluate and analyze the production performance of Rampur Hybrid 10 variety of maize under different nutrition application combining Zinc and Boron with NPK.

2.MATERIALS AND METHOD

2.1 SITE DESCRIPTION

The experiment was conducted at the Hirminiya village, ward no. 6, of Duduwa Rural Municipality of Banke district of Nepal from March to July 2023.The experimental site was selected in western Nepal, Lumbini province, and 8 km south from Nepalgunj Sub-Metropolitan city. Geographically, it is located at 28.0 N 81.65 E and at an altitude of 147 meter above sea level. The site was selected because, PMAMP Maize Zone covers different ward of Duduwa Rural Municipality. It is also the zone of maize and has huge number of commercial maize growers. The soil was sandy loam textured with pH slightly acidic to neutral with low OM and nitrogen content, medium to high phosphorous, low to neutral potassium and negligible amount of Zinc and Boron according to the standard rating of Directorate of Soil Management, Ministry of Agricultural Development, Government of Nepal, Khajura, Banke, Nepal (Table 1).

Table 1: Physio-chemical properties of the soil of experimental site during 2023.

S.N.	Properties	Status of soil properties	Rating	Methods and References
1.	Physical properties			Hydrometer
	Sand (%)	64.3	Sandy Loam	(Estefan, Sommer &
	Silt (%)	26.7		Ryan, 2014)
	Clay (%)	9.0		
2.	Chemical properties	15-30 Cm	Rating	Methods and References (Estefan et al., 2014)
	Soil pH	7.6	Alkaline	Beekman Glass Electrode pH meter
	Soil organic matter (%)	1.03	Low	Walkey and Black
	Total nitrogen (%)	0.05	Low	Micro Kjeldhal Distilation
	Available phosphorus (Kg/ha)	615.0	High	Modified Olsen's Method
	Available potassium (kg/ha)	21.2	Low	Ammonium Acetate Method

The area has sub-humid type of weather condition with cool winter, hot summer, and distinct rainy season with annual rainfall 1912mm per year (DHM Banke, 2022). The weather data during the cropping season was recorded from metrological station of the Department of Hydrology and Meteorology (DHM) Khajura, Banke (Figure 1).

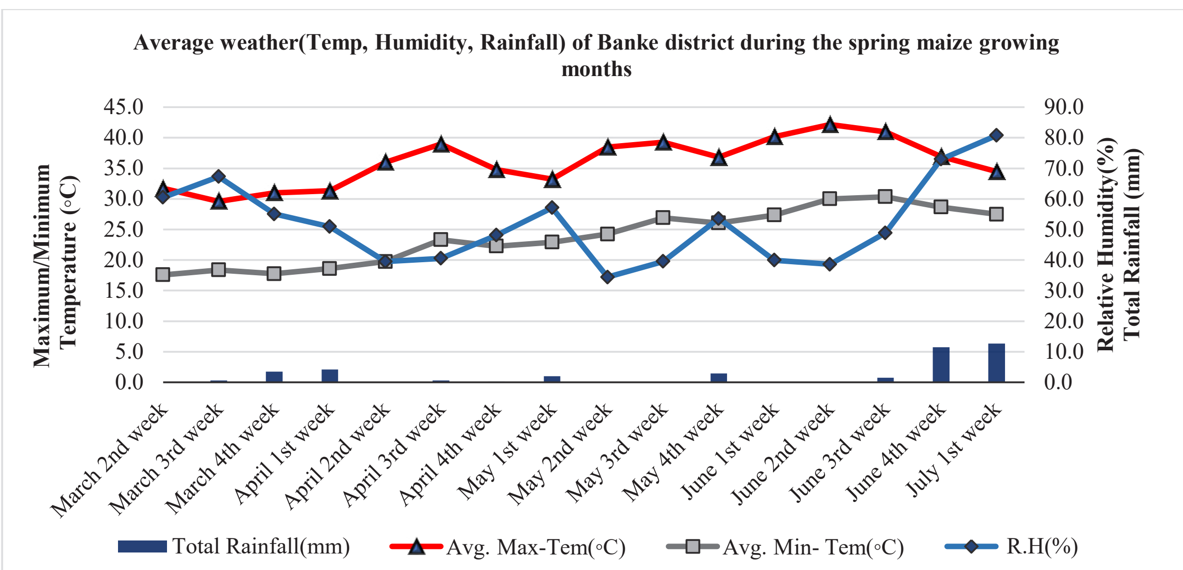


Figure 1. Weekly average maximum and minimum temperature (ºC), average relative humidity (%), weekly total rainfall (mm) during spring at Khajura, Banke, Nepal

2.2 EXPERIMENTAL DESIGN AND TREATMENT

The experiment was laid out in Randomized Complete Block Design (RCBD) with five different macro and micro nutrient fertilizers as treatments with four replications. The five different treatments comprise of (A) 100 kg N ha^{-1} and 50 Kg P_2O_5 ha^{-1} as Farmers' practice (B) 100% recommended dose (160 kg N ha^{-1},60 kg P_2O_5 ha^{-1} ,40 kg K_2O ha^{-1}, (C) recommended dose of 160 kg N ha^{-1},60 kg P_2O_5 ha^{-1} ,40 kg of K_2O ha^{-1} with zinc at the rate of 15 kg^{-1} ha as a basal dose, (D) recommended dose of 160 kg N ha^{-1},60 kg P_2O_5 ha^{-1} ,40 kg K_2O ha^{-1} with boron at the rate of 2 kg^{-1} ha as a basal dose, and (E) recommended dose of 160 kg N ha^{-1},60 kg P_2O_5 ha^{-1}, 40 kg of K_2O ha^{-1} with zinc 15 kg^{-1} ha and boron 2 kg^{-1} ha. P_2O_5, K_2O, Boron and Zinc were applied as basal dose in all treatment at the time of field preparation. Nitrogen, phosphorous and potassium nutrients were supplied through Urea, Diammonium phosphate (DAP) and Muriate of Potash (MOP) respectively. The recommended amount of Phosphatic and Potassic fertilizers @ 60:40 (N:P_2O_5) kg ha^{-1}, were calculated and weighed separately for all treatment. The total amount of nitrogen fertilizer through urea for each plot was divided into three equal parts. Full dose of phosphorus and potassium and one third of nitrogen were applied as basal dose 5 cm apart from maize row at 5 cm depth and second split dose of nitrogen was applied as side-dressing (top dressing) at knee high stage and finally last dose was side dressed at tasseling stage. Zinc sulphate (15 kg ha^{-1}) and Borax (2 kg ha^{-1}) were also applied at sowing time as basal dose (Losak et al., 2011). Rampur hybrid-10 variety of maize was sown @ 25 kg ha^{-1} ha with row spacing of 60 cm and plant to plant spacing of 25 cm in plot size of 8m^2 (4m x 2m).

2.3 CROP MANAGEMENT

The field was ploughed 15 days prior to seed sowing by using mini-tiller to bring the soil under good tilth. Again, ploughing was done at the time of sowing and planking was done after ploughing for leveling the land. Seeds were treated with Bavistin 2g kg^{-1} of seeds one day prior of sowing, which was sown manually in line by using Zea-Planter in each hill. Gap filling was done after two weeks of sowing so as to maintain the plant population. During the early vegetative phase at 50 DAS, American Fall Army Worm was found problematic in the field. Emamectin benzoate (SG) @ 5g per 16 liter of water was sprayed. Firsthand weeding and earthing up were done at 30 days after sowing (DAS) whilst, second hand weeding were performed at 60 DAS. Irrigation was done at 7 DAS as the soil was prone to moisture loss because of high temperature. Irrigation was done twice a week regardless of, crucial stage; knee high stage, tasseling stage, silking stage and early grain filling stage irrigation were pivotal in which watering was done in the regular basic according to the climatic and soil condition.

2.4 OBSERVATION TAKEN

The crop was harvested at physiological maturity stage from the net plot area of 8m^2 for determination of yield. The data recorded was converted and reported as the number of plants ha^{-1}. Five representative cobs from each net plot were taken to record the cob length. The cob length and sterile length was measured with a scale, average was worked out and expressed in cm. The number of grain rows of five cobs were taken and average data was reported as the number of grain rows per cobs. Thousand grains were counted from the randomly separated grain of net plot and weighed with the help of portable automatic electronic balance and grain moisture content was also recorded. For the computation of the sterility, total unfilled length from the tip of cob was measured with the help of scale in cm and sterility percentage was calculate as:

$$\text{Sterility percentage} = \frac{\text{Unfilled length of cob (cm)}}{\text{Total length of cob (cm)}} \times 100$$

Biomass yield and grain yield were taken at harvesting time from the net plot i.e., central 5 Rows (8 m^2). Cobs were separated from the stover and both cobs and stover of each plot were sun-dried, then shelling of grain and final weight of grain was taken along with exact grain moisture percent. The grain yield per hectare was computed for each treatment from the net plot yield. Finally, grain yield was adjusted at 14% moisture using the formula as

$$\text{Grain Yield (kg ha}^{-1}\text{) at 14\% moisture} = \frac{(100-\text{Mc})\times \text{plot yield (kg)}\times 10000()}{(100-14)\times \text{net plot area (8m2)}}$$

Where, MC is the moisture content of the grain in percentage

Sun-dried stover weight and sample of each plot were taken and the samples were oven-dried. Similar procedure was applied for husks and nubbins from each plot. Finally, the weight of non-grain above- ground biomass was translated into dry weight $kgha^{-1}$. The harvest index (HI) was determined by calculating the ratio of grain yield and biological yield and expressed in percentage. The B:C ratio was calculated by dividing the gross returns (based on the local market price of Banke) by total cost of cultivation.

2.5 STATISTICAL ANALYSIS

The data recorded on different parameters from field and laboratory were first tabulated in Microsoft Excel (MS- Excel), then Analysis of Variance (ANOVA) for all data were computed using RStudio computer software package. All the analyzed data were subjected to Duncan's Multiple Range Test (DMRT) for mean comparison at 5% level of significance.

4.RESULTS AND DISCUSSION

4.1 GROWTH CHARACTERS

4.1.1 Leaf Area Index (LAI)

The highest LAI was obtained with Recommended Nitrogen, Phosphorus, Potassium + Zn + B (0.26) at 30 days after sowing (DAS), followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (0.12), Recommended Nitrogen, Phosphorus, Potassium + B (0.12) which were statistically similar whereas, the lowest leaf area index was seen in Farmer's practice (0.07) and Recmmended NPK (0.10). Similarly, at 45DAS the highest leaf area index was recorded with Recommended Nitrogen, Phosphorus, Potassium + Zn +B (0.43) and the least leaf area index was obtained in Farmer's practice (0.26) whereas Recommended Nitrogen, Phosphorus, Potassium + Zn (0.34), Recommended Nitrogen, Phosphorus, Potassium + B (0.35) and Recommended Nitrogen, Phosphorus, Potassium (0.32) were found statistically similar. While at 60DAS, the highest leaf area index was recorded with Recommended Nitrogen, Phosphorus, Potassium +

Zn + B (0.50) and the lowest leaf area index was obtained in Farmer's practice (0.03) whereas Recommended Nitrogen, Phosphorus, Potassium + Zn (0.41), Recommended Nitrogen, Phosphorus, Potassium + B (0.04) and Recommended Nitrogen, Phosphorus, Potassium (0.39) were found statistically similar (Table 2). At 75DAS Recommended Nitrogen, Phosphorus, Potassium + Zn + B (0.64) showed the highest leaf area index followed by Recommended Nitrogen, Phosphorus, Potassium + B (0.53) and Recommended Nitrogen, Phosphorus, Potassium + Zn (0.51) while the lowest leaf area index was recorded in Farmer's practice (0.42) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium (0.48) (Table 2). Leaf area index at 90 DAS was the highest at Recommended Nitrogen, Phosphorus, Potassium + Zn + B (0.72) followed by Recommended Nitrogen, Phosphorus, Potassium + B (0.62) and Recommended Nitrogen, Phosphorus, Potassium + Zn (0.60) which were statistically similar while and the lowest was recorded in Farmer's practice (0.48). It might be due to longer maturity duration of leaf with good photosynthesis in Recommended Nitrogen, Phosphorus, Potassium + Zn + B while least in farmer practice might be due to early aging and senescence. According to Jones and Smith (2015), a higher LAI enhances the canopy's capacity to capture solar radiation, boosting photosynthetic assimilation and biomass production. Additionally, Li et al. (2018) noted that increased leaf area supports greater carbohydrate availability for grain filling, improving yields, as long as light penetration and gas exchange remain adequate and water and nutrient use are optimized with proper spacing and inputs.

Table 2: Leaf area index of maize as influenced by the application of different nutrients at Banke, Nepal (2023)

Treatments	LAI				
	30 DAS	**45DAS**	**60DAS**	**75 DAS**	**90 DAS**
Farmer's practice (A)	0.07[d]	0.26[c]	0.34[c]	0.42 [c]	0.48[d]
Recommended Nitrogen, Phosphorus, Potassium (B)	0.10[c]	0.32[b]	0.39 [b]	0.48[bc]	0.56[c]
Recommended Nitrogen, Phosphorus, Potassium + Zinc (C)	0.13 [b]	0.35[b]	0.41 [b]	0.51 [b]	0.60[bc]
Recommended Nitrogen, Phosphorus, Potassium + Boron (D)	0.13 [b]	0.35 [b]	0.40[b]	0.53 [b]	0.62[b]
Recommended Nitrogen, Phosphorus, Potassium + Zinc + Boron (E)	0.26 [a]	0.43[a]	0.50 [a]	0.64 [a]	0.72 [a]
Sem (±)	0.002	0.004	0.003	0.010	0.007
LSD value	0.018	0.031	0.023	0.070	0.049
CV%	8.856	5.912	3.705	8.826	5.346
F-probability (0.05)	<0.001	<0.001	<0.001	<0.001	<0.001
Grand mean	0.1375	0.3435	0.4115	0.519	0.6015

Note: Mean followed by common letter(s) within columns are non-significantly different based on DMRT P=0.05, Sem: Standard error of mean, CV: Coefficient of variance, LSD: least significant difference, DAS: days after sowing, LAI: leaf area index.

4.1.2 Plant height

At 30 days after sowing (DAS) the highest plant height was obtained in Recommended Nitrogen, Phosphorus, Potassium + Zn + B (62.50cm) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium + B (56.86cm) followed by the Recommended Nitrogen, Phosphorus, Potassium + Zn(54.47cm) and Recommended Nitrogen, Phosphorus, Potassium (51.22cm) whereas the lowest height was obtained with the Farmer‘s practice (41.80cm) (Table 3).Similarly, at 45 DAS the highest plant height was obtained with Recommended Nitrogen, Phosphorus, Potassium + Zn + B (158.30cm) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium + B (140.10cm) followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (138.40cm) and Recommended Nitrogen, Phosphorus, Potassium (136.70cm) whereas the lowest height was obtained in Farmer's practice (95.65cm). At 60 DAS and 75DAS no statistical different in plant height was obtained among the treatment. This might be due to the plant height as a plant varietal character. While, at 90 DAS the highest plant height was obtained in Recommended Nitrogen, Phosphorus, Potassium + Zn + B (278.60cm) followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (270.35cm). Both Recommended Nitrogen, Phosphorus, Potassium + B (262.45cm) and Recommended Nitrogen, Phosphorus, Potassium (259.30cm) were found statistically similar whereas the least plant height was obtained in Farmer's practice (245.00cm) (Table 3). Taller plants generally have a larger leaf area and better-developed canopy, which increases light interception and photosynthesis. There is a moderate positive correlation between plant height and yield when light is efficiently used and there is no shading or lodging. Height contributes to more vegetative biomass, which may act as a source for photosynthates. However, excessively tall plants are more prone to lodging, especially under high wind or rainfall, which reduces grain yield due to disrupted grain filling and harvesting difficulties. The grain yield (sink strength) depends on whether the plant efficiently partitions assimilates to reproductive parts (Xie et al., 2009; Zhang et al., 2017).

Table 3: Plants height influenced by the application of different plant nutrients

Treatments	Plant height(cm)				
	30 DAS	**45DAS**	**60DAS**	**75 DAS**	**90 DAS**
Farmer's practice (A)	41.80^{c}	95.65^{c}	189.35^{b}	247.300^{c}	245.00^{d}
Recommended Nitrogen, Phosphorus, Potassium (B)	51.22^{b}	136.70^{b}	214.95^{a}	260.20^{ab}	259.30^{c}
Recommended Nitrogen, Phosphorus, Potassium + Zinc (C)	54.47^{b}	138.40^{b}	213.60^{a}	267.05^{a}	270.35^{b}
Recommended Nitrogen, Phosphorus, Potassium + Boron (D)	56.86^{ab}	140.10^{ab}	219.05^{a}	255.80^{bc}	262.45^{c}

Treatments	Plant height(cm)				
	30 DAS	45DAS	60DAS	75 DAS	90 DAS
Recommended Nitrogen, Phosphorus, Potassium + Zinc + Boron (E)	62.50[a]	158.30[a]	227.00[a]	268.87 [a]	278.60[a]
Sem (±)	0.821	2.713	2.617	1.578	1.062
LSD value	5.660	18.697	18.032	10.878	7.317
CV%	6.884	9.068	5.500	2.717	1.805
F-probability (0.05)	<0.001	<0.001	<0.01	<0.01	<0.001
Grand mean	53.373	133.83	212.79	259.845	263.14

Note: Mean followed by common letter(s) within columns are non-significantly different based on DMRT P=0.05, Sem: Standard error of mean, CV: Coefficient of variance, LSD: least significant difference, DAS: days after sowing.

4.2 PHENOLOGICAL OBSERVATION

4.2.1 Days to tasseling, silking and anthesis

Maximum days to 50% tasseling was found in Farmer's Practice (66.75 days) which was followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (66.00days) and Recommended Nitrogen, Phosphorus, Potassium (65.75days) whereas minimum days was obtained with Recommended Nitrogen, Phosphorus, Potassium + Zn + B (63.25days) followed by Recommended Nitrogen, Phosphorus, Potassium + B(65.50days). Similarly, maximum days to silking wsa recorded with Farmer's Practice (70.75 days) (Table 4) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium (69.50days) followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (69.00 days) and Recommended Nitrogen, Phosphorus, Potassium + B (68.25 days) which were statistically similar while minimum days of silking was obtained with Recommended Nitrogen, Phosphorus, Potassium + Zn + B (65.50 days). Maximum anthesis silking interval (ASI) was obtained with Farmer's Practice (4.00 days) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium (3.75 days) followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (3.00 days) while the least anthesis silking interval (ASI) was recorded with Recommended Nitrogen, Phosphorus, Potassium + Zn + B (2.25 days) (Table 4), which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium + B (2.75 days). Lower the anthesis silking interval greater will be the pollination duration so obviously, Recommended Nitrogen, Phosphorus, Potassium + Zn + B has better pollination. Marschner and Rengel (2014) demonstrated that sufficient nutrients, including N, P, K, and micronutrients like Zn and B, enhance vigorous vegetative growth, accelerate leaf development, and support timely reproductive initiation, improving anthesis and silking synchronization for better fertilization success. Ali et al. (2017) reported that a balanced nutrient supply strengthens the source–sink relationship, leading to higher grain set and yield, with a shorter Anthesis–Silking Interval (ASI) serving as a key indicator of improved physiological health.

Table 4: Maize phenological observation as influenced by the application of different plant nutrients.

Treatments	Phenological observations		
	Days to tasseling	**Days to silking**	**ASI (days)**
Farmer's practice (A)	66.75[a]	70.75[a]	4.00[a]
Recommended Nitrogen, Phosphorus, Potassium (B)	65.75[ab]	69.50[ab]	3.75[a]
Recommended Nitrogen, Phosphorus, Potassium + Zinc (C)	66.00[ab]	69.00[b]	3.00[b]
Recommended Nitrogen, Phosphorus, Potassium + Boron (D)	65.50[b]	68.25[b]	2.75[bc]
Recommended Nitrogen, Phosphorus, Potassium + Zinc + Boron (E)	63.25[c]	65.50[c]	2.25[c]
Sem (±)	0.145	0.185	0.102
LSD value	1.004	1.281	0.703
CV%	0.996	1.212	14.489
F-probability (0.05)	<0.001	<0.001	<0.001
Grand mean	65.45	68.6	3.15

Note: Mean followed by common letter(s) within columns are non-significantly different based on DMRT P=0.05, Sem: Standard error of mean, CV: Coefficient of variance, LSD: least significant difference, DAS: days after sowing; ASI: Anthesis Silking Interval.

4.2.2 Influence on Cob length, Sterile length and Sterility percentage

The highest cob length was obtained the with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (21.38cm). The second highest was found in Recommended Nitrogen, Phosphorus, Potassium + B (19.68cm) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium + Zn (19.41cm) and whereas the lowest cob length was obtained with the Recommended Nitrogen, Phosphorus, Potassium (18.35cm) and Farmer's practice(16.82cm) (Table 5). Similarly, the highest sterile length was obtained the with the Farmer's practice (2.18cm) followed by Recommended Nitrogen, Phosphorus, Potassium1.80cm). The sterile length of Recommended Nitrogen, Phosphorus, Potassium + Zn (1.12cm) was found statistically similar with Recommended Nitrogen, Phosphorus, Potassium + B (1.04cm) whereas the lowest sterile length was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (0.39cm) (Table 5) while, the highest sterility % was obtained with the Farmer's practice (13.00%) followed by Recommended Nitrogen, Phosphorus, Potassium (9.85%) whereas the lowest sterility % was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (1.85%).The sterility % of Recommended Nitrogen, Phosphorus, Potassium + B (5.30%) was statistically similar with and Recommended Nitrogen, Phosphorus, Potassium + Zn (5.82%) (Table 5). Ciampitti and Vyn (2013) found that cob length is influenced by kernel set and ear axis elongation, with adequate nitrogen, phosphorus, and potassium (NPK) supporting a high photosynthetic rate, biomass accumulation, floral organ development, and hormonal balance involving auxins and gibberellins. Sharma and Kumar (2016) observed that micronutrients like Zn and B improve pollen viability and silk receptivity, enhancing full cob development in maize. Barnabás and Fehér (2015) highlighted that adequate auxin and gibberellin activity during ear initiation promotes longer ear development, influencing cob length and the potential for increased grain numbers in maize. Liu et al. (2018) noted that cob length, reflecting the number of rows and grains, is shaped by the plant's nutrient status, hormonal balance, and assimilate supply, with longer cobs indicating stronger sink strength for kernel setting.

Table 5: Cob length, sterile length and sterility percent as influenced by the application of different nutrients.

Treatment	Cob length (cm)	Sterile length (cm)	Sterility %
Farmer's practice(A)	16.82^{d}	2.18^{a}	13.00^{a}
Recommended Nitrogen, Phosphorus, Potassium (B)	18.35^{c}	1.80^{b}	9.85^{b}
Recommended Nitrogen, Phosphorus, Potassium + Zinc(C)	19.41^{b}	1.12^{c}	5.82^{c}
Recommended Nitrogen, Phosphorus, Potassium + Boron(D)	19.68 ^{b}	1.04^{c}	5.30^{c}
Recommended Nitrogen, Phosphorus, Potassium + Zinc + Boron (E)	21.38^{a}	0.39^{d}	1.85^{d}
Sem (±)	0.080	0.021	0.126
LSD value	0.552	0.148	0.868
CV%	1.874	7.341	7.870
F-probability (0.05)	<0.001	<0.001	<0.001
Grand mean	19.13	1.309	7.165

Note: Mean followed by common letter(s) within columns are non-significantly different based on DMRT P=0.05, Sem: Standard error of mean, CV: Coefficient of variance, LSD: least significant difference.

4.2.3 Yield and yield attributes

The highest cob length was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (21.38cm). The second highest was found in Recommended Nitrogen, Phosphorus, Potassium + B (19.68cm) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium + Zn (19.41cm) and whereas the lowest cob length was obtained with the Recommended Nitrogen, Phosphorus, Potassium (18.35cm) and Farmer's practice (16.82cm). Similarly, the highest row number per cob was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (14.62), followed by Recommended Nitrogen, Phosphorus, Potassium + B (13.40) and Recommended Nitrogen, Phosphorus, Potassium + Zn (13.25) which were statistically similar. The lowest was observed in Farmer's practice (12.15) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium (12.35). The highest grains per row was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (31.05) followed by Recommended Nitrogen, Phosphorus, Potassium + B (29.28), Recommended Nitrogen, Phosphorus, Potassium + Zn (28.54) and Recommended Nitrogen, Phosphorus, Potassium (28.50) which were statistically similar while the lowest grains per row was obtained with the farmer's practice (26.64) (Table 6). Similarly, the highest grains yield was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (11.45ton/ha) followed by Recommended Nitrogen, Phosphorus, Potassium + B (10.58 ton/ha) which was statistically similar with the Recommended Nitrogen, Phosphorus, Potassium + Zn (10.28 ton/ha) while the lowest grains yield was obtained with the farmer's practice (7.45ton/ha) followed by Recommended Nitrogen, Phosphorus, Potassium (8.65 ton/ha) (Table 6). The effect of Zn, B on nitrogen use efficiency increased grain filling duration as plant attained tasseling stage earlier and senescence was late, which caused maximum yield in Recommended Nitrogen, Phosphorus, Potassium + Zn + B. Similarly, the highest harvest index was found in Recommended Nitrogen, Phosphorus, Potassium + Zn + B (0.44) followed by Recommended Nitrogen, Phosphorus, Potassium + B (0.40) which was statistically similar with Recommended Nitrogen, Phosphorus, Potassium + Zn (0.42) while, the lowest harvest index was found with the farmer's practice (0.34) and Recommended Nitrogen, Phosphorus, Potassium (0.34) (Table 6). Monneveux et al. (2018) demonstrated that grain yield increases with enhanced photosynthesis from vigorous vegetative growth and large leaf area, boosting photosynthate production for developing grains, alongside improved root development for better water and nutrient uptake, and timely, synchronized tasseling, silking, and anthesis for higher pollination success. Farooq et al. (2012) found that micronutrients like zinc (Zn) and boron (B) enhance pollen viability, silk elongation, and kernel formation, contributing to improved grain yield in maize.

Table 6: Yield and yield attributes as influenced by the application of different nutrients at Duduwa-6, Banke

Treatment	Yield attributes				
	Cob length (cm)	Row num/ cob.	Grain per row	Grain yield (MT/ha)	Harvest Index
Farmer's practice (A)	16.82 ^{d}	12.15^{c}	26.64 ^{c}	7.45^{d}	0.34^{c}
Recommended Nitrogen, Phosphorus, Potassium (B)	18.35 ^{c}	12.35^{c}	28.50^{b}	8.65^{c}	0.34^{c}
Recommended Nitrogen, Phosphorus, Potassium + Zinc (C)	19.41 ^{b}	13.25^{b}	28.54^{b}	10.28^{b}	0.42^{ab}
Recommended Nitrogen, Phosphorus, Potassium + Boron (D)	19.68 ^{b}	13.40^{b}	29.281^{b}	10.58^{ab}	0.40^{b}
Recommended Nitrogen, Phosphorus, Potassium + Zinc + Boron (E)	21.38 ^{a}	14.62^{a}	31.05^{a}	11.45^{a}	0.44^{a}
Sem (±)	0.080	0.092	0.196	0.165	0.004

Treatment	Yield attributes				
	Cob length (cm)	Row num/ cob.	Grain per row	Grain yield (MT/ha)	Harvest Index
LSD value	0.552	0.636	1.354	1.141	0.028
CV%	1.874	3.140	3.052	7.647	4.657
F-probability (0.05)	<0.001	<0.001	<0.001	<0.001	<0.001
Grand mean	19.13	13.155	28.80445	9.6875	0.391

Table 6: Mean followed by common letter(s) within columns are non-significantly different based on DMRT P=0.05, Sem: Standard error of mean, CV: Coefficient of variance, LSD: least significant difference.

4.3 BENEFIT: COST RATIO

The highest cost of cultivation was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (Rs.1,17,557) followed by Recommended Nitrogen, Phosphorus, Potassium + B (Rs.1,14,837) and Recommended Nitrogen, Phosphorus, Potassium + Zn (Rs.1,13,748) while the lowest cost of cultivation was obtained with the farmer's practice (Rs.1,08,191) which was followed by Recommended Nitrogen, Phosphorus, Potassium (Rs.1,11,028) (Table 7). Similarly, the highest net return was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (Rs.1,07,693) followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (Rs.91,252) and Recommended Nitrogen, Phosphorus, Potassium + B (Rs.84,913) while the lowest net return was obtained with the Farmer's practice (Rs.54,809) which was followed by Recommended Nitrogen, Phosphorus, Potassium (Rs.66,722) (Table 7). Similarly, the highest benefit: cost ratio (B:C) was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zn + B (1.92) followed by Recommended Nitrogen, Phosphorus, Potassium + Zn (1.80) and Recommended Nitrogen, Phosphorus, Potassium + B (1.74) while the lowest B:C ratio was obtained with the farmer's practice which was followed by Recommended Nitrogen, Phosphorus, Potassium (1.60) (Table 7) &. Cost of cultivation included all the fix and variable expenses like cost of land on lease, land preparation, labor cost, fertilizer, insecticide while gross return was calculated based on local price of maize grain and maize straw. Nearly, double return was obtained with the Recommended Nitrogen, Phosphorus, Potassium + Zinc compared to farmer practice.

Table 7: B:C ratio of Rampur hybrid maize production as influenced by the application of different nutrient at Duduwa-6, Banke Nepal

Treatment	BC ratio			
	Cost of cultivation (Rs/ha)	Gross return (Rs/ha)	Net return (Rs/ha)	B:C ratio
Farmer's practice (A)	**1,08,191**	**1,63,000**	**54,809**	**1.51**
Recommended Nitrogen, Phosphorus, Potassium (B)	**1,11,028**	**1,77,750**	**66,722**	**1.60**
Recommended Nitrogen, Phosphorus, Potassium + Zinc (C)	**1,13,748**	**2,05,000**	**91,252**	**1.80**
Recommended Nitrogen, Phosphorus, Potassium + Boron (D)	**1,14,837**	**1,99,750**	**84,913**	**1.74**
Recommended Nitrogen, Phosphorus, Potassium + Zinc + Boron (E)	**1,17,557**	**2,25,250**	**1,07,693**	**1.92**

4.4 CORRELATION COEFFICIENT

Correlation coefficient is a statistical measure that quantifies the strength and direction of the relationship between two variables. In the context of agriculture, the significance of correlation coefficients lies in their ability to provide valuable insights into various aspects of agricultural practices and outcomes.

4.4.1 Grain yield and number of grains per row

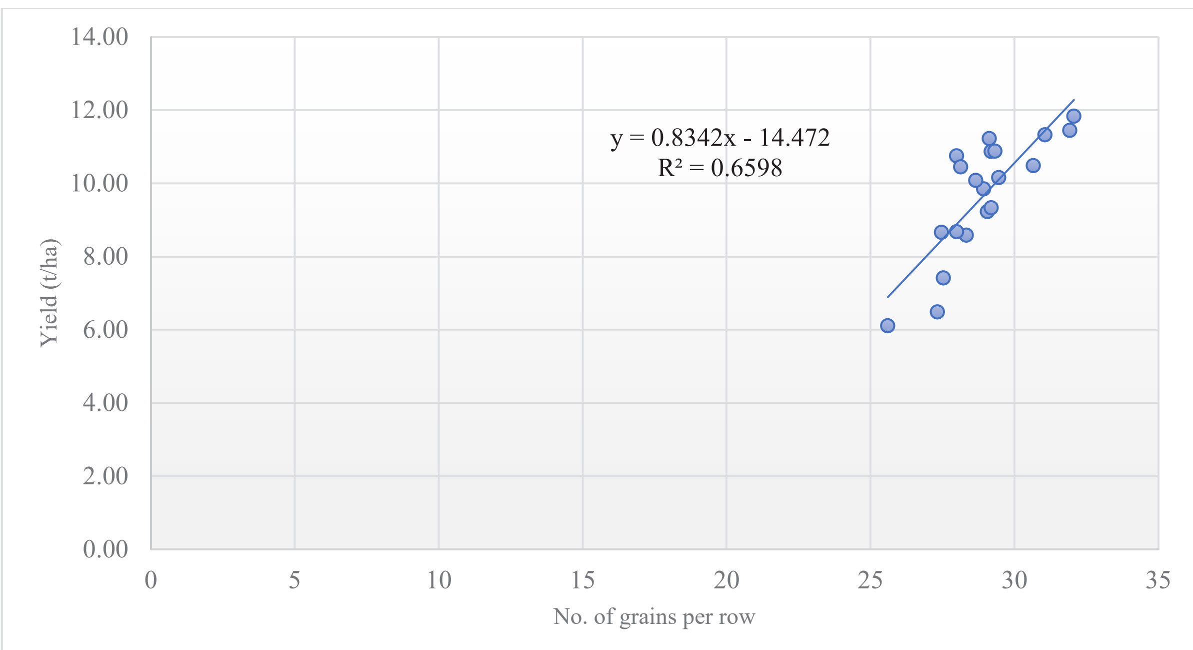


Figure 2: Correlation between grain yield and number of grains per row

The correlation between grain yield and number of grain per row was found ($p<0.001$) positive ($r= 0.81$) (Figure 2). The coefficient of determination $R^2= 0.65$ which means there is 65.59 % effect of number of grain per row on grain yield and rest was due to other factors.

4.4.2 Grain yield and 1000 grain weight

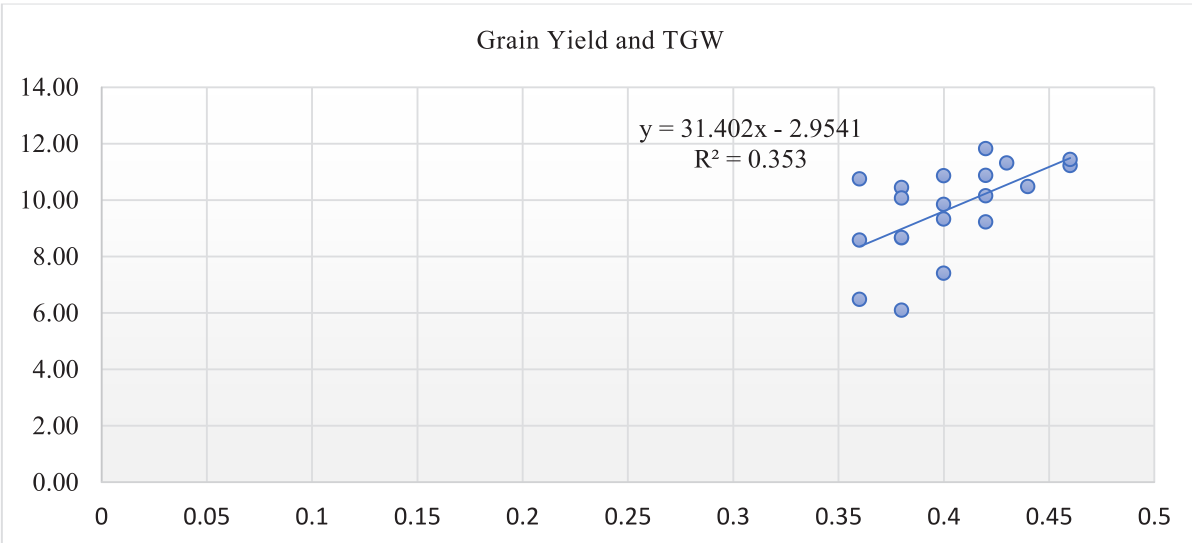


Figure 3: Correlation between grain yield(tons/ha) and 1000 grain weight (gm)

The correlation between grain yield and 1000 grain weight was found ($p<0.001$) positive ($r= 0.59$). The coefficient of determination $R^2= 0.35$ (Figure 3) that means there is 35.30 % effect of 1000 grain weight on grain yield and rest was due to other factors.

4.4.3 Yield and number of kernel row

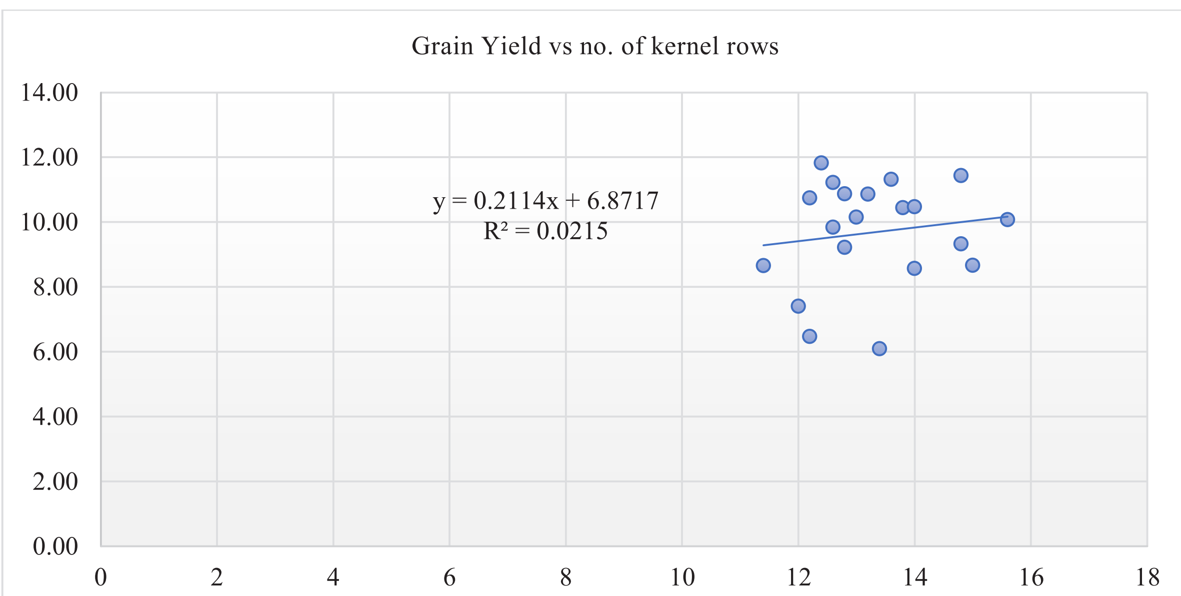


Figure 4: Correlation between grain yield (tons/ha) and number of kernel rows

The correlation between grain yield and number of row was found ($p<0.001$) positive (r= 0.14). The coefficient of determination R^2=0.021 (Figure 4) that means there was 2.14% effect of number of row on grain yield and rest was due to other factors.

4.4.4 Sterility percentage and grain yield

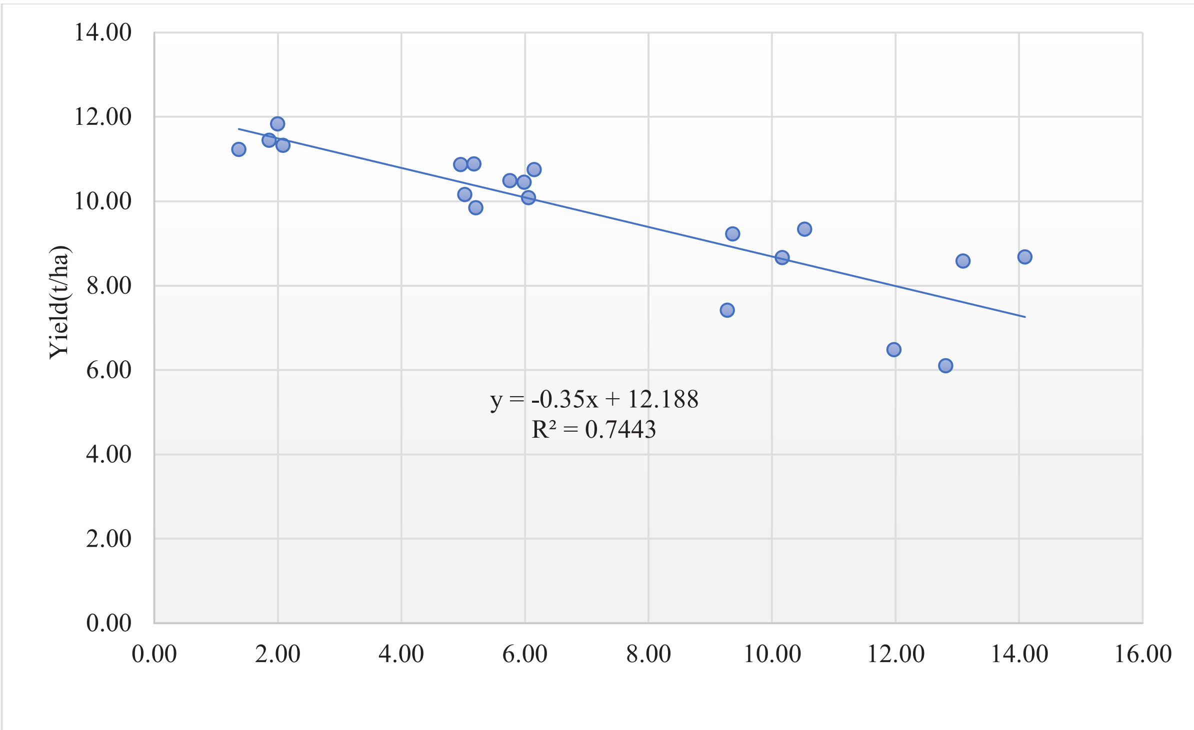


Figure 5: Correlation between sterility percentage and grain yield of maize

The correlation between grain yield and sterility percentage was found ($p<0.001$) negative corelated (r= -0.86). The coefficient of determination R^2=0.74 (Figure 5) that means there is 74.44% effect of sterility % on grain yield and rest was due to other factors.The correlation between grain yield and number of grain per row, grain yield and 1000 grain weight , grain yield and number of row was found positively significant while correlation between grain yield and sterility percentage was found negatively corelated (Figure 5).

5.CONCLUSION

The combined application of Recommended N:P_2O_5:K_2O (160:60:40 kg/ha) along with Zn (15 kg/ha) and B (2 kg/ha) increased the yield attributing traits namely cob length, thousand-grain weight, grain yield, net return and thereby grain yield in Rampur hybrid 10 variety of maize which increased the net return and B:C ratio. Days to tasseling (50%), Silking (50%), and Anthesis silking interval and the lowest in zinc and boron applied field along with Recommended Nitrogen, Phosphorus, Potassium. The application of N:P_2O_5:K_2O (160:60:40 kg/ha) together with Zinc (15 kg/ha) and Boron (2 kg/ha)could be recommended to get the higher spring maize production in Banke district, and similar agro-climatic conditions of Nepal.

DECLARATION

The authors declare no conflict of interests.

REFERENCES

Adhikari, S. P., Timsina, K. P., Brown, P. R., Ghimire, Y. N., & Lamichhane, J. (2018). Technical efficiency of hybrid maize production in eastern Terai of Nepal: A stochastic frontier approach. *Journal of Agriculture and Natural Resources*, *1*(1), 189–196.

Adhikari, S., & Ozarska, B. (2018). Minimizing environmental impacts of timber products through the production process "From sawmill to final products." *Environmental Systems Research*, *7*(1), 6. https://doi.org/10.1186/s40068-018-0109-x

Adnan, M. (2020). Role of potassium in maize production: A review. *Open Access Journal of Biological Science and Research*, *3*(5), 1–4.

Ali, Amjed & Safdar, Muhammad & Asif, Muhammad & Mahmood, Athar & Nadeem, Mubashar & Javed, Muhammad & Ahmad, Salman & Qamar, Rafi & Bilal, Hafiz & Khan, Bilal & Amin, Muhammad & Raza, Ali. (2020). Role of potassium in enhancing growth, yield and quality of maize (Zea mays L.). International Journal of Biosciences (IJB). 2020. 10.12692/ijb/16.6.210-219.

Ali, M. A., Abbas, G., & Khan, M. I. (2017). Balanced nutrient supply and the anthesis–silking interval: Impacts on fertilization success and yield in cereals. *Agronomy Journal, 109*(5), 2105–2116. https://doi.org/10.2134/agronj2017.02.0098

Alias, Ahmad & Usman, Muhammad & Ullah, Ehsan & Waraich, Ejaz. (2003). Effects of Different Phosphorus Levels on the Growth and Yield of Two Cultivars of Maize (Zea mays L.).

Barnabás, B., & Fehér, A. (2015). Hormonal regulation of cob length and kernel setting in maize: Roles of auxin and gibberellin. *Journal of Experimental Botany, 66*(10), 2989–2998. https://doi.org/10.1093/jxb/erv123

Cakmak, I. (2008). Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant and Soil*, *302*, 1–17.

Ciampitti, I. A., & Vyn, T. J. (2013). Maize nutrient dynamics and cob development: Roles of NPK in kernel set and ear elongation. *Field Crops Research, 150*, 34–43. https://doi.org/10.1016/j.fcr.2013.06.013

Craufurd, P. (2021). *CIMMYT in Nepal*.

Dell, B., & Huang, L. (1997). Physiological response of plants to low boron. *Plant and Soil*, *193*, 103–120.

Farooq, M., Wahid, A., & Siddique, K. H. M. (2012). Micronutrient application and pollen viability: Impacts on silk elongation, kernel formation, and grain yield in maize. *Plant and Soil, 350*(1-2), 279–290. https://doi.org/10.1007/s11104-011-0905-x

Humtsoe, B. M., Dawson, J., & Rajana, P. (2018). Effect of nitrogen, boron and zinc as basal and foliar application on growth and yield of maize (*Zea mays* L.). *Journal of Pharmacognosy and Phytochemistry*, *7*(6), 1–5.

Jones, R. T., & Smith, J. A. (2015). Leaf area index and its influence on photosynthetic efficiency and biomass accumulation in cereal crops. *Agronomy Journal, 107*(4), 1345–1356. https://doi.org/10.2134/agronj14.0523

Julio Silva Cruz, Sihelio & Júnior, José & Oliveira, Silvia & Grah, Vanessa & Valicheski, Romano. (2022). Boron and Zinc Fertilizer Application to Maize Crops in a Lithic Quartzipsamment. Revista Caatinga. 35. 848-856. 10.1590/1983-21252022v35n412rc.

Kandel, B. (2021). Status, prospect and problems of hybrid maize (*Zea mays* L.) in Nepal: A brief review. *Genetic Resources and Crop Evolution*, *68*, 1–10. https://doi.org/10.1007/s10722-020-01032-0

Li, X., Zhang, W., & Chen, L. (2018). Optimizing leaf area index for improved water use efficiency and grain yield in maize under varying nutrient conditions. *Field Crops Research, 215*, 88–97. https://doi.org/10.1016/j.fcr.2017.10.015

Liu, Y., Wang, Q., & Zhang, H. (2018). Nutrient status and assimilate supply effects on cob length and sink strength in maize. *Crop Science, 58*(3), 1325–1334. https://doi.org/10.2135/cropsci2017.09.0542

Lordkaew, S., Dell, B., Jamjod, S., & Rerkasem, B. (2011). Boron deficiency in maize. *Plant and Soil*, *342*(1–2), 207–220. https://doi.org/10.1007/s11104-010-0685-7

Losak, T., Hlusek, J., Martinec, J., Jandak, J., Szostkova, M., Filipcik, R., Manasek, J., Prokes, K., Peterka, J., Varga, L., Ducsay, L., Orosz, F., & Martensson, A. (2011). Nitrogen fertilization does not affect micronutrient uptake in grain maize (*Zea mays* L.). *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, *61*(6), 543–550. https://doi.org/10.1080/09064710.2010.520729

Maňásek, J., Lošák, T., Prokeš, K., Hlušek, J., Vítězová, M., Škarpa, P., & Filipčík, R. (2013). Effect of nitrogen and potassium fertilization on micronutrient content in grain maize (*Zea mays* L.). *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *61*(1), 123–128.

Marschner, P., & Rengel, Z. (2014). Nutrient availability and its role in vegetative growth, reproductive development, and grain set in maize. *Plant and Soil, 384*(1-2), 153–167. https://doi.org/10.1007/s11104-014-2213-8

Martens, D. C., & Westermann, D. T. (2018). Fertilizer applications for correcting micronutrient deficiencies. In *Micronutrients in agriculture*. https://api.semanticscholar.org/CorpusID:97023632

Moeinian, M. R., Zargari, K., & Hasanpour, J. (2011). Effect of boron foliar spraying application on quality characteristics and growth parameters of wheat grain under drought stress. [Publication/source not specified].

Monib, Abdul & Niazi, Parwiz & Sediqi, Sayedwali. (2023). Investigating Approaches for Optimizing Agricultural Yield: A Comprehensive Review of the Crucial Role of Micronutrients in Enhancing Plant Growth and Maximizing Production. Journal for Research in Applied Sciences and Biotechnology. 2. 168-180. 10.55544/jrasb.2.5.26.

Monneveux, P., Sánchez, C., & Tiessen, A. (2018). Photosynthesis, root development, and synchronized reproductive stages: Effects on pollination success and grain yield in cereals. *Field Crops Research, 221*, 172–182. https://doi.org/10.1016/j.fcr.2018.02.015

Pandey, G., & Basnet, S. (2018). *Objective agriculture book at a glance* (pp. 28–29). Kapil Group & Company Pvt. Ltd.

Reid, R. J., Hayes, J. E., Post, A., Stangoulis, J. C. R., & Graham, R. D. (2004). A critical analysis of the causes of boron toxicity in plants. *Plant, Cell & Environment*, *27*(11), 1405–1414.

Sankadiya, Sourabh & Sanodiya, Lalit. (2021). Effect of phosphorus and potassium levels on growth and yield of maize (Zea mays L.).

Savithri, P. P., Perumal, R. S., & Nagarajan, R. (2004). Soil and crop management technologies for enhancing rice production under micronutrient constraints. *Nutrient Cycling in Agroecosystems*, *53*, 83–92. https://api.semanticscholar.org/CorpusID:11603422

Shabaz, Muhammad & Ali, Hakoomat & Sajjad, Muhammad & Ahsan, Syed & Shah, Nawaz. (2015). Role of Zinc Nutrition in Maize for Growth and Yield: An Overview. 15. 1323-1330. 10.5829/idosi.aejaes.2015.15.7.12706.

Sharma, A., & Kumar, R. (2016). Micronutrient effects on pollen viability and silk receptivity in maize: Implications for cob length and yield. *Plant Physiology and Biochemistry, 98*, 112–120. https://doi.org/10.1016/j.plaphy.2015.11.008

Wahid, M., Ahmad, W., Cheema, M., Saleem, M., & Sattar, A. (2011). Impact of foliar applied boron on yield and yield components of spring maize (*Zea mays* L.) under drought condition. *Soil and Crop Environment Science*, 382–383.

Woodruf, J. R., Moore, F. W., & Musen, H. L. (1987). Potassium, boron, nitrogen, and lime effects on corn yield and earleaf nutrient concentrations. *Agronomy Journal*, *79*, 520–524. https://api.semanticscholar.org/CorpusID:94390473

Xie, Q., Mayes, S., & Sparkes, D. L. (2009). Carpel size, grain filling, and morphology determine individual grain weight in wheat. Journal of Experimental Botany, 60(2), 539–546. https://doi.org/10.1093/jxb/ern306

Zhang, W., Liu, G., Wang, H., & Wang, Y. (2017). Effects of nitrogen application on lodging resistance and grain yield in winter wheat (Triticum aestivum L.). Field Crops Research, 203, 74–82. https://doi.org/10.1016/j.fcr.2016.12.011

https://doi.org/10.3126/adj.v18i1.82089

EFFECT OF ORGANIC SOURCES OF NUTRITION IN PERFORMANCE OF TOMATO AND SOIL PROPERTIES INSIDE PLASTIC HOUSE

Shukra Raj Shrestha[1,*], Kishor Bhandari[2], Manish Kumar Thakur[3], Surendra Prasad Yadav[1], Diagambar Yadav[4], Bikash Dahal[1] and Damali Sherpa[1]

[1] Directorate of Agricultural Research, Koshi Province, Sunsari
[2] Nepal Agricultural Research Council, Singhadurbar plaza
[3] National Commercial Agriculture Research Program
[4] Soil and Fertilizer Testing Laboratory, Koshi Province Sunsari

ABSTRACT

The experiments were conducted during September-March over two years, in 2022-23 and 2023-24 under plastic house at Directorate of Agricultural Research, Tarahara, Sunsari to evaluate the responses of organic sources of nutrition on growth, yield, yield attributes and fruit quality of tomato and to monitor changes in soil properties. Experiments were laid out in a Randomized Complete Block Design (RCBD) with eight treatments comprising organic manures and compost like farmyard manure, vermicompost, poultry manure, goat manure, mustard oil cake, self-prepared compost and Jeevamrut including the control plots without any fertilizers. Each treatment was replicated thrice. The doses of manures and compost were calculated to fulfill the nitrogen requirement recommended for Tomato cv. 'Srijana'. The pooled analysis revealed that the plant height, days to first flower, number of fruits per cluster, number of fruits per plant and fruits yields showed significant variation among the treatments. The highest fruit yield (2.93 kg/plant i.e.74.92 t/ha) was obtained from plants treated with vermicompost followed by the plants receiving farmyard manure (2.88 kg/plant). Treatments did not show significant change in the Total soluble solids (TSS) and titratable acidity (TA) of tomato fruits. The soil samples of each experimental plot were analyzed for chemical and physical properties at the beginning and after the crop's final harvest in both the years. The significant improvement in total nitrogen, available phosphorus, available potassium and soil organic matter was observed in fertilized plots over the control during trial period.

Keywords:

Compost, Fruit quality, Growth, Organic manures, Tomato, Yield

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), the edible berry belonging to Solanaceae family is a popular and commonly used ingredient in cuisines worldwide. It is an essential constituent in Nepalese cooking as well. Tomato is a good source of potassium, folate, vitamin A, C and E and phytochemicals-carotenoids such as lycopene, β Carotene, phytoene and phytofluene (Kirstie

* Corresponding author Email: shukrarajshrestha@gmail.com

et al., 2005). The estimated total production of tomato is about 186 million tonnes in 2022 ranking second after the potato having production of about 375 million tonnes (FAOSTAT, 2024). It is widely cultivated fruit vegetables in different agro-ecological domains of Nepal. It was cultivated in 4,998 hectares of land with an annual production of 1,26,354 mt in 2021/22 in Koshi Province (MoALD, 2023). The national production in the same year was 4,22,703 mt from 22,911 hectares of land.

Excessive and inappropriate use of chemicals has put forth a question on sustainability of agriculture in the long run and concerns have been raised time and again over its adverse effects on soil productivity and environment. The use of chemical fertilizers and pesticides during production can have an impact on the sanitary, organoleptic and nutritional quality of the tomato and even on the health of the consumer (Khan et al., 2008). Continuous use of inorganic fertilizers alone to soils had a deleterious effect on soil productivity and a steady declining trend in crop productivity associated mainly with loss of inherent soil fertility (Bhattacharyya et al., 2015). Alarmingly, about 50 percent of the chemical fertilizers applied to soil remain unused and causes enormous reactions resulting in deterioration in the water conservation and nutrients holding capacity of soil (Reazuddin, 1994). Furthermore, increased use of hybrid seeds of cereals and vegetables has been driven to more demand for pesticides and chemical fertilizers, and Nepal which does not manufacture such fertilizers/pesticides, will become over dependent and rely more on imports. These scenarios have drawn the attention of many agricultural scientists and specialists towards organic farming practices so that the environment friendly and sustainable agriculture can be achieved. Increasing consciousness about ill effects of the chemical pesticides and fertilizers have led to a demand of more policies and agricultural management methods to achieve sustainable agriculture.

IFOAM, 2008 in its definition of organic agriculture has highlighted on health of soils, ecosystems, and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. The trend of organic production of vegetables has emerged these days and many promotional activities were conducted in different parts of Koshi Province. While initiating, practicing and promoting organic agriculture, the use of organic manures/amendments is one of the essential and mandatory components. There is no alternative method of nourishing soil other than organic manures in organic agriculture/farming. Organic manures improve soil physical, chemical and biological properties (Khan et al., 2010) and its regular application improves soil structure and leads to better environment for root development, ultimately increased crops' yield. Application of organic manures are directly associated with bio-chemical properties of tomato fruits as well. Studies have suggested that tomatoes grown with organic manure often exhibit a more balanced sweetness-acidity ratio that provides better taste with slight variations depending on the type of organic manure used. Improved microbial activity and better soil structure associated with organic manure application enhance nutrient cycling, particularly potassium, which plays a crucial role in sugar accumulation (Patil et al., 2004). Hence, to study the response of organic sources of nutrition in growth parameters, yields, yield attributes and bio-chemical properties of tomato and the soil properties dynamics the field experiments were conducted for consecutive two years 2022-23 and 2023-24.

METHODOLOGY

EXPERIMENTAL SITE

The field experiments were conducted at Directorate of Agricultural Research (DoAR), Tarahara, Sunsari (Figure 1) in the predominant plain soil having Silty clay loam texture. The experimental site is situated in Eastern Terai of Nepal at 26°42' North latitude and 87°16' East longitude, located at an elevation of 127 meter above mean sea level.

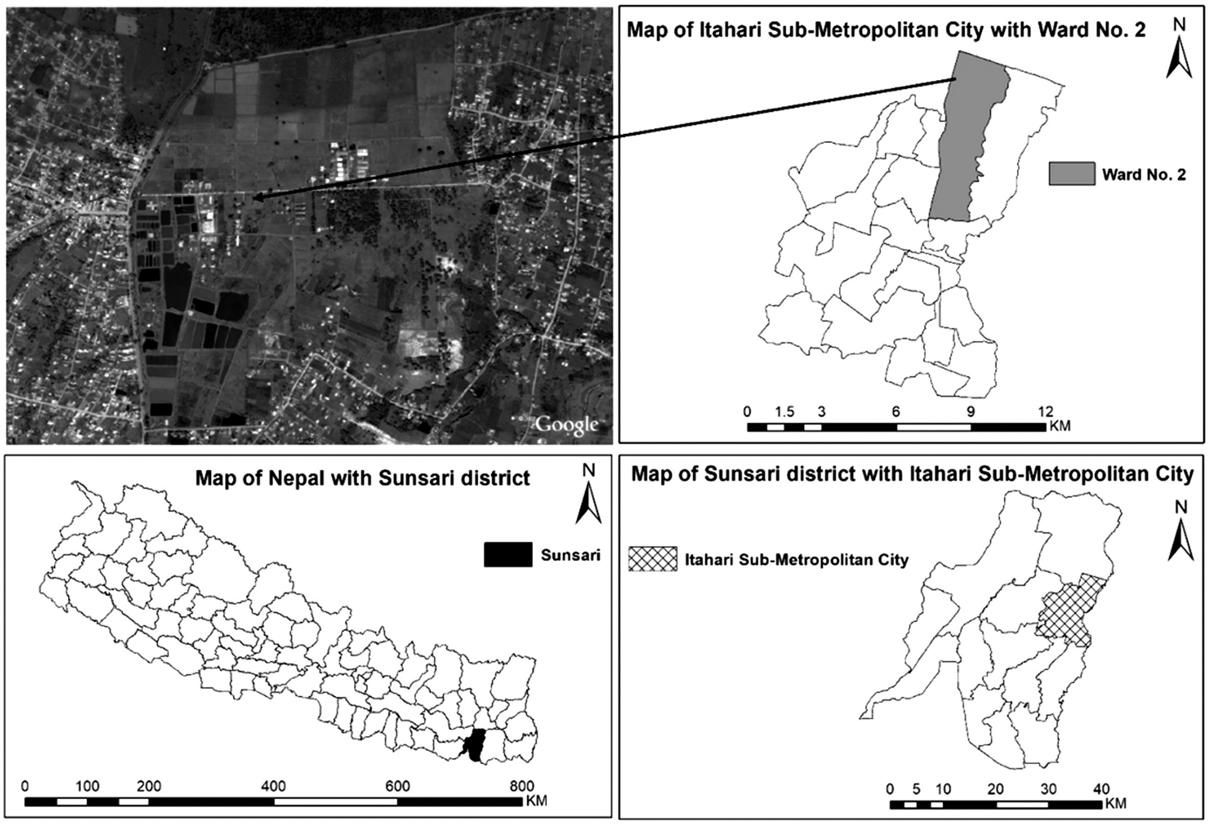


Figure 1. Different maps showing the study district, sub-metropolitan city, ward and experimental site

SOIL SAMPLING AND ANALYSIS

A composite soil sample of experimental plot representing 30 samples of upper layer (0-25 cm depth) was taken before transplanting of the crop to estimate the initial value of soil properties; total nitrogen, available phosphorus, available potassium, soil organic matter, pH, soil texture and bulk density. The samples were analyzed at the soil lab of Directorate of Agricultural Research, Tarahara, Sunsari following standard lab methods of NARC (Table 1). The soil samples of each experimental plot were analyzed for chemical properties and bulk density after the crop's final harvest in both the years.

Table 1. Initial status of soil properties and methods adopted for the laboratory analysis at DoAR, Tarahara, Sunsari, 2022

SN	Parameter	Unit	Method	Analysis status	Ratings/Remarks
1	Total Nitrogen	%	Kjeldahl Digestion (Bremner & Mulvaney, 1982)	0.12	Medium
2	Available P_2O_5	ppm	Olsen (Olsen et al., 1954)	23.6	Low
3	Available K_2O	ppm	Ammonium acetate extraction (Jackson, 1967)	38.5	Very low
4	Soil Organic Matter	%	Walkley-Black wet oxidation (Walkley & Black, 1934)	2.7	Medium
5	pH		Potentiometric 1:2.5 (Jackson, 1973)	6.2	Slightly acidic
6	Sand	%		15.7	
7	Silt	%		50.1	
8	Clay	%		34.2	
9	Soil texture		Hydrometer (Bouyoucos, 1962)	Silty clay loam	
10	Bulk density	g/cm^3		1.48	Moderate (acceptable for many crops)

Note: The status is based on ratings provided by National Soil Science Research Center, Khumaltar, NARC

EXPERIMENTAL SETUP AND CROP VARIETY

The experiments were laid out in Randomized Complete Block Design (RCBD) with eight treatments replicated thrice. The tomato variety 'Srijana' F1 hybrid registered by National Seed Board in 2010 was used in the experiment. The spacings of 70 cm (RR) and 60 cm (PP) were maintained. The individual net plot and gross plot sizes were 1.68 and 3.90 m^2 respectively with 10 observable plant population accommodated in each plot. The seedlings raised in tray with growth media were transplanted after 20 days of seeding.

TREATMENTS' DETAIL

The following 8 treatments shown in table below comprising different organic sources were applied during experiments.

Table 2. Treatments for the field experiments at DoAR, Tarahara, Sunsari (2022-23 and 2023-24).

T/ No.	Treatments	Remarks
T1	Control	No any external inputs were applied as soil amendments and fertilizers
T2	Farmyard manure	A well rotten farmyard manure
T3	Vermicompost	A well rotten vermicompost
T4	Poultry manure	A well rotten poultry manure
T5	Goat manure	A well rotten goat manure
T6	Mustard oil cake	A well powdered mustard oil cake
T7	Compost	Prepared by mixing 10 kg farmyard manure, 10 kg wooden dust, 10 kg fresh banmara (*Eupatorium adenophorum* L.), 10 kg rice bran, 10 kg oil cake, 5 kg ash of rice straw, 2 kg jaggery, 10 liter of buffalo urine and 5 liter of liquid fertilizer containing effective microorganisms and used after 40 days of mixing.
T8	Jeevamrut	Prepared by mixing 1 kg of fresh cow dung, 1 liter of cow urine, 200 g of jaggery, 200 g of chickpea flour and handful of forest soil in 20 liters of water. The solution was mixed well.

After 6 days of storage, Jeevamrut was applied @ 1 liter per plant around the trunk in soil. Jeevamrut was first applied at 15 days of transplanting and thereafter at every interval of 20 days. In total 6 liter of Jeevamrut was applied to each plant.

All the recommended dose of solid manures and compost were placed in pit and mixed with soil before 5 days of transplanting. Intercultural operations like weeding, irrigation, pruning and staking were done as per the necessary. For disease and insect management the organic proven pesticides/insecticides were used.

Estimation of the dose of manures and compost: Nutrient content of well decomposed manure and compost were assessed following the standard methods at DoAR, Tarahara and Soil and Fertilizer Testing Laboratory, Jhumka. The dose of manures and compost were then calculated to fulfill the nitrogen requirement recommended for 'Srijana' variety that comes to be 35 g/plant (Shrestha et al., 2021) on per plant basis (Table 3). The average nitrogen, phosphorus and potassium contents in different manures and compost were shown in table below.

Table 3. Dose of manures and compost with nutrient content provided to plants during the experiments at DoAR, Tarahara, Sunsari (2022-23 and 2023-24).

T/No.	Manures	N content (%)	P_2O_5 content (%)	K_2O content (%)	Amount (g/ plant)
T1	Control	-	-	-	-
T2	Farmyard manure	0.58	0.27	0.54	6034.48
T3	Vermicompost	2.30	1.38	2.17	1521.74
T4	Poultry manure	3.94	2.54	2.15	888.32
T5	Goat manure	1.74	0.58	1.62	2011.49
T6	Mustard oil cake	4.83	0.95	1.05	724.64
T7	Compost	1.69	1.25	0.85	2071.01
T8	Jeevamrut (Soil)	-			-

DATA COLLECTION

The alternate 3 plants from first row and 2 plants from second row were selected and tagged in each plot to measure plant height (cm), days to first flower (DAT), number of fruits per cluster, no. of fruits per plant, fruits yield per plant (kg) and fruits yield per hectare (t/ha). The fruits yields mentioned in table 3 are average value of marketable yield. The plant height was measured once using a measuring scale at the final harvest. Number of fruits from five clusters were counted at each harvest and average value was recorded. For individual fruit weight, five fruits were randomly selected from each treatment/plot, weighed and average value was recorded. The fruits yield per plant was the average yield obtained from five plants. Fruits yield per hectare was calculated on the basis of yield and plant population of net plot area.

Total Soluble Solids (TSS): The sample fruits were harvested at light-red ripe stage. The juice from selected 5 tomatoes from each plot (treatment) was extracted and homogenized for 2 min at high-speed food blender and then filtered using a muslin cloth. TSS were measured by using a digital refractometer. The refractometer was first standardized by adding few drops of water and one to two drops of clear juice were placed on the prism for observation. The resulted value was expressed as ^{o}Brix.

Titratable Acidity (TA): For TA, 5 ml extracted juice was taken and diluted with 95 ml distilled water and phenolphthalein as an indicator. TA was then calculated by titrating 5 ml tomato juice against 0.1 N NaOH. The titratable acidity (TA) of the tomato was determined by the titration method explained by Teka (2013). Titratable acidity was expressed as a percentage of citric acid and it was calculated by using the following equation;

$$\%\ \text{Citric acid} = \frac{\text{Volume of NaOH (ml)} * 0.1\ \text{(Normality of NaOH)} * 0.064 * 100}{\text{Volume of juice (ml)}}$$

Where, 0.064 is the citric acid milliequivalent factor.

STATISTICAL ANALYSIS

The collected data were analyzed as per the procedure given in R-STAT software (Version 4.1.1) for the randomized complete block design (R Core Team, 2021). Analysis of variance (ANOVA) was performed and the treatment means were compared by the Least Significant Difference (LSD) test at 5% level (Gomez and Gomez, 1984).

RESULTS

GROWTH ATTRIBUTES

The plots receiving poultry manure recorded significantly ($p<0.05$) higher plant height at harvest (228.47 cm) followed by the plots receiving mustard oil cake (218.43 cm) and Jeevamrut (216.23 cm). The lowest plant height was observed in control plots (196.03 cm). The earliest inflorescence (20 DAT) was reported in control plots while Jeevamrut treated plots experienced first flower at 21 DAT and rest of the treatments resulted first flowers at 22 DAT showing statistical at par (Table 4).

YIELDS AND YIELD ATTRIBUTES

The data obtained from pooled analysis revealed that the number of fruits per cluster, number of fruits per plant and fruits yields varied significantly ($p<0.05$) with different treatments (Table 4). The number of fruits per cluster showed statistically similar results among the treatments with application of vermicompost, poultry manure and Jeevamrut resulting higher number of fruits per cluster (8.7) followed by the plots treated with farmyard manure, goat manure and mustard oil cake (8.0). The plots receiving vermicompost counted significantly higher number of fruits per plant (87) followed by the application of goat manures (85) with an increase in 19.5% and 17.6% over the control respectively. The plots receiving poultry manure and mustard oil cake resulted similar number of fruits per plant (84). A significant variation was observed in fruits yield per plant because of different organic sources of nutrition. In the study, the highest fruit yield (2.93 kg i.e., 74.92 t/ha) was obtained from plants treated with vermicompost followed by the plants receiving farmyard manure (2.88 kg) and self-made compost (2.85 kg). The plots where no external inputs were applied i.e., control plots registered significantly lower number of fruits per cluster (7.3), number of fruits per plant (70), fruits yield per plant (2.04 kg) with 51.83 t/ha fruits yield.

FRUITS CHEMICAL PROPERTIES

Fruits chemical properties like total soluble solid and titratable acidity did not significantly vary among the treatments. The highest TSS was found in fruits treated with vermicompost (5.28 ^{o}Brix) followed by goat manure (5.16 ^{o}Brix) and poultry manure (5.11^{o}Brix) with lowest value in fruits of control plots (4.83 ^{o}Brix). Titratable acidity of fruits treated with different organic manures ranges from 0.23% to 0.25%.

Table 4. Average value of growth parameters, yield, yield attributes and fruit quality of tomato as influenced by organic nutrient management practices at DoAR, Tarahara during 2022-23 and 2023-24.

Treatments (Treatment Code)	Plant height (cm)	Days to first flower (DAT)	No. of fruits per cluster	No. of fruits per plant	Fruits yield per plant (kg)	Fruits yield (t/ha)	Total Soluble Solid (°Brix)	Titratable Acidity (%)
T1 (Control)	196.03[c]	20[c]	7	70[c]	2.04[d]	51.83[d]	4.83	0.23
T2 (FYM)	213.33[b]	22[ab]	8	83[ab]	2.88[ab]	72.25[ab]	4.95	0.23
T3 (Vermi)	209.73[b]	22[a]	9	87[a]	2.93[a]	74.92[a]	5.28	0.24
T4 (Poultry M)	228.47[a]	22[ab]	9	84[ab]	2.79[abc]	69.67[bc]	5.11	0.23
T5 (Goat M)	214.43[b]	22[a]	8	85[ab]	2.68[c]	70.33[abc]	5.16	0.23
T6 (MOC)	218.43[ab]	22[ab]	8	83[ab]	2.73[bc]	66.50[c]	4.98	0.25
T7 (Compost)	214.30[b]	22[a]	8	84[ab]	2.85[abc]	72.17[ab]	5.01	0.24
T8 (Jeevamrut)	216.23[ab]	21[bc]	9	79[b]	2.81[abc]	68.33[bc]	5.07	0.23
P value	0.011	0.002	0.35	0.008	<0.001	<0.001	0.56	0.12
LSD $_{(0.05)}$	13.38	0.72	1.37	7.23	0.20	4.72	1.31	0.01
SEm (±)	1.56	0.08	0.16	0.84	0.02	0.58	0.05	0.002
CV (%)	3.57	1.90	9.64	5.05	4.18	3.96	5.08	3.27

Note-Means in each column with the same superscript are not significantly different by DMRT (p<0.05). CV: Coefficient of Variance, LSD: Least Significant Difference; SEm: Standard Error Mean, MOC: Mustard oil cake, M: Manure

CHANGE IN SOIL PROPERTIES

All the tested soil parameters except the soil pH in second year varied significantly ($p<0.05$) under different treatments (Table 5). The total nitrogen, available phosphorus, available potassium and soil organic matter of control plots declined significantly over the trial period by 50, 45.2, 55.5 and 34.1 percent respectively.

TOTAL NITROGEN

The total nitrogen in soil after first and second harvest varied significantly among the treatments. Application of different organic manures, compost and Jeevamrut significantly increases the total nitrogen content in soil at the end of experiment. After first harvest the highest total nitrogen was revealed in poultry manure treated plots (0.16%) followed by the farmyard manure treated plots (0.15%). The final harvest resulted the highest total nitrogen content in the farmyard manure treated plots (0.19%).

AVAILABLE PHOSPHORUS

In both the years the available phosphorus content in soil varied significantly among the treatments (Table 4) with application of poultry manure resulting significantly higher amount in first (45.5 ppm) and second (51.8 ppm) harvests. The continuous application of manures, compost and Jeevamrut in two years showed ascended content of available phosphorus in soil.

AVAILABLE POTASSIUM

The available potassium was significantly higher in poultry manure treated plots in both the first (49.7 ppm) and second (54.9 ppm) harvests (Table 5). This highest value was followed by vermicompost treated plots, which accorded the available potassium content in soil with 46.1 and 48.9 ppm in first and second harvests respectively.

SOIL ORGANIC MATTER

The farmyard manure treated plots showed significantly higher soil organic matter content over the trial period followed by the compost. The plots treated with farmyard manure and compost treated plots resulted net increment of 35.7% and 30.8% soil organic matter respectively.

SOIL pH

The soil pH was significantly lower in control plots after first harvest (5.5) with highest fluctuation in farmyard manure (6.2-6.9) and poultry manure (6.2-7.0) treated plots (Table 5).

BULK DENSITY

The application of manures and compost significantly lowered the soil bulk density. In first year, the application of vermicompost and goat manure resulted the lowest bulk density (1.44 g/cm^3), while in second year, significantly lower bulk density was observed in poultry manure treated plots (1.42 g/cm^3).

Table 5. Change in soil properties after first (2023) and second (2024) harvest under different practices of organic nutrition in tomato at DoAR, Tarahara.

Treatments	**Total Nitrogen (%)**		**Available P_2O_5 (ppm)**		**Available K_2O (ppm)**		**Soil organic matter (%)**		**pH**		**Bulk Density (g/cm^3)**	
	2023	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**	**2023**	**2024**
T1 (Control)	0.08^f	0.06^c	16.9^c	12.9^c	20.8^c	17.13^c	2.2^d	1.8^e	5.5^b	5.9	1.55^a	1.58^a
T2 (FYM)	0.15^{ab}	0.19^a	41.3^{ab}	42.2^{ab}	38.1^b	44.03^{ab}	3.9^a	4.2^{ab}	6.8^a	6.9	1.45^b	1.43^b
T3 (Vermi)	0.14^{bc}	0.15^{ab}	37.8^b	39.1^b	46.1^{ab}	48.9^{ab}	3.3^{bc}	3.6^{bc}	6.3^a	6.5	1.44^b	1.44^b
T4 (Poultry M)	0.16^a	0.18^a	45.5^a	51.8^a	49.7^a	54.9^a	3.0^c	3.4^{cd}	6.5^a	7.0	1.46^b	1.42^b
T5 (Goat M)	0.13^{de}	0.14^{ab}	34.2^b	38.8^b	40.1^b	43.3^{ab}	3.0^c	3.3^{cd}	6.6^a	6.8	1.44^b	1.43^b
T6 (MOC)	0.14^{bcd}	0.16^{ab}	39.2^{abc}	44.7^{ab}	34.3^b	36.6^b	3.0^c	3.2^{cd}	6.2^a	6.5	1.47^b	1.45^b
T7 (Compost)	0.12^e	0.15^{ab}	36.2^b	45.3^{ab}	37.4^b	42.3^{ab}	3.7^{ab}	3.9^{ab}	6.1^a	6.3	1.46^b	1.46^b
T8 (Jeevamrut)	0.13^{cde}	0.14^b	33.9^b	40.1^b	35.8^b	41.7^{ab}	2.8^c	3.1^d	6.3^a	6.4	1.48^b	1.44^b
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.01	0.15	0.006	0.03

LSD $_{(0.05)}$	0.01	0.04	7.15	9.08	9.12	13.07	0.46	0.43	0.75	0.95	0.05	0.06
SEm (±)	0.002	0.004	0.83	1.06	1.06	1.52	0.05	0.05	0.09	0.11	0.006	0.007
CV (%)	5.75	14.53	11.78	13.92	14.18	18.13	8.40	7.48	6.73	8.28	2.01	2.25

Note-Means in each column with the same superscript are not significantly different by DMRT (p<0.05). CV: Coefficient of Variance, LSD: Least Significant Difference; SEm: Standard Error Mean

DISCUSSION

The increase in plant height following the application of different organic manures is consistent with the findings of Laxmi et al., (2015), who reported that organic fertilizers are rich in essential macro and micronutrients that enhance photosynthesis and protein synthesis supporting cell division and elongation. The earlier and forced inflorescence in control plots might be due to the low nitrogen leading to increased synthesis of abscisic acid (ABA) and a reduction in cytokinins, both of which promote earlier flowering. A deficiency in phosphorus can also trigger early flowering as suggested by Grant et al., (2001), as it's a key element in energy transfer during reproduction. Obi & Ebo (1995) observed that the application of organic manures along with compost improved soil water relationship, which affected bulk density and porosity of the soil, made available the moisture contents in proper proportion with required soil nutrients. These factors as justified by them helps to promote the number of fruits per cluster and number of fruits per plant. The significantly higher fruit yield by the application of vermicompost are in close resemblance with Ali et al., (2015), who reported that the vermicompost provides a more balanced and slow-release supply of nutrients, making them more readily available to plants over time and reducing the risk of nutrient leaching with richness in beneficial microbes and enzymes. Despite the higher content of NPK in poultry manure, it releases nutrients too quickly and possess lesser buffering capacity which failed to influence fruits yield as compared to vermicompost. In addition, Akand et al., (2015) advocated that the higher fruits yield by the application of organic fertilizers is due to the promoted vegetative growth and other yield parameters like fruits per cluster and fruits weight. Organic manures have been shown to enhance TSS in tomato compared to unfertilized fruits. This improvement is attributed to the better nutrient availability, including macro and micro-nutrients provided by organic inputs. Decomposition of organic matter improves soil structure and moisture retention, facilitating a steady nutrient supply, which supports sugar accumulation and the development of soluble solids in fruit (Alexander et al., 2006). The narrow range of titratable acidity of fruits treated with different organic manures could be linked to the slow nutrient release from organic sources, which alters the plant's metabolic balance, promoting the synthesis of organic acids. Organic manures also improve soil moisture and reduce plant stress, stabilizing acid production in fruits.

The depletion of primary nutrients in control plots after harvest is due to crop uptake from the soil during the growth and development without replenishment. Decline in soil organic matter is due to null application of organic sources of nutrition in control plots. Organic manures when applied to soil release nitrogen as they decompose, adding both organic and inorganic forms of nitrogen. A study by Mahajan et al., (2019) observed a 15-20% increase in soil nitrogen after three years of continuous organic manure application compared to chemical fertilizers. Sanchez & Leakey (2020) highlighted that the application of composted manures enhances microbial activity, leading to increased nitrogen mineralization rates, which is crucial for the conversion of organic nitrogen to ammonium (NH_4^+) and nitrate (NO_3^-) forms. This contributes to a higher buildup of soil total nitrogen over time. A study conducted by Singh & Singh (2022) also demonstrated that farmyard manure (FYM), vermicompost and poultry manure significantly increased the availability of soil phosphorus in tomato fields. The organic acids released during manure decomposition can chelate Fe and Al ions reducing their interaction with phosphorus and thereby enhancing P availability. This might be the reason behind the unavailable forms of phosphorus in the acidic soil of trial plots got transferred to available forms with enhanced P content as prevailed in the result. Furthermore, organic manures when decompose, release phosphorus in both organic and inorganic forms making it available to plants and also increasing its content in soil. Boraiah et al., (2017) reported that the microbial populations boosted by organic manure applications enhanced phosphorus solubilization through the production of organic acids and enzymes. Organic manures stimulate microbial activities, which aids in the breakdown of potassium-bearing minerals in the soil, releasing potassium into plant-available forms. Also, the addition of organic matter by the continuous application of manures and compost improves the soil's cation exchange capacity (CEC), reducing potassium leaching in soils. Whalen & Chang, after examining long-term impacts of manure application on soil potassium in 2002 revealed that the application of manures including vermicompost improved microbial activity, which contributed to potassium mineralization, increasing its availability by 30-35% compared to control plots. Organic manures stimulate microbial populations (bacteria, fungi and actinomycetes) by providing energy source i.e., carbon and nutrients and their activities enhances the breakdown of organic materials and the formation of stable organic matter. The result is in harmony with the findings of Verma et al., 2024 who revealed the improved organic matter by the application of manures and organic amendments in different solanaceous group of vegetables. The increased soil pH by the application of vermicompost, goat manure and mustard oil cake is due to enriched content of cations like calcium and potassium in it as revealed by Ayeni & Ezeh (2017). Organic manures improve soil structure by binding soil particles into aggregates, creating a more porous structure. These materials add lightweight organic matter, which increases the volume of pores in the soil, reducing its overall density.

CONCLUSION

The application of organic amendments significantly influenced the growth and yield parameters of the crop compared to the control (T1). Among all treatments, vermicompost (T3) consistently resulted in superior performance, with the highest number of fruits per plant maximum fruit yield per plant, and highest total yield, while also recording the highest TSS, indicating better fruit quality. Poultry manure (T4) also showed promising results, particularly in plant height, highlighting its positive impact on vegetative growth. The data demonstrate that organic inputs such as vermicompost and poultry manure can effectively enhance both quantitative and qualitative traits of crop performance, offering sustainable alternatives to conventional practices. The application of organic amendments had a significant positive impact on soil fertility and physical properties. Poultry manure (T4) emerged as the most effective treatment, showing the highest levels of total nitrogen, available phosphorus, and available potassium, indicating enhanced nutrient availability. Farmyard manure (T2) also performed well, especially in increasing soil organic matter and maintaining favorable pH and bulk density. Across treatments, all organic inputs improved soil nutrient status and organic matter content compared to the control (T1), which consistently recorded the lowest values. Moreover, treatments reduced soil bulk density and maintained near-neutral pH levels, contributing to better soil structure and health. These findings highlight the long-term benefits of organic amendments in sustaining soil fertility and improving soil quality. This study clearly indicated the positive influence of manures and compost in soil chemical and physical properties. But to unveil the increment trend of primary nutrients and organic matter with the application of similar dose of organic manures the same experiment needs to be conducted for more than two years.

DECLARATION

The authors declare no conflict of interests.

ACKNOWLEDGEMENTS

The authors express their gratitude to the government of Nepal, Nepal Agricultural Research Council (NARC) for supporting this study. The authors are thankful to Directorate of Agricultural Research, Tarahara, Sunsari, National Soil Science Research Center, Khumaltar, Lalitpur, Soil and Fertilizer Testing Laboratory, Jhumka, Sunsari and Horticulture Research Unit, DoAR, Tarahara for laboratory facilities and the technical supports.

REFERENCES

Akand, H. M., Khairul Mazed, H. E. M., Islam, M. A., Pulok, M., Chowdhury, S. N., & Moonmoon, J. F. (2015). Effect of organic manures on assessment of shelf life of tomato varieties (*Lycopersicon esculentum* Mill.) *International Journal of Applied Research*, 1(5), 94-97.

Alexander, W. C., Linh, B., Erica, N. C., Renaud, MVH., & Alyson, E. M. (2006).Three year comparison of the content of antioxidant micro constituents and several quality characteristics in organic and conventionally managed tomatoes and bell peppers. J.Agic Food Chem., 54: 8244-8252.

Ali, I., Khattak, A. M., Ali, M., & Ullah, K. (2015). Performance of different tomato cultivars under Organic and Inorganic regimes. Pakistan J. Agric. Res. 28(3): 245-254.

Ayeni, A. S., & Ezeh, P. (2017). "Comparative Effect of NPK, Organic, and Organo-Mineral Fertilizers on Soil Properties and Tomato Yield," Applied Tropical Agriculture; 23(4): 345-57.

