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

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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

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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).

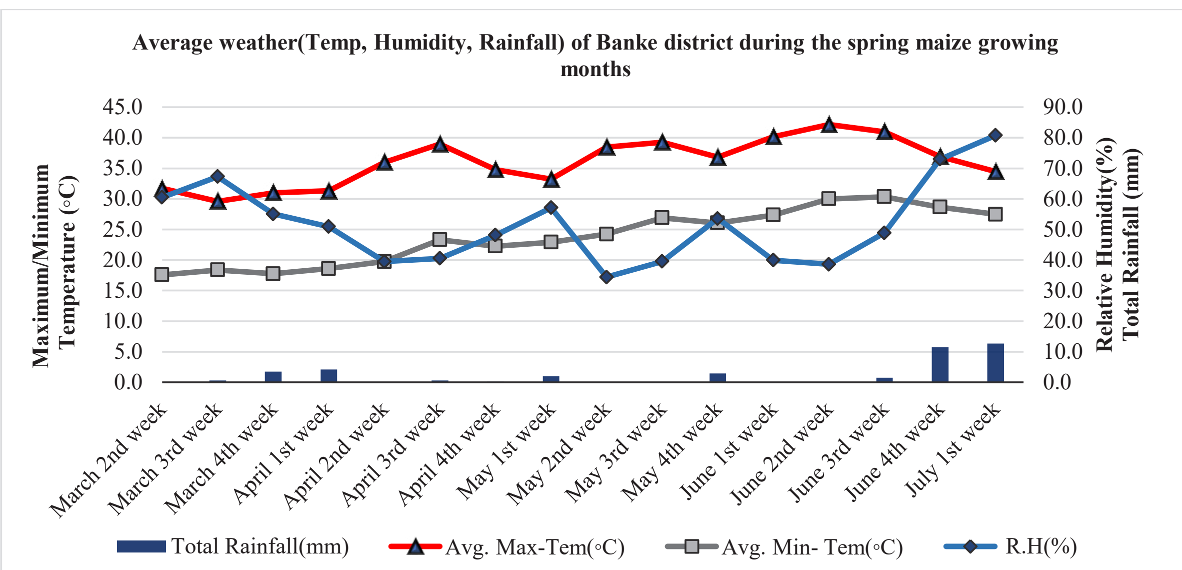

Figure 1. Weekly average maximum and minimum temperature (ºC), average relative humidity (%), weekly total rainfall (mm) during spring at Khajura, Banke, Nepal

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:

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

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

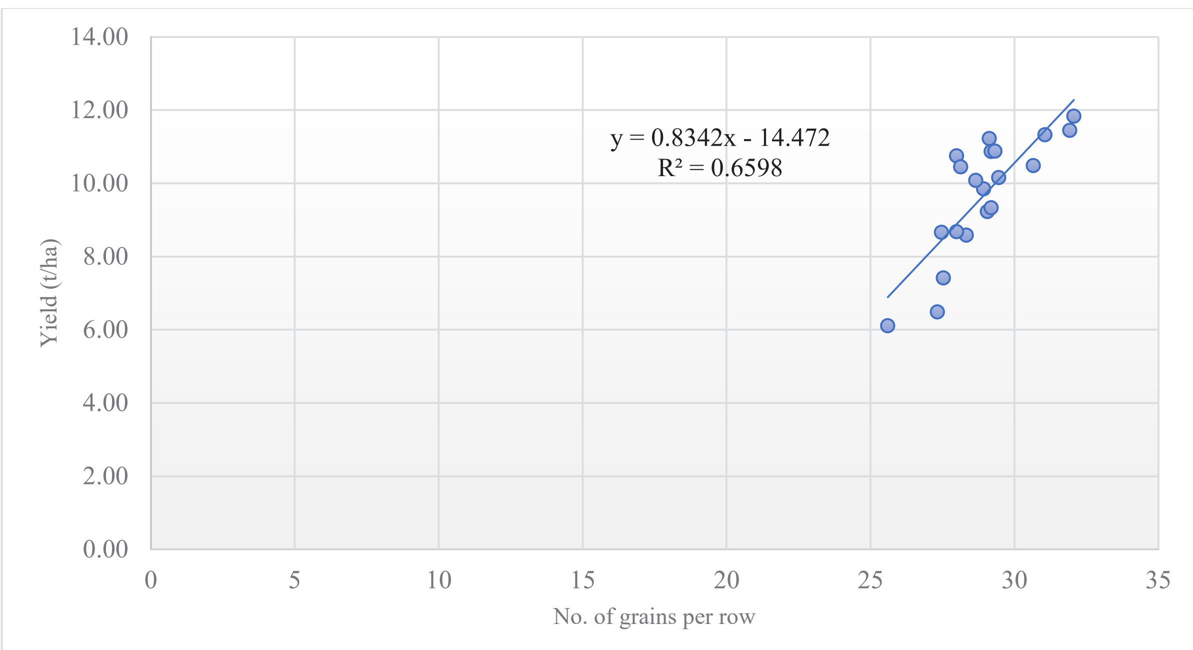

Figure 2: Correlation between grain yield and number of grains per row

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

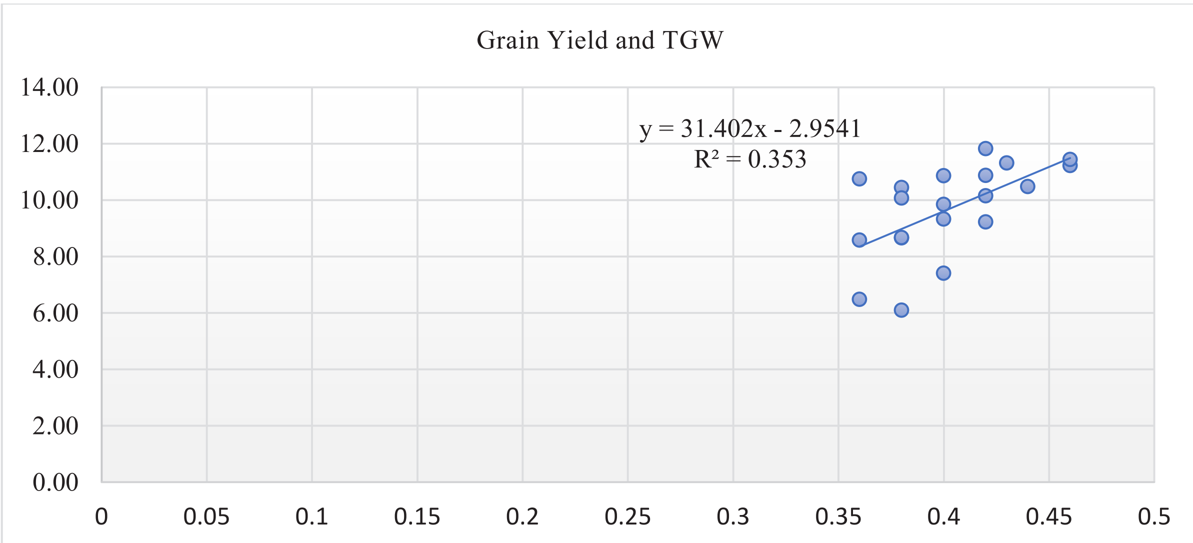

Figure 3: Correlation between grain yield(tons/ha) and 1000 grain weight (gm)

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

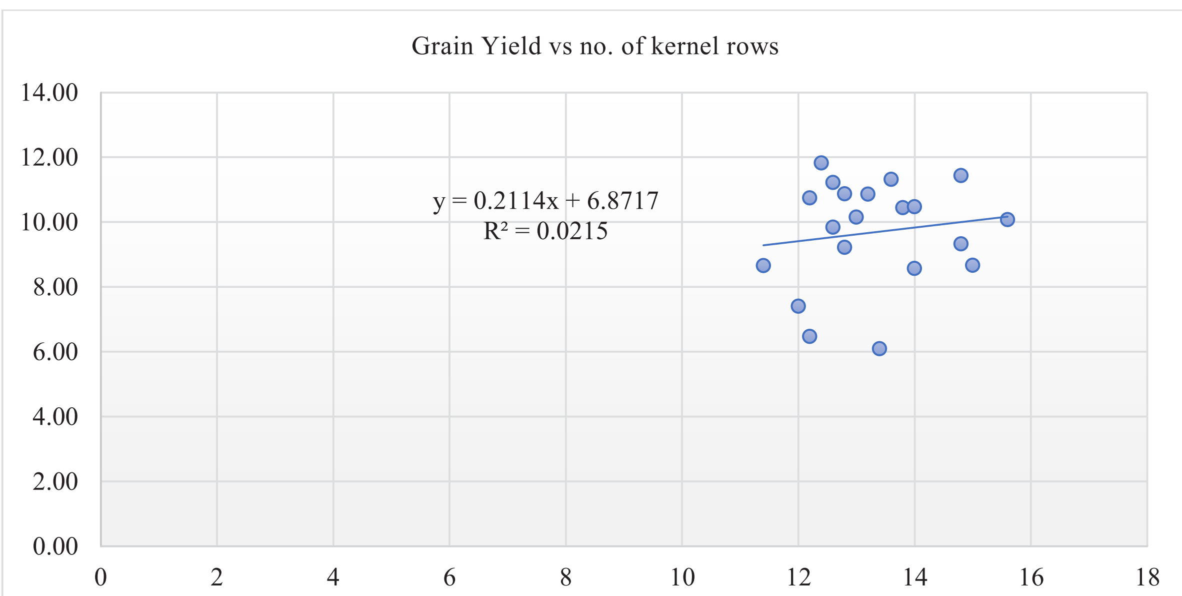

Figure 4: Correlation between grain yield (tons/ha) and number of kernel rows

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

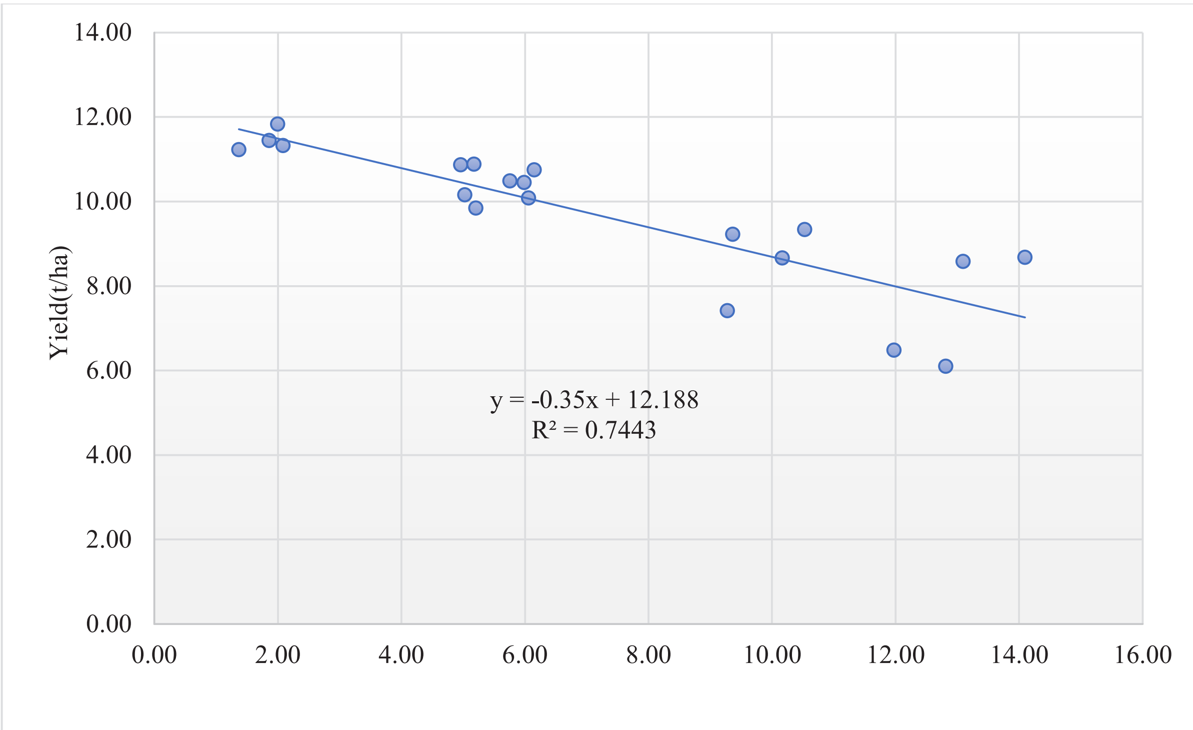

Figure 5: Correlation between sterility percentage and grain yield of maize

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.

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