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Effect of Phosphorus Levels and PSB on Spring Maize Performance in Surkhet, Nepal

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Abstract

A field experiment was conducted to evaluate the performance of spring maize var. Arun-2, under different levels of phosphorous with phosphate solubilizing bacteria (PSB) in Gurbhakot Municipality-09, Surkhet district from February to July 2023. For this study, randomized complete block design (RCBD) was implied with six treatments and four replications. Treatments included different levels of phosphorus fertilizer (P₂O₅) and PSB viz. T1 (0kg P₂O₅+PSB/ha), T2 (30kg P₂O₅+PSB/ha), T3 (60kg P₂O₅+PSB/ha), T4 (90kg P₂O₅+PSB/ha), T5 (120kg P₂O₅+PSB/ha) and T6 (60kg P₂O₅/ha without PSB as RDF). The result showed significant effect of phosphorous on growth, phenology, yield attributing traits and yield of maize at 5% level of significance, except for 1000 grain weight. Days to 75% tasseling, silking and maturity significantly decreased with the increasing level of phosphorus, whereas plant height and number of leaves increased with increasing dose of phosphorous. However, cob length, number of grains per cob and grain yields were found to be the highest in T3 and the lowest in T1. Similarly, application of phosphorous @60 kg/ha along with PSB could be suggested for maximizing yield of spring maize (Arun-2) in the agro-ecological conditions of Surkhet.

Keywords : Cob length, Grains per cob, PSB, Spring maize, Profitability

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Introduction

Maize (*Zea mays* L.), is a principal crop grown mainly for food, in hilly region whereas animal feed for growing livestock industries in Terai region of Nepal (KC et al., 2015), which provides significant source of nutrition and income for many rural families (Upadhyay et al., 1970). Enriched with vitamins particularly E, A and B, it also contains 11.1%, 3.6%, 2.7% proteins, fats and fibers respectively (Joshi & Gauchan, 2017). Nepal produces 3,193,869 mt of maize within the area of 916,044 ha with the productivity of 3.49 mt/ha annually contributing to 28.28% of total cereal production in Nepal (MoALD, 2025). However, the productivity of maize in Nepal is very low as compared to neighboring countries and a wide gap prevails between attainable yield and actual yield of maize at farm level (Gurung et al., 2018).

The productivity of maize is largely dependent on its nutrient management. Phosphorus, is a vital nutrient in improving growth, grain yield and quality of maize (Garg & Bahl, 2008). It also plays important role in photosynthesis, cell division, energy transfer, root growth, cell enlargement, root formation (Baral et al., 2015) and enhances water use efficiency and hastens crop maturity by affecting various physiological and biochemical process (Meier et al., 2021). Maize is often considered a phosphorus indicator plant because it tends to show visible signs of deficiency symptoms like stunted growth, changes in leaf coloration (purpling), and reduced yield, when grown in soil with low levels of available phosphorus (Sarker et al., 2010). Phosphorus deficiency is responsible for crooked and missing rows as kernel twist and produce small ears nubbins in maize (Sankadiya & Sanodiya, 2021). Phosphate-solubilizing bacteria (PSB) are beneficial microorganisms that have the ability to solubilize insoluble phosphate compounds in the soil, making them available for plant uptake (Hussain et al., 2013). PSB has the ability to convert insoluble soil phosphorus into soluble forms through organic acid production (Tuscano & Gajbhiye, 2024), and hence PSB can be used in soils with low fertility for improving grain yields in Nepal. PSB has been reported to improve grain yields by improving root growth, plant vigor and biomass accumulation (Bargaz et al., 2021). But the use of biofertilizers like PSB is very low in maize production, especially in Nepal.

The Government of Nepal provides subsidies for seeds, fertilizers, and agricultural machinery, yet maize production remains low (2.9 t/ha) in Surkhet district (MoALD, 2025). Phosphorus fertilizer affects maize yield differently, with both insufficient and excessive application reducing growth and productivity (Boldea et al., 2015). Overuse can also lead to environmental pollution and economic losses. This study aims to provide practical recommendations for efficient phosphorus use in spring maize production in Surkhet using phosphate-solubilizing bacteria.