Bhattacharyya, P., Nayak, A. K., Shahid, M., Tripathi, R., Mohanty, S., Kumar, A., Rajagounder, R., Panda, B. B., Lal, B., Gautam, P., Swain, C. K., Singh, R. K., & Dash, P. K. (2015). Effects of 42-year long-term fertilizer management on soil phosphorus availability, fractionation, adsorption–desorption isotherm and plant uptake in flooded tropical rice. The Crop Journal, 4: 34-41.

Boraiah, H. K., Singh, A. K., Beer, K., & Pal, A. K. (2017). Effect of vermicompost and biofertilizers on soil phosphorus under strawberry cultivation. Ann Plant Soil Research; 17 (2): 196-199.

Bouyoucos, G. J. (1962). Hydrometer method improved for making particle size analyses of soils. Agronomy Journal 54 (5): 464-465.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen total. In: A. L. Page (ed.), Methods of soil analysis. Agron. No. 9, Part 2: Chemical and microbiological properties. 2nd edition. Am. Soc. Agron., WI, USA; pp. 595-624.

FAO. (2024). World Food and Agriculture – Statistical Yearbook 2024. Rome. https://doi.org/10.4060/cd2971en

Gomez, K. A., & Gomez, A. A. (1984). Statistical Procedure for Agricultural Research (2nd edn.). Int. Rice Res. Inst. And Willey, New York; pp. 28-192.

Grant, C. A., Flaten, D. N., Tomasiewicz, D. J., & Sheppard, S. C. (2001). The importance of phosphorus in crop production. Canadian Journal of Plant Science, 81(2), 211–224. https://doi.org/10.4141/P00-093

International Federation of Organic Agriculture Movement (IFOAM). (2008). The Policy Framework of Organic Food and Farming. The General Assembly, 2008.

Jackson, M. L. (1967). Handling soil samples in the laboratory. In: Soil chemical analysis. Prentice hall of India, Pvt. Ltd., New Delhi 2: 30-37.

Jackson, M. L. (1973). Soil Chemical Analysis. Pentice Hall of India Pvt. Ltd., New Delhi.

Jenkins, J. A. (1948). The origin of the cultivated tomato. Econ Bot 2, 379-392. https: //doi.org/10.1007/BF02859492.

Khan, A. I., Malik, A. U., Umer, F., & Bodla, M. I. (2010). Effect of Tillage and Farmyard Manure on Physical and Chemical Properties of Soil. International Research Journal of Plant Science, 1(4) 75-82.

Khan, D. A., Bhatti, M. M., Khan, F. A., Naqvi, S. T., & Karam, A. (2008). Adverse effects of pesticides residues on biochemical markers in Pakistani tobacco farmers. Int J Clin Exp Med, 1(3): 274-282.

Kirstie, C. A., Campbell, J. K., Zaripheh, S., Elizabeth, H. J., & Erdman, J. W. (2005). The Tomato as a Functional Food. American Society for Nutritional Sciences. 135: 1226-1230.

Laxmi, P. R., Saravanan, S., & Naik, M. L. (2015). Effect of organic manures and inorganic fertilizers on plant growth, yield, fruit quality and shelf life of tomato (Solanum lycopersicon L.) CV PKM-1. Int J Agric Sci Res; 5(2):7–1.

Mahajan, A., Gupta, R. D., & Sharma, R. K. (2019). Effect of long-term application of organic manures on soil fertility and crop yield. Journal of Soil and Water Conservation, 78(3), 234-241.

MoALD. (2023). Statistical Information on Nepalese Agriculture 2021/22. Government of Nepal, Ministry of Agriculture & Livestock Development, Planning & Development

Cooperation Coordination Division, Statistics and Analysis Section, Singha durbar, Kathmandu, Nepal.

Obi, M. E., & Ebo, P. (1995). The effect of organic and inorganic amendments on soil physical properties and production in a severely degraded sandy soil in southern Nigeria. Bioresource Technol. 51(2-3): 117-123

Olsen, S. R., Cole, C. V., & Dean, L. A. (1954). Estimation of available phosphorus in soil by extraction with sodium carbonate. In: Method of soil analysis, Part 2. (CA Black, ed) American Soc. Agron. Inc, Medison, USA; pp. 1044-1046.

Patil, M. B., Mohammed, R. G., & Ghadge, P. M. (2004). Effect of organic and inorganic fertilizers on growth, yield and quality of tomato. Journal of Maharashtra Agricultural Universities, 29(2): 124-127.

Reazuddin, M. (1994). The Issues of Agro-chemicals and Environment: Towards Sustainable Agricultural Development. In: A paper presented at the Seminar held at BARC on January, vol. 5 p.

Sanchez, P. A., & Leakey, R. R. B. (2020). Nutrient cycling and soil productivity in agroforestry systems. Agroforestry Systems, 99(2): 189-210.

Shrestha, S. L., Ghimire, D., Gotame, T. P., Gautam, I. P., & Khatiwada, P. P. (2021). Growth, Yield and Keeping Quality of Tomato Cultivars at Central Mid-Hills of Nepal. Proceeding of 12th National Horticulture Seminar. Pp. 161-168.

Singh, V. N., & Singh, S. S. (2022). Studies on the effect of INM on growth, yield and economics of tomato [Solanum lycopersicon (L.)] cv. NDT-6. J. Multidiscipl Ina Adv Res. 2(2):94–102.35.

Teka, T. A. (2013). Analysis of the effect of maturity stage on the postharvestbiochemical quality characteristics of tomato (Lycopersicon esculentum Mill.) fruit. Intl. Res. J. Pharmaceut. Appl. Sci. (IRJPAS) 3 (5): 180–186.

Verma, S., Pradhan S. S., Singh, A., & Kushuwaha, M. (2024). “Effect of Organic Manure on Different Soil Properties: A Review”. International Journal of Plant & Soil Science 36 (5):182-87.

Walkley, A. J., & Black, I. A. (1934). Estimation of soil organic carbon by the chromic acid titration method. Soil Science 37 (1): 29-38.

Whalen, J. K., & Chang, C. (2002). "Macro organic matter properties and microbial populations after 25 years of manure and fertilizer application." Biology and Fertility of Soils, 6(12): 214-228.

https://doi.org/10.3126/adj.v18i1.82090

Agriculture Development Journal, Volume 18 (2025)

PERFORMANCE EVALUATION AND TRAIT ASSOCIATION ANALYSIS OF PROSO MILLET GENOTYPES IN BAJURA DISTRICT, NEPAL

Kailash Bhatta[1,*], Pragati Raj Sipkhan[2], Bishnu Bhusal[2], Laxman Khatri[2] and Rajendra Dhakal[2]

[1] International Center for Integrated Mountain Development (ICIMOD) Kathmandu, Nepal

[2] Local Initiatives for Biodiversity, Research and Development (Li-BIRD), Pokhara, Nepal

ABSTRACT

Proso millet (Panicum miliaceum L.), an indigenous crop cultivated by the farmers in Bajura for generations, was once the major millet crop of the area. The crop is now experiencing a sharp decline due to shifting food preferences, yield reduction and limited crop improvement program, which has threatened the existence of the crop in Nepal's hill and mountains region. Therefore, an on-farm experiment was conducted using a randomized complete block design for the first time in Bajura, aimed at evaluating eight genotypes of proso millet—including two local landraces (Mal Chino and Dudhe Chino) and six accessions (NGRC07344, NGRC07345, NGRC07348, NGRC07349, NGRC07350, and NGRC07351) from the National Agriculture Genetic Resource Center (NAGRC)—under local conditions. The local landrace - Mal Chino outperformed all other genotypes yielding 2.06 t/ha and driven by maximum tillering (10.2), leaf number (69.73), and longest flag leaf (49.19 cm). Among the introduced lines, NGRC07345 recorded the second-highest yield (1.7 t/ha) and demonstrated adaptability in the studied region. Correlation and regression analysis identified flag leaf length and tiller number as a key determinant for grain yield. The study emphasized the potential of millets and landrace crops to improve food security and livelihoods in hilly and Himalayan areas of Nepal. Future efforts should be explored for multi-year and multi-location crop improvement study of promising and adapting genotypes to integrate in Nepal's formal seed system.

Keywords:

Future smart crops, landraces, revitalization, food security, yield performance

1 INTRODUCTION

Millet crops take sixth position among cereal crops that contribute to sustaining global food security, hence proclaiming them as future smart crops (Changmei and Dorothy, 2014). Proso millet (*Panicum miliaceum* L.) (*Chino* in Nepali) is one of the oldest domesticated millets, cultivated more than 10,000 years ago in Northern China (Liu et al., 2015; Rajasekaran et al., 2023). Though exact timing for domestication of proso millet is still a subject of debate, most of the archaeologists believe Northwest China, Central China, and Inner Mongolia as

* Corresponding author Email: kailash.bhatta07@gmail.com

a primary centre of origin (Zhao, 2005; Lu et al., 2009; Bettinger et al., 2010). The crop is widely cultivated in the northern altitude of Hindu Kush Himalayan regional countries such as China, Nepal, India, Myanmar, Sri Lanka, Pakistan (Joshi et al., 2023). It thrives under low input conditions, tolerates drought, and performs well in marginal and less fertile soils, making it suitable for dry and high-altitude areas with erratic rainfall (Samineni et al., 2025; Kalinova and Moudry, 2006). In Nepal, although proso millet is typically cultivated in high hills and mountainous areas, successful cultivation has also been reported in low-altitude regions such as the western Terai, at around 200 masl (Raut et al., 2024). The inherent character it possesses makes it a potential crop to deal with the growing climate change impacts (Lagler et al., 2005).

Renowned for its unique nutritional qualities, it is considered a healthy food due to its high protein content, easily absorbed amino acids, and balanced array of trace elements including vitamin precursors (Habiyaremye et al., 2017). These traits make proso millet an increasingly important and valuable crop in the context of existing food and nutrition consumption. The high-hills and hilly areas of western region of Nepal including Bajura are highly rich in diversity proso millet (Ghimire et al., 2018). Bajura district, located in the far-western hills of Nepal, is one of the remotest regions that takes 77th position in terms of Human Development Index (0.364) with 71% of households residing below the poverty line (Human Development Index Report, 2015 and 2020). Agriculture is the prime source of livelihood with more than 80% of people engaged in it (Bhattarai et al., 2022). Millets have contributed a significant part among the communities of Bajura with production of 2,050 tons in 2,460 ha in the year 2022/23 (MoALD, 2023). A recent article by 'The Kathmandu Post, 2025' reported an export of 2.200 quintals of millets worth of 6.6 million Nepalese rupees in the FY 2023/24. Proso millet had served as a staple crop for the ages, contributing significantly to local food security and agricultural resilience (Rajput & Santra, 2016).

Despite its traditional importance and nutritional values, its cultivation has been gradually declining in hilly regions, and the farmers have shifted towards the cultivation of other cereal crops such as rice, wheat, and maize in recent years (MoALD, 2022). The low productivity, change in food habits, and shift in paddy farming are the reasons for decline for millet production, particularly proso millet (Ghimire et al., 2018). Moreover, the decline of millet production can be linked with more focus on crop improvement programs for rice, wheat and maize crops, and negligence in the study of millet crops (The Rising Nepal, 2023). In Bajura, proso millet cultivation is limited by several challenges, including rugged terrain, lack of improved varieties, poor input and manure supply, irrigation difficulties, traditional intercultural practices, and biotic stresses (Dhakal et al., 2023; Prechsl, 2008).To date, only a single variety of proso millet has been registered in Nepal (MoALD, 2022).Farmers continue to rely on local landraces with minimal agronomic support, limited mechanization, and poor market access. Moreover, water management practices are poorly adopted despite their significance in improving yield under increasingly erratic rainfall patterns. With the prioritization in conservation and promotion of millet crops by the year 2023 (FAO, 2018), the crop is revitalizing and is gaining changes in the local economy of the mountain region. Local initiatives and support from agricultural extension agencies in Bajura are beginning to promote millet cultivation through awareness campaigns, biodiversity block establishment, seed distribution, and the introduction of improved post-harvest practices (Dhakal et al., 2023; Bhandari et al., 2021; The Rising Nepal, 2023). The growing recognition of millet's role in climate adaptation and food sovereignty has stimulated interest in identifying and evaluating resilient landraces suitable for variety development and formal registration. Therefore, we studied six genotypes collected from the National Agriculture Genetic Resource Center (NAGRC) (Genebank) and two local landraces commonly available in the Bajura district to compare the phenological and yield performance of local landraces with collected genotypes from NAGRC. This study will be the baseline for generating evidence for identifying promising and resilient lines for further crop improvement programs and variety registration of local landraces of Bajura district. Moreover, this is the first systematic study conducted in Bajura to evaluate and compare the growth and yield performance of local landraces and collected genotypes of proso millet.

The objective of this study was to evaluate the growth and yield performance of local genotypes and collected accession lines to contribute to generating evidence for identifying promising and resilient lines for further crop improvement program and baseline for formal variety registration of local landraces of Bajura district. Moreover, research was also conducted to examine the interrelationships among agro-morphological and yield-related traits and to identify key determinants influencing grain yield, thereby supporting data-driven selection and breeding strategies.

2 MATERIALS AND METHODS

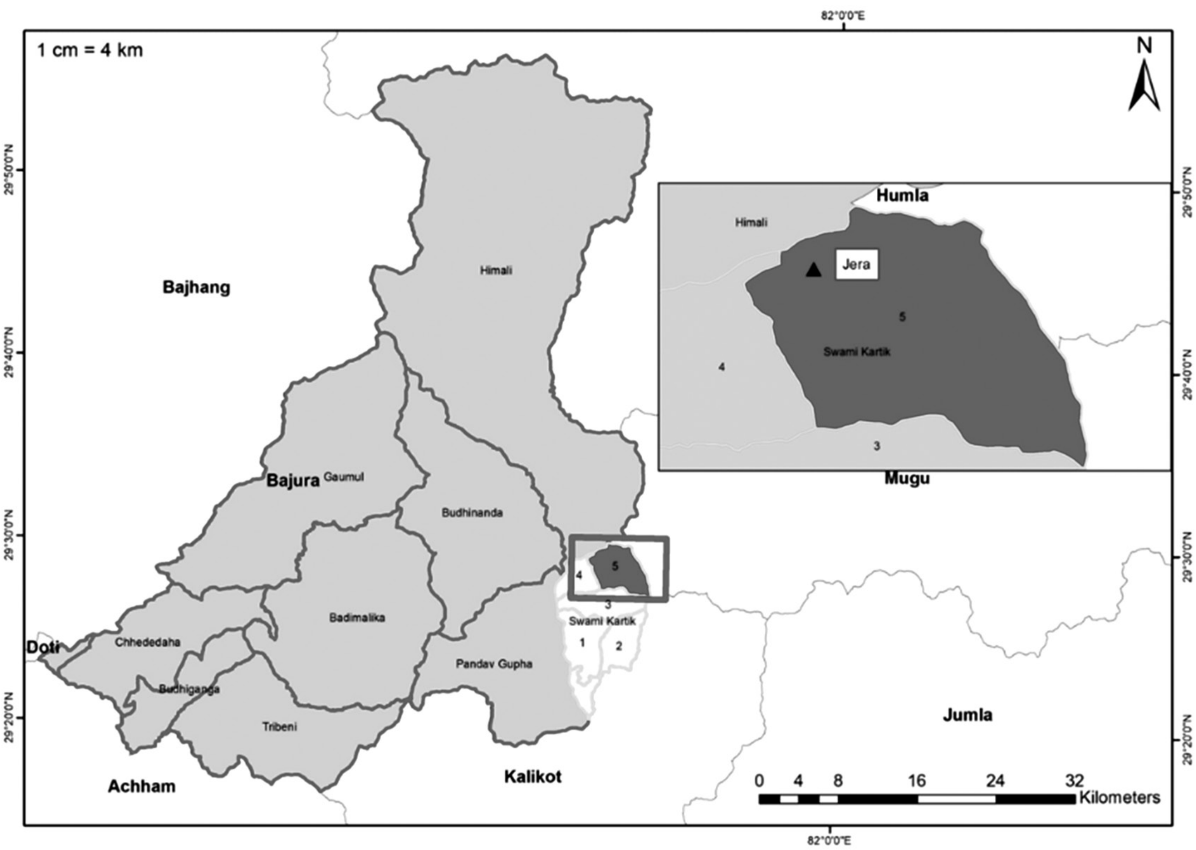


Figure 1 Geographical map locating the study area

2.1 STUDY AREA

The study was conducted from June to August 2023 at Jera village of Swamikartik Khapar Rural Municipality-5, Bajura district. The study site was geographically located at 29.4948°N latitude and 81.751°E longitude with an elevation of 1255 meters above sea level (masl). The region has an arid climate with minimal annual rainfall (500-850 mm) and the soil is mostly rocky and sandy (Environment Statistics of Nepal, 2019; Paudel et al., 2012). The climatic conditions over here and soil structure pose challenges for agricultural production, especially the climate sensitive high value vegetables and other crops, making it suitable for producing drought-resistant indigenous crops including proso millets.

2.2 TREATMENTS AND EXPERIMENTAL DESIGN

The field trial was conducted using a Randomized Completely Block Design (RCBD) with 8 treatments, representing 8 proso millet genotypes (two local landraces: Mal Chino and Dudhe Chino, and 6 accession lines from NAGRC) and three replications (Table 1). Mal Chino has the characteristics of shallow roots, narrow with dark green colored leaf, flat and pointed shaped seeds with shiny grey or umber color lined with creamy color. Similarly, Dudhe chino were characterized by thicker and longer roots, long, flat and light green colored leaves, oval to spherical seeds and creamy white to soft, beige-colored seeds. The accessions from NAGRC were selected based on the history of their origin and recommendations provided by the genebank. These accessions were previously collected from high altitudes of western region (Ghimire et al., 2018). These local landraces and accession lines were chosen to evaluate their performance under the local environmental conditions of Bajura. Each plot measuring 1.25m^2 (1m × 1.25m) was prepared, maintaining a spacing of 10 cm between the plants and 25 cm within the rows. At the beginning, continuous line sowing was made and upon emergence of seedlings the spacing between the plants was adjusted at 10 cm by scouting the surplus seedlings. Each individual plot was separated by 50 cm distance to minimize the edge effect and facilitate other intercultural operations. Five plants were selected randomly from each plot as a sample plants.

Table 1 Treatment details and source of collection of proso millet genotypes

Treatment	Genotypes	Source of Collection
T1	NGRC07344	NAGRC, Genebank Khumaltar
T2	NGRC07345	NAGRC, Genebank Khumaltar
T3	NGRC07348	NAGRC, Genebank Khumaltar
T4	NGRC07349	NAGRC, Genebank Khumaltar
T5	NGRC07350	NAGRC, Genebank Khumaltar
T6	NGRC07351	NAGRC, Genebank Khumaltar
T7	*Mal Chino*	Locally collected from Jera village
T8	*Dudhe Chino*	Locally collected from Jera village

2.3 LAND PREPARATION AND CULTIVATION PRACTICES

The experimental field was prepared by clearing any weeds and debris from the area. We applied a surface irrigation a week before ploughing to retain some moisture in soil. It was then ploughed to a depth of approximately 20-25cm with the use of spade followed by breaking up large soil clod and levelling the land to ensure uniformity across the experimental plots. Before ploughing, Farmyard Manure (FYM) was applied at the rate 750 kg/ropani to the whole plot. No additional organic or chemical fertilizers were applied at the time of field preparation. All agronomic practices such as irrigation and weeding were applied uniformly for all treatments in each plot. Irrigation was applied for three times i.e. 1 week prior to ploughing, 30 days after sowing (DAS) and 45 DAS). Weeding was done two times and was done 1 day before each irrigation applied after sowing of crops.

2.4 OBSERVED PARAMETERS

During the field experiment the following parameters were observed, and data were collected for further analysis.

2.4.1. Plant height

Plant height is an important growth parameter reflecting vegetative vigor and nutrient assimilation efficiency that is directly related to biomass accumulation and potential grain yield. It was recorded by measuring the above ground length of five tagged prosomillet plants from ground height to the tip of the uppermost leaf with the help of 1.5 m scale. Data was recorded when all of the plants ceased vegetative stage i.e. 45 DAS.

2.4.2. No. of tillers

Tillering capacity directly affects panicle number and hence grain yield. A higher number of fertile tillers is generally associated with increased yield potential in proso millet. The number of tillers was recorded at 45 DAS by counting the tillers bearing panicles or showing signs of panicle development.

2.4.3. Flag leaf length

The flag leaf is crucial for photosynthesis during grain filling. Its size, especially length, contributes significantly to the assimilated supply during reproductive stages. It was measured from the leaf base (ligule) to the leaf tip on the main tiller of five randomly selected plants per plot, when the flag leaf is fully expanded i.e. on 55 DAS. Measurements were taken using a measuring tape or scale.

2.4.4. Panicle length

Panicle length was measured from the base (peduncle attachment) to the tip of the panicle on five randomly selected plants per plot on 60 DAS. Measurements were recorded after panicle emergence and full development using a measuring scale.

2.4.5 Plot yield

At full maturity, all plants from the net plot area were harvested, threshed, and cleaned. The grain yield from each plot was weighed using a digital balance and recorded in grams.

Grain yield in grams per plot was extrapolated to tonnes per hectare using the following formula:

$$Grain\ yield\ \left(\frac{t}{ha}\right) = \frac{plot\ yield\ (gm)}{plot\ area\ (m2)} * 10$$

2.5 STATISTICAL ANALYSIS

The collected data was tabulated using MS Office Excel (2019) and subjected to analysis of variance (ANOVA) to assess the significance of difference among the genotypes using GenStat. Mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at a 5% level of significance using the method given by Gomez and Gomez (1984). The association of different growth and yield parameters were analyzed using correlation and regression analysis using SPSS software (version 24.0). Regression model was calculated by using the formula,

$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_p x_{ip}$

Where,

i=n observations y_i =dependent variable x_i=explanatory variables

β_0=y-intercept (constant term) β_p = slope coefficients for each explanatory variable

3 RESULTS

3.1 YIELD AND YIELD ATTRIBUTING TRAITS

3.1.1 Plant height

The Analysis of Variance (ANOVA) showed significant differences in plant height ($p < 0.05$) for the tested genotypes. The plant height (149.49 – 198.25 cm) ranged with the mean average of 179.04 cm across the genotypes. Local landrace, *Mal Chino* possessed the lowest plant height (149.49 cm) followed by NGRC07344 (176.04 cm) and NGRC07348 (176.03 cm). In contrast, *Dudhe Chino*, another local landrace, recorded the tallest plant height (198.25 cm) (Table 2).

3.1.2 Tiller number

Tiller number does not possess a significant difference among the tested genotypes. The tiller number (6.27 – 10.2) ranged with the mean average of 7.3 across the genotypes. *Mal Chino* recorded a maximum tiller number (10.2) followed by the genotypes NGRC07345 (8.33) and NGRC07344 (7.67). A minimum tiller number was recorded in genotype NGRC07350 (Table 2).

3.1.3 Leaf number

A significant difference ($p < 0.01$) was observed among the tested genotypes for leaf number. The leaf number (38.8 – 65.6) ranged with the mean average of 51.89 across the genotypes. The highest leaf number was recorded in *Mal Chino* and lowest in NGRC07350 (Table 2).

3.1.4 Panicle length

Panicle length showed a significant variation among the tested genotypes ($p < 0.01$). The panicle length (39.84 cm – 45.6 cm) ranged with the mean average of 43.84 cm across the genotypes.

The results showed maximum length of panicle in *Mal Chino*, resembling a statistically similar value with *Dudhe Chino*, NGRC07344, NGRC07345, NGRC07350 and NGRC07351. In contrast, minimum panicle length was observed in NGRC07349 (Table 2).

3.1.5 Flag leaf length

ANOVA revealed significant differences in flag leaf length ($p < 0.05$) across the tested landraces. The flag leaf length (42.21 cm – 49.19 cm) ranged with the mean average of 44.73 cm across the genotypes. *Mal Chino* was characterized by the longest flag leaf followed by NGRC07345 and NGRC07350, and NGRC07344 possessed the shortest flag leaf (Table 2).

3.1.6 Grain yield

Grain yield (MT/ha) showed a significant variation for the tested genotypes of proso millet ($p < 0.01$). The highest yield (2.06 MT/ha) was observed in *Mal Chino followed by NGRC07345 (1.7 t/ha) and NGRC07348 (1.7 t/ha), which are statistically similar with Mal Chino.* In contrast, another local variety, Dudhe Chino exhibited the lowest grain yield (1.24 t/ha) (Table 2).

Table 2 Mean comparison of yield and yield attributing traits of proso millet genotypes

Genotype	Plant height (cm)	No. of tillers	No. of leaves	Panicle length (cm)	Flag leaf length (cm)	Yield (t/ha)
Mal Chino	149.49[a]	10.2[a]	65.6[a]	45.60[a]	49.19[a]	2.06[a]
Dudhe Chino	198.25[c]	6.27[b]	51.05[b]	44.52[a]	42.72[bc]	1.24[c]
NGRC07344	176.04[b]	7.67[ab]	52.2[b]	44.35[a]	42.21[c]	1.35[bc]
NGRC07345	190.78[bc]	8.33[ab]	53.07[b]	46.29[a]	47.60[ab]	1.7[ab]
NGRC07348	176.03[b]	7.07[b]	50.47[b]	39.84[b]	44.06[bc]	1.7[ab]
NGRC07349	177.62[bc]	6.67[b]	50.70[b]	41.33[b]	42.53[bc]	1.32[bc]
NGRC07350	181.01[bc]	5.9[b]	38.80[c]	44.07[a]	46.23[abc]	1.4[bc]
NGRC07351	183.1[bc]	6.33[b]	53.20[b]	44.68[a]	43.30[bc]	1.4[bc]
GM	179.04	7.3	51.89	43.84	44.73	1.4
Sem (±)	7.15	0.95	3.28	0.82	1.563	0.13
LSD (α=0.05)	22.68	2.87	9.94	2.49	4.741	0.9656
CV (%)	6.92	22.51	10.94	3.24	6.1	15.1
F test (α=0.05)	*	ns	**	**	*	**

3.2 ASSOCIATION OF YIELD AND YIELD ATTRIBUTING TRAITS

The significance of the association of yield and yield attributing traits was examined using simple correlation analysis. The coefficient of yield was strongly significant and positively correlated with the tiller number ($r = 0.757^{**}$), leaf number ($r = 0.659^{**}$) and flag leaf length ($r = 0.65^{**}$), and weak but positive correlation with panicle length ($r = 0.323$), suggesting that more tillers and leaves, and longer flag leaf and panicle contribute to increased yield. In contrast, yield showed weak but negative correlation with plant height ($r = -0.316$) (Table 3).

Table 3 Correlation analysis among yield and yield attributing traits

	Plant height	Tiller number	Leaf number	Panicle length	Flag leaf length	Yield
Plant height	1					
Tiller number	-0.365	1				
Leaf number	-0.301	0.854**	1			
Panicle length	0.13	0.36	0.383	1		
Flag leaf length	-0.292	0.445*	0.347	0.357	1	
Yield	-0.316	0.757**	0.659**	0.323	0.65**	1

***Significant at $p<0.01$, *Significant at $p<0.05$*

A multiple regression analysis was conducted to evaluate the relationship between grain yield and yield attributing traits and the calculated regression model is,

$$Y = -267.893 - 2.181 X_1 + 25.510 X_2 + 1.049 X_3 + + 0.211 X_4 + 12.064 X_5$$

$$r^2 = 0.7$$

Where Y is grain yield, X_1 is plant height, X_2 is tiller number, X_3 is leaf number, X_4 is panicle length, and X_5 is flag leaf length.

The regression analysis revealed that grain yield of the tested genotypes showed significant coefficients of determination ($r^2 = 0.7$) with yield attributing traits. These indicate that 70% variation in grain yield was due to the combined effect of five yields attributing traits i.e. plant height, tiller number, leaf number, panicle length, and flag leaf length, and the rest of 30% variation in grain yield is due to other factors.

Among the independent variables, tiller number and flag leaf length are the most influential variables, given their larger positive coefficients, indicating that focusing on the improvement in these traits could significantly boost grain yield. Plant height has a negative effect, which might suggest that taller plants could be less productive due to resource allocation on vegetative parts rather than the yield.

4 DISCUSSIONS

The study showed significant variations in the parameters observed which highlight the potential of genetic diversity within these millet genotypes. The result suggested the promising adaptability of some genotypes to the low moisture and nutrient deficient soils typical of Bajura district. Notably, the local landrace Mal Chino recorded the highest grain yield at 2.06 t/ha, attributed to its superior character for tiller number, total number of leaves, panicle length, and flag leaves length, which likely enhanced its photosynthetic efficiency. Mal Chino has been traditionally cultivated in the region, suggesting its adaptation may be deeply rooted in its long-term exposure to local agroecological stresses. Bajura, characterized by poor soil fertility, erratic rainfall, and limited access to agricultural inputs, might benefit significantly from the promotion of such resilient cultivars.

In addition to Mal Chino, NGRC07345 also showed potential, producing 1.7 t/ha grain yield with a comparatively high tiller number, and long flag leaves. Its performance, close to that of Mal Chino, suggests it could be a promising genotype for future participatory trials and breeding efforts, especially if combined with locally adaptive traits. NGRC07347, though having equal yield potential to NGRC07345, had slightly shorter panicles and fewer tillers. Yet, its yield parity with NGRC07345 indicates efficient genetic potential, resource use and potentially better stress adaptation.

In contrast, Dudhe Chino, despite its taller height, recorded a lower yield (1.24 MT/ha). This might be due to its lower tiller number (7.2 tillers / plant) and shorter flag leaves (21.4 cm) limiting its overall grain production efficiency. The variation among genotypes might be due to genetic potential. Our findings align with the study of Asnake et al. (2023) and Dash et al. (2018), who highlighted differences among crop varieties associated with their genetic makeup.

Our result also aligns with the study of Saline et al. (2010), Subedi et al. (2022), Khatun et al. (2023), Singode et al. (2023) and Raut et al. (2024), who found significant difference among germplasms. Phenotypic correlations among plant traits can inform the selection of genotypes with desirable characteristics for breeding programs. Traits like tiller numbers, panicle length, and flag leaf dimensions, which are positively associated with grain yield components, highlight their potential as key indicators for enhancing productivity and selecting lodging-resistant genotypes (Selvi et al., 2014). Tiller numbers can significantly contribute to yield suggesting selection of germplasm with high tillering behavior for higher productivity (Liu et al., 2015). The higher tillering capacity of local landrace *Mal Chino* could better explain its superior yield performance even under a low moisture and poor nutrient soil. This statement is supported by Martinez et al. (2015), which states that the tiller number is positively correlated with the grain yield in rice. In our study, flag leaf length, associated with the photosynthesis capacity of the plant, is associated positively with the grain yield (β=12.064). Larger flag leaves provide greater surface area for photosynthesis, enhancing grain filling. This is consistent with the research conducted by Siddique et al. (1989) which states, larger leaves, particularly flag leaves contribute significantly to wheat yield under water limited conditions, as larger flag leaves help capturing more light for photosynthesis, especially in the later stage of crop development. Flag leaves play a critical role in supporting grain development, as their removal led to significant defects, including delayed maturation, reduced grain size, and increased sterility (Racz et al., 2022). The observed two-fold reduction in 100-grain weight in rice cultivars underscores the importance of flag leaves as a primary source of photosynthates essential for grain filling and overall yield (Rahman et al., 2013). The higher yield achieved in *Mal Chino* may partly be associated with its longer flag leaf enhancing photosynthesis during critical stage of grain development.

5 CONCLUSIONS AND RECOMMENDATIONS

The study highlights the agronomic superiority of the local landrace *Mal Chino,* which exhibited significantly higher yield and better morphological traits including shorter plant height, greater tiller and leaf numbers, longer panicles and flag leaves under low-input, stress-prone conditions in Bajura. NGRC07345, an accession collected from the national gene bank, also demonstrated yield potential comparable to *Mal Chino*, supporting its scope for further participatory breeding and selection programs. The findings reveal that tillers, leaves and flag leaf length are critical yield determinants, accounting for a major portion of yield variability that needs more emphasis in future selection and breeding strategies. Importantly, this is the first scientific evaluation of proso millet genotypes conducted in Bajura, offering a crucial baseline for future variety selection and registration. To validate and scale these results, multi-location and multi-year trials are essential in the same agro-ecological condition of Bajura district. Strengthening local seed systems through participatory approach might be the key steps towards genetic conservation, and revitalization of millet-based farming systems in the marginal and resource poor conditions of hill regions Bajura.

DECLARATION

The authors declare no conflict of interests.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to the Green Resilient Agricultural Productive Ecosystems (GRAPE) Project, the Himalayan Resilience Enabling Action Programme (HI-REAP), the International Centre for Integrated Mountain Development (ICIMOD), and Local Initiatives for Biodiversity, Research and Development (LI-BIRD) for creating a conducive environment and providing essential resources to carry out this study. We extend our thanks to the National Agriculture Genetic Resource Center (Genebank) for supplying proso millet genotypes and to the farmers of Bajura for their active participation and collaboration. We are especially grateful to the farmers from Jera village of Swamikartik Khapar rural municipality – 5, Bajura district, whose support and involvement were instrumental in the successful implementation of this field experiment. Special appreciation goes to Dr. Kamal Aryal and Dr. Abid Hussain for their valuable feedback and continuous support throughout the research process.

REFRENCES

Asnake, D., Alemayehu, M. and Asredie, S. (2023). Growth and tuber yield responses of potato (*Solanum tuberosum* L.) varieties to seed tuber size in northwest highlands of Ethiopia. *Heliyon, 9*(3). https://doi.org/10.1016/j.heliyon.2023.e14586

Bettinger, R. L., Barton, L., & Morgan, C. (2010). The origins of food production in North China: A different kind of agricultural revolution. *Evolutionary Anthropology, 19*(1), 9–21. https://doi.org/10.1002/evan.2023

Bhandari, G. R., Gauchan, D., Bhandari, B., Joshi, B. K., & Panta, S. (2021). Advancement, Simplification and Piloting of Electrical Proso Millet De-Husker (Chino Kutak). *Journal of Nepal Agricultural Research Council, 7,* 67-74. https://doi.org/10.3126/jnarc.v7i1.36922

Bhattarai, K., Aryal, Y., Khatri, D., Basnet, B., & Joshi, P. P. Perspective of olive farming at Bajura, Nepal: main opportunities and challenges. *Sustainability in Food and Agriculture, 3*(2): 50-56.

Changmei, S., & Dorothy, J. (2014). Millet: The frugal grain. *International Journal of Scientific Research and Review, 3*(1), 75–90.

Dash, S.N., S. Behera and Pushpavathi, Y. (2018). *Effect of Planting Dates and Varieties on Potato Yield. Int. J. Curr. Microbiol. App. Sci. 7*(3), 1868-1873. https://doi.org/10.20546/ijcmas.2018.703.221

Environment Statistics of Nepal (2019). Central Bureau of Statistics (CBS), Government of Nepal. Thapathali Kathmandu, Nepal. Available on: http://climate.mohp.gov.np/downloads/Environment_Statistics_of_Nepal_2019.pdf (Accessed on: 30 May 2025)

Food and Agriculture Organization of the United Nations (FAO). (2018). *Proposal for an international year of millets*.

Ghimire, K. H., Joshi, B. K., Dhakal, R., & Sthapit, B. R. (2018). Diversity in proso millet (*Panicum miliaceum* L.) landraces collected from Himalayan mountains of Nepal. *Genetic Resources and Crop Evolution, 65*(2), 503–512. https://doi.org/10.1007/s10722-017-0548-7

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). John Wiley & Sons.

Habiyaremye, C., Matanguihan, J. B., D'Alpoim Guedes, J., Ganjyal, G. M., Whiteman, M. R., Kidwell, K. K., & Murphy, K. M. (2017). Proso millet (*Panicum miliaceum* L.) and its potential for cultivation in the Pacific Northwest, U.S.: A review. *Frontiers in Plant Science, 7*. https://doi.org/10.3389/fpls.2016.01961

Joshi, B. K., Bhattarai, M., Bhusal, B., Sharma, S., KC, N., & Ghimire, K. H. (2023). Millet genetic resources and diversity in Nepal. *International Journal of Agriculture and Environmental Research, 9*(5), 750–765.

Kalinova, J., & Moudry, J. (2006). Content and quality of protein in proso millet (Panicum miliaceum L.) varieties. *Plant foods for human nutrition (Dordrecht, Netherlands),* 61(1), 45–49. https://doi.org/10.1007/s11130-006-0013-9

Khatun, M. F., Islam, M. S., Jahan, N., Ahmed, Q. M., Islam, M. R., & Pervin, N. (2023). Morphological characterization and diversity analysis of proso millet (*Panicum miliaceum* L.) germplasm in Bangladesh. *International Journal of Agriculture and Environmental Research, 9*(5), 750–765.

Lágler, R., Gyulai, G., Humphreys, M., Szabó, Z., Horváth, L., Bittsánszky, A., Kiss, J., Holly, L., & Heszky, L. (2005). Morphological and molecular analysis of common millet (Panicum miliaceum) cultivars compared to an ancient DNA sample from the 15th century (Hungary). *Euphytica, 146*(1–2), 77–85. https://doi.org/10.1007/s10681-005-5814-7

Liu, X., Fuller, D., & Jones, M. (2015). Early agriculture in China. In *The Cambridge world history, Volume 2: A world with agriculture, 12,000 BCE-500 CE* (pp. 57–83). Cambridge University Press.

Lu, H., Zhang, J., Liu, K. B., Wu, N., Li, Y., Zhou, K., et al. (2009). Earliest domestication of common millet (Panicum miliaceum) in East Asia extended to 10,000 years ago. *Proceedings of the National Academy of Sciences, 106*(19), 7367–7372. https://doi.org/10.1073/pnas.0900158106

Martínez-Eixarch, M., Català, M. M., Tomàs, N., Pla, E., & Zhu, D. (2015). Tillering and yield formation of a temperate Japonica rice cultivar in a Mediterranean rice agrosystem. *Spanish Journal of Agricultural Research, 13*(4), e0905. https://doi.org/10.5424/sjar/2015134-7085

Ministry of Agriculture and Livestock Development, Government of Nepal. (2023). *Statistical information on Nepalese agriculture 2021/22.* https://moald.gov.np/wp-content/uploads/2023/08/Statistical-Information-on-Nepalese-Agriculture-2078-79-2021-22.pdf

Paudel, S., Jnawali, S. R. and Lamichhane, J. R. (2012). Use of geographic information system and direct survey methods to detect spatial distribution of wild olive (*Olea cuspidata* Wall.) from high mountain forests of northwestern Nepal. *Journal of Sustainable Forestry, 31*(7), pp.674-686. https://doi.org/10.1080/10549811.2012.704769

Prechsl, U. (2008). Explorative agricultural study of Shangrila project villages in Jumla and Mugu District, Western Nepal. Available at: https://www.stiftung-fiat-panis.de/images/PF/PF2008_15.pdf

Racz, I., Hirişcău, D., Berindean, I., Kadar, R., Muntean, E., Tritean, N., Russu, F., Ona, A., & Muntean, L. (2022). The Influence of Flag Leaf Removal and Its Characteristics on Main Yield Components and Yield Quality Indices on Wheat. *Agronomy, 12*(10), 2545. https://doi.org/10.3390/agronomy12102545

Rahman, M. A., Haque, M. E., Sikdar, B., Islam, M. A., & Matin, M. N. (2013). Correlation analysis of flag leaf with yield in several rice cultivars. *Journal of Life and Earth Science*, *8*, 49-54.

Rajput, S. G., & Santra, D. K. (2016). Evaluation of genetic diversity of proso millet germplasm available in the United States using simple-sequence repeat markers. *Crop Science, 56*(1), 1–9. https://doi.org/10.2135/cropsci2015.10.0644

Raut, S. K., Sharma, R., Ghimire, R., Rajbanshi, D., & Bohara, B. (2024). Evaluation of Proso Millet (Panicummiliaceum L.) Germplasm for Yield and Related Traits in Godawari Municipality, Kailali, Nepal. *Contemporary Research: An Interdisciplinary Academic Journal*, *7*(2), 228–241. https://doi.org/10.3126/craiaj.v7i2.72169

Salini, K., Nirmalakumari, A., Muthiah, A. R., & Senthil, N. (2010). Evaluation of proso millet (*Panicum miliaceum* L.) germplasm collections. *Electronic Journal of Plant Breeding, 1*(4), 489–499.

Samineni, S., Gummadi, S., Thushar, S., Khan, D. N., Gkanogiannis, A., Becerra Lopez-Lavalle, L. A., & Singh, R. K. (2025). Exploring Proso Millet Resilience to Abiotic Stresses: High-Yield Potential in Desert Environments of the Middle East. Agronomy, 15(1), 165. https://doi.org/10.3390/agronomy15010165

Sarki, S. B. (2023, September 22). Millet cultivation declines in Bajura. *The Rising Nepal*. Available on: https://risingnepaldaily.com/news/32769 Accessed on: (30 May 2025)

Selvi, V. M., Nirmalakumari, A. & Subramanian, A. (2014). Genetics and interrelationships of yield traits for enhancing productivity of little millet. *Electronic Journal of Plant Breeding,* 5(*1*) 82-86.

Shah, A. (2025, February 28). Bajura sells food grains but reels under rice shortage. *The Kathmandu Post*. Available on: https://kathmandupost.com/sudurpaschim-province/2024/02/28/bajura-sells-food-grains-but-reels-under-rice-shortage Accessed on: (30 May 2025).

Siddique, K., Belford, R., Perry, M., & Tennant, D. (1989). Growth, development, and light interception of old and modern wheat cultivars in a Mediterranean-type environment. *Australian Journal of Agricultural Research, 40*(3), 473. https://doi.org/10.1071/AR9890473

Singode, A., Chapke, R. R., Sangappa, Domathoti, B., Padmaja, P. G., Bhat, V. B., Malathi, V. M., Venkateswarlu, R., Dheeravathu, S. N., & Ratnavathi, C. V. (2023). Proso millet: Importance and cultivation. *Indian Farming, 73*(1), 110–111.

Subedi, S., Neupane, S., Neupane, P., & Shrestha, J. (2022). Assessment of proso millet genotypes against blast caused by *Pyricularia grisea* (Cooke) Sacc. under field condition at mid hill region of Nepal. *Journal of Nepal Agricultural Research Council*. 27-34. https://doi.org/10.3126/jnarc.v8i.44853

Zhao, Z. (2005). Palaeoethnobotany and its new achievements in China. *Kaogu, 2005*, 42–49.

Agriculture Development Journal

Guidelines to Authors: Manuscript preparation and submission

Agriculture Development Journal is an open access journal published annually by the Agriculture Information and Training Center (AITC), Ministry of Agriculture and Livestock Development, Government of Nepal. The journal publishes original research, case study, short-communication and review articles in the field of agriculture. The overall aim of this journal is to enhance the scientific research and extension in agriculture and allied discipline. The journal is managed by a five-member editorial board and the manuscripts are subjected to a peer-review process. Manuscripts (not published before) must demonstrate high intellectual rigor. Every author publishing in the Agriculture Development Journal (author, reviewer) must accept and respect intellectual property and avoid plagiarism. The author (s) should strictly follow these guidelines during manuscript preparation and submission.

1) All contents in the manuscript must be written in English. Manuscripts should be typed in **Times New Roman** font.
2) The title should be short, clear and informative; it should, nevertheless, reflect the contents in the paper. Title font size should be 12 pts.
3) The abstract should be in *italics,* 10 point font size, not exceeding 200 words and contain a brief account of the introductory words, major objective, methodology, findings and conclusions. It should not include any diagram, table, references etc.
4) Key words: 5-10 words follows the abstract in alphabetical order.
5) Main text of the technical manuscripts should include Introduction, Methodology, Results, Discussion, Conclusion, References (APA 7th style), Author(s) contribution role, Funding information (if any), Ethical statement and Acknowledgement. Tables and figures should be arranged in accordance with APA formatting.
6) The manuscript should be arranged in the following sequence in general: Title, Authors along with affiliation, Abstract and key words, Introduction, Methodology, Results, Discussion, Conclusion, References, Author(s) contribution role, Funding information, Ethical statement and Acknowledgement.
7) The manuscript should not exceed 5000 words in total. It should be written in MS-Word with pages set A4 size, the top and left margins at 3cm and the right and bottom margins at 2.5cm. The text format should be in Times New Roman font, unless otherwise specified, in 12-point size.
    a. The title of the manuscript set as HEADING 1 (paragraph style) should be all capitalized in bold 12-point font size.
    b. Name of the author(s) should follow the title in new paragraph in normal 10-pointfont size. Other details of every author's identification such as working organization, contact addresses including telephone, and e-mail should go in the foot notes. The foot notes should be in 8-point font size.
    c. The first level headings should be all capitalized and bold. The second level headings should be all capitalized and normal. The third level headings should be in sentence case, italicized and normal.
    d. In tables, borders should be minimized, and text and numbers should be in 9-pointfont size.
    e. Bibliographic entries in the reference should be in 9-point font size.
8) References: APA 7th style guidelines should be followed as per following description:

a. Book with single author: Last name, Initial (s). (Year). Title. Publisher. For example, Pant, P. R. (1975). *Social science research and dissertation writing*. Buddha Academic Enterprises.

b. Book with two authors or more: Last name, Initial (s), & Last name, initial (s). (Year). Title. Publisher. For example, Phillips, J., Ajrouch, K., & Hillcoat-Nalletamby, S. (2010). *Key concepts in social gerontology*. Sage

c. Edited book: Last name, Initial (s). (Ed.). (Year). Title (ed.). Publisher. For example. Cash, T. F., & Smolak, L. (Eds.). (2011). *Body image: A handbook of science, practice, and prevention* (2nd ed.). Guilford Press.

d. Use (Ed.) if one editor and (Eds.) if two or more editors: Kozier, B., Erb, G., Berman, A., Snyder, S., Harvey, S., & Morgan-Samuel, H. (Eds.). (2012). *Fundamentals of nursing: Concepts, process and practice* (2nd ed.). Pearson.

e. Chapter in an edited book: Last name, Initial (s). (Year). Chapter title. In initial. Last name (eds.)., Book title (pages of chapter). Publisher. For example, Benton, D. (2011). Diet, behaviour and cognition in children. In D. Kilcast & F. Angus (Eds.), *Developing children's food products* (pp. 62-81). Woodhead.

f. E-book: Last name, Initial (s). (Year). Title (ed.), Retrieved from URL. For example, Ogden, J. (2007). *Health psychology: A textbook* (4th ed.). http://www.dawsonera.com.

g. Thesis: Author, A. A. (year). Title of doctoral dissertation or master's thesis (Unpublished doctoral dissertation or master's thesis). Name of institution. For example, Pokhrel, N. (2014). *Effects of different fertilization and feeding systems on water quality and growth performance in Nile tilapia* [Unpublished master's thesis]. Agriculture and Forestry University.

h. Journal article: Last name, Initial (s), & Last name, initial (s). (Year). Article title, Volume number (issue or part number if needed), page numbers. For example, Blann, A. (2014). Why do we test for urea and electrolytes? *Nursing Times*, *110*(5), 19-21.

   Tapper, K., Shaw, C., Ilsley, J., Hill, A. J., Bond. F. W., & Moore, L. (2009). Exploratory randomized controlled trial of a mindfulness-based weight loss intervention for women. *Appetite*, *52*, 396-404.

i. Online journal article: Last name, Initial (s), & Last name, initial (s). (Year). Article title, Volume, Page numbers. DOI or journal homepage URL. For example, Allen, S. J., Jordan, S., Storey, M., Thornton, C. A., Gravenor, M., Garaiova, I., Morgan, G. (2010). Dietary supplementation with lactobacilli and bifidobacteria is well tolerated and not associated with adverse events during late pregnancy and early infancy. *The Journal of Nutrition*, *140*, 483-488. https:// doi:10.3945/jn.109.117093

j. Newspaper article: Ruddick, G. (2013, October 3). Tesco suffers sales slump in all global businesses: UK rivals gain ground but boss Clarke confident turnaround plan is working. *Daily Telegraph*, p. 1.

k. Magazine: Allen, L. (2004, August). Will Tuvalu disappear beneath the sea? Global warming threatens to swamp a small island nation. *Smithsonian*, *35*(5), 44-52.

   Begley, S., & Murr, A. (2007, July 2). Which of these is not causing global warming? A. Sport utility vehicles; B. Rice fields; C. Increased solar output. *Newsweek*, *150*(2), 48-50.

l. Book review in a journal: Nagorski, A. (2013). The totalitarian temptation [Review of the book *The devil in history: Communism, fascism and some lessons of the 20th century*, by V.Tismaneanu]. *Foreign Affairs, 92*, 172-176.

m. Website: Author. (Year). Title, Retrieved month day, year, from URL. For example, Benson, A., & Kipp, R. M. (2012, November 23). *Potamopyrgus antipodarum*.

http://nas.er.usgs.gov/queries/FactSheet.asp?SpeciesID=1008

n. Conference paper (unpublished): Lastname, A. (Year, Month Day-Day). Title of paper in sentence case [Type of material]. Name of Conference, City, Country. For example, Whipple, S. (2018, March 6-9). *Control beliefs as a moderator of stress on anxiety* [Paper presentation]. Southeastern Psychological Association 64th Annual Meeting, Charleston, SC, United States.

o. Conference paper in Proceedings (published as a book): Lastname, A. B. (Year). Title of paper. In A. Lastname (Ed.; if applicable), Proceedings book title in sentence case (pp. firstpage-lastpage). Publisher. For example, Cismas, S. C. (2010). Educating academic writing skills in engineering. In P. Dondon & O. Martin (Eds.), *Latest trends on engineering education* (pp. 225-247). WSEAS Press.

p. Bowker, N., & Tuffin, K. (2002). Users with disabilities' social and economic development through online access. In M. Boumedine (Ed.), *Proceedings of the IASTED International Conference on Information and Knowledge Sharing* (pp. 122–127). ACTA Press.

In-text citations: APA 7th style guidelines should be followed.

9) Author(s) should fill up the author declaration form available on the website (aitc.gov.np).
10) Manuscripts lacking proper referencing/citations and a more than 20% similarity index will be automatically rejected.
11) Manuscripts must be submitted to the official email address of AITC: info@aitc.gov.np

Government of Nepal

Ministry of Agriculture and Livestock Development

Agriculture Information and Training Centre

Hariharbhawan, Lalitpur, Nepal

Emall: info@aitc.gov.np, Website: www.aitc.gov.np