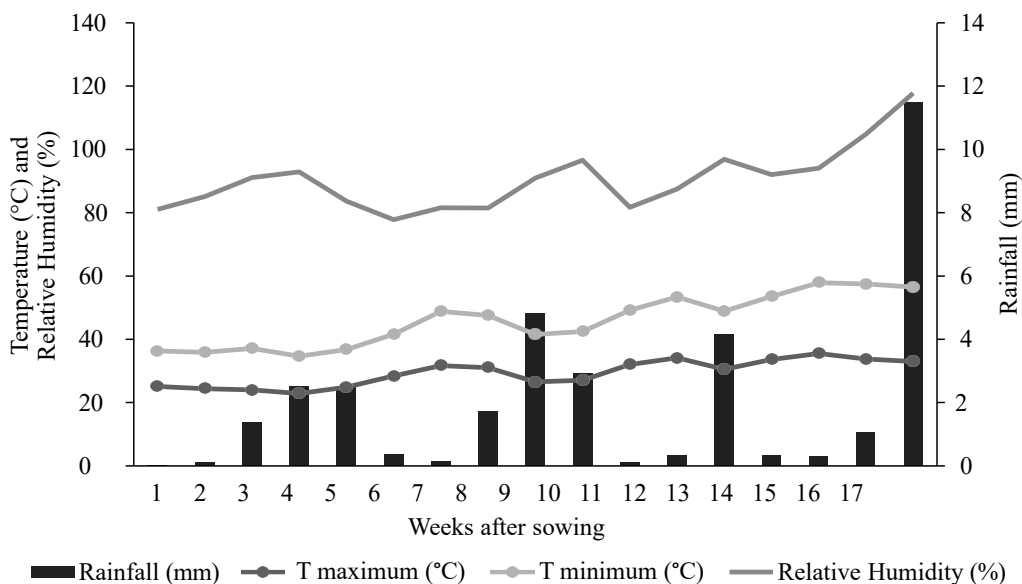
Materials and Methods

Experimental site

This field research was conducted in Gurbhakot Municipality-9 Botechaur, Surkhet district, Nepal from February to June, 2023. It was also the command area of maize zone under Prime Minister Agriculture Modernization Project (PMAMP). Located at 480 meter above sea level, the site had sandy loam soil with moderate organic matter content (3.75%), 0.20% nitrogen, 94 kg/ha phosphorus and 161 kg/ha potassium, with soil pH of 7.3. During this research in field, the average maximum temperature was 29.36°C ranging from 22.8°C to 34.16°C whereas the average minimum temperature was 16.53°C which ranged from 11.2°C to 23.53°C. The average rainfall was 2.01 mm per week out of total of 34.30 mm rainfall was observed in the experimentation field, as shown in figure1. These all parameters indicated that the area was suitable for spring maize production.

Figure 1

Meteorological data of research site during field experiment



(Source: POWER NASA, 2023)

Experimental Design

A randomized complete block design (RCBD) containing six treatments and four replications were implied. Various combination of phosphorus fertilizer (P₂O₅) along with phosphate solubilizing bacteria (PSB) were used as treatments in this study. Each treatments received a plot size 5m x 5m for this research, where farmyard manure@10t/

ha along with half dose of nitrogen and full dose of potassium (120:60:40 kg NPK/ha), as recommended by GoN were incorporated in soil before to sowing. But phosphorous was applied through single super phosphate and PSB @25ml per kilogram of maize seed, as per the treatments (table 1). The remaining half of nitrogen were top dressed 25 and 45 days after sowing.

Table 1

Treatment details

Treatments	Remarks
T ₁ – 0 kg P ₂ O ₅ +PSB/ha	Application of PSB with no Phosphorus fertilizer
T ₂ – 30 kg P ₂ O ₅ +PSB/ha	Application of PSB with Phosphorus fertilizer dose reduced to half on R.D
T ₃ – 60 kg P ₂ O ₅ +PSB/ha	Recommended dose of Phosphorus with PSB
T ₄ – 90 kg P ₂ O ₅ +PSB/ha	Application of PSB with Phosphorus fertilizer dose increased by 50 % over R.D
T ₅ – 120 kg P ₂ O ₅ +PSB/ha	Application of PSB with Phosphorus fertilizer dose doubled on R.D
T ₆ – 60 kg P ₂ O ₅ /ha	Recommended dose of Phosphorus with no PSB

Cultivation Practices

Arun-2 variety of spring maize was sown in the field on 27th February 2023 at spacing of 60cm×25 cm. Plant population was maintained as 66,666/ha. Sowing was done @ 2-3 seeds per hole by using Jab Planter. Maize seed was treated with PSB @250ml/10 kg seed in one litre water, which was dried on shade for 2 hours before sowing in the field as per the treatment. Thinning was done 25 days after sowing (DAS), whereas weeding was done at 25 and 50 DAS. Irrigation was given with pipe at 25, 45, 80 and 95 DAS. Emamectin Benzoate 5% SG (Emar) @1ml/3litre with Chloropyriphos 50%+ Cypermethrin 5% EC @ 2ml/litre of water was sprayed at 30 and 60 DAS for managing fall army worm and maize stem borer. Harvesting was done when the sheath covering the cob turned yellow and the seeds were fairly hard and dry.

Data Collection and Observation

Ten sample plants were tagged in 'X' pattern at 25 DAS, avoiding border rows for collecting data. Growth parameter like leaf number and plant height was recorded at 30, 60 and 90 DAS, whereas yield and yield attributing traits like cob length (cm), no. of grains/cob, 1000 grain weight, grain yield (mt/ha) and biological yield (mt/ha) were recorded at the time of harvest. Similarly, phenological observations were done for days to 75% tasseling, silking and physiological maturity, by visiting the field every day.

Data Analysis

The collected and arranged data were analyzed using the package ‘doebioresearch’ in the software RStudio 0.1.0 version. ANOVA table was prepared for each parameter and the treatment means were compared using Duncan’s Multiple Range Test (DMRT) at 5% level of significance ($P \leq 0.05$).

Economic Analysis

Cost of cultivation was calculated on the basis of local charges for different agri-input viz. seed, labor, fertilizer, irrigation, pesticides and other necessary materials. Economic yield was converted into gross return (NRs/ha) on the basis of local market price. The net return was calculated by subtracting total cost from gross return. The benefit cost (B:C) ratio was calculated as:

$$\text{B:C ratio} = \text{Gross return} / \text{Cost of cultivation (total cost)}.$$

Results and Discussion

Phenological Parameters

Days to Tasseling and Silking

Significant influence of treatments was observed for both the days to 75% tasseling and silking, with earliest tasseling in T₅. Maize plant significantly delayed flowering at low doses of phosphorous, taking the longest time for T₁ (without application of phosphorous) followed by T₂ (30kg P₂O₅+PSB/ha), which was at par with 60kg phosphorous with and without PSB. Days to silking also reported similar trend with the earliest silking in T₅ (120 kg P₂O₅ +PSB/ha) and delayed silking in T₁ as shown in table 2. Adequate amount of phosphorus ensured sufficient energy to the plants to invest in both vegetative and reproductive development, leading to timely tasseling and silking and shortened vegetative growth stage than control treatment. Also, phosphorous fertilizers induces flowering by assisting important physiological and biochemical functions in crops related to stress tolerance, energy flow, hormone regulation and flower bud formation (Dangi et al., 2019). This finding aligns with the findings from Pokharel et al. (2016), who reported shortened vegetative growth stages with application of phosphorous.

Days to Physiological Maturity

Days to physiological maturity was significantly affected by different levels of phosphorus with PSB, with the earliest maturity in T₅ (120 kg P₂O₅ +PSB/ha) followed by T₄ (114.35 days) and T₃ (114.57 days) which was statistically at par with T₆ (table 2). 5 days delay in maturity was observed in T₁ (0 kg P₂O₅ + PSB/ha) when compared with T₅. These results indicated that days to physiological maturity decreased with the increasing dose of phosphorus. This could be attributed to the enhanced phosphorus availability during these stages, which potentially leads to improved pollination, seed

development, and early maturity (Pandey et al., 2024). Absence of phosphorus has been reported to delay maturity in maize (Pokharel et al., 2016).

Table 2

Performance of phenological parameters of spring maize under different levels of phosphorous with PSB at Botechaur, Surkhet, 2023

Treatments	Days to 75% tasseling	Days to 75% Silking	Days to physiological maturity
T1(0 kg P ₂ O ₅ + PSB/ha)	94.25 ^a	99.26 ^a	117.65 ^a
T2(30 kg P ₂ O ₅ +PSB/ha)	93.75 ^{ab}	98.77 ^{ab}	116.52 ^{ab}
T3(60 kg P ₂ O ₅ + PSB/ha)	92.75 ^{ab}	98.75 ^{ab}	114.57 ^{abc}
T4(90 kg P ₂ O ₅ +PSB/ha)	92.25 ^{bc}	97.25 ^{bc}	114.35 ^{bc}
T5(120 kg P ₂ O ₅ +PSB/ha)	90.75 ^c	95.75 ^c	112.02 ^c
T6(60 kg P ₂ O ₅ /ha)	93.50 ^{ab}	98.50 ^{ab}	115.17 ^{abc}
Grand Mean	92.87	97.87	115.05
SEm (±)	0.59	0.58	1.06
F-test	*	*	*
CV (%)	1.28	1.21	1.84

Note: LSD: Least significant difference, SEM: Standard error of mean, CV: Coefficient of variation, ns: non-significant, ‘*’ Significant at 0.05 levels of significance

Biometric Parameters

Plant Height

Significant influence of phosphorous were observed in plant heights among the treatments. The highest (165.12 cm) plant height was recorded in T5 (120 kg P₂O₅ + PSB/ha) followed by T4 (163.50 cm) which was statistically equivalent to T3 (162.37 cm) and the shortest (158.12 cm) plant height was found in T1 (0 kg P₂O₅ + PSB/ha). This significant rise in plant height could likely be attributed to an enhanced uptake and availability of phosphorus ions, facilitated by the introduction of phosphate solubilizing bacteria and reason could be the stimulated root proliferation and nutrient absorption ultimately contributing to the overall growth performance and resulting in taller plants (Zenelt et al., 2024). Similar findings were recorded by Ali et al. (2019) in which they revealed that the available P ions significantly affect overall plant growth. Similar findings were reported by Masood et al., (2011), who reported increase in plant height of maize with increasing dose of phosphorus.

Leaf Number

The number of leaves per plant was significantly impacted by varying doses of phosphorus at 5% level of significance. The most abundant leaf count (13.62) was recorded

in T5 (120 kg P₂O₅ + PSB/ha) followed by T4 (13.40) whereas the lowest (12.82) number of leaves occurred in T1 (0 kg P₂O₅ + PSB/ha). However, treatments T2, T3, and T6 exhibited statistically similar number of leaves. Additionally, it was observed that the internodes of the maize plants elongated significantly, resulting in taller maize plants with larger leaf sizes. Similar increase in leaf count were observed by Khan et al. (2014), who concluded that the number of leaves increased with application of phosphorus at 120 kg/ha along with N at 180 kg/ha.

Table 3

Performance of biometric parameters of spring maize under different levels of phosphorous with PSB at Botechaur, Surkhet, 2023

Treatments	Plant height (cm)	Number of leaves/plant
T1(0 kg P ₂ O ₅ + PSB/ha)	158.12 ^c	12.82 ^c
T2(30 kg P ₂ O ₅ +PSB/ha)	161.25 ^{bc}	13.10 ^{bc}
T3(60 kg P ₂ O ₅ + PSB/ha)	162.37 ^{ab}	13.17 ^{bc}
T4(90 kg P ₂ O ₅ +PSB/ha)	163.50 ^{ab}	13.40 ^{ab}
T5(120 kg P ₂ O ₅ +PSB/ha)	165.12 ^a	13.62 ^a
T6(60 kg P ₂ O ₅ /ha)	161.50 ^{bc}	13.12 ^{bc}
Grand Mean	161.97	13.20
SEm (±)	1.05	0.14
F-test	**	*
CV (%)	1.29	2.23

Note. SEm: Standard error of mean, CV: Coefficient of variation, ns: non-significant, ‘*’, Significant at 0.05 levels of significance

Yield and Yield Attributing Traits

Cob length

Cob length of spring maize was significantly influenced by the treatments at 5% level of significance. The longest cobs (18cm) were observed in T3 (60 kg P₂O₅ + PSB/ha) followed by T6 (60 kg P₂O₅/ha) i.e. 17.12cm and T4 (90 kg P₂O₅ +PSB/ha) i.e. 16.85cm. Significantly smallest cobs (15.82 cm) were recorded in T1 followed by T₅. However, both T2 (30kg phosphorous) and T5 (90kg phosphorous) were statistically at par with each other. These results indicated that the maize plant used optimal dose of phosphorus to attain maximum cob length in T3 (60 kg P₂O₅ + PSB/ha) over higher doses or lower doses. Application of PSB with 60kg/ha phosphorous might have increased the readily available phosphorus at early growth stages and triggered the flowering. Adequately available phosphorous has been reported to enhance cell formation, translocation, metabolism process, rapid growth (Khan et al., 2023).

This was also justified by Sankadiya & Sanodiya (2021) in which phosphorus and potassium encouraged formation of new cells, promoted plant vigorously and hastens leaf development, which help in harvesting more solar energy and better utilization of nitrogen, inducing higher growth attributes as a result significantly promotes cob length.

Number of Grains per Cob

There was significant difference among the treatments for number of grains/cob of maize. The highest number of grains per cob (377.74) was recorded in T3 (60 kg P₂O₅ + PSB/ha) followed by T6 (60 kg P₂O₅/ha) i.e., 347.80 and the least number was observed in T1. However, T1, T2, T4 and T5 were statistically at par in generating number of grains per cob. Despite statistically longer cobs, the number of grains is the highest with optimal level of phosphorous indicating use of balanced number of chemical fertilizers. Also, application of PSB might have supported the activities in the soil for readily available phosphorous (Pan & Cai, 2023). Besides the soil was slightly alkaline, indicating unavailability of phosphorous at higher doses by altering the pH of soil. In contradictory to this finding, Masood et al. (2011) reported that number of grains/cob significantly increased with increasing phosphorus levels up to 120 kg P₂O₅/ha. Phosphorus unavailability has been reported to produce small ears in maize with crooked and missing rows, leading to lesser number of grains (Sankadiya & Sanodiya, 2021).

1000 Grain Weight

There was no significant difference among the treatments for 1000 grain weight at 5% level of significance, which were in line with that reported by Masood et al. (2011). But contradictory with the findings, Fazlullah et al. (2018) and Baral et al. (2015) reported highly significant increase in 1000 grain weight at higher doses of phosphorus i.e. 90 kg phosphorous along with PSB in maize.

Grain Yield

The grain yield of spring maize was significantly impacted by different levels of phosphorus combined with PSB. The maximum grain yield (5.71 mt/ha) was observed in T3 (60 kg P₂O₅ + PSB/ha) followed closely by T6 (60 kg P₂O₅/ha) at 4.71 mt/ha which was statistically similar with T4 (90 kg P₂O₅ + PSB/ha) at 4.69 mt/ha. During the field observation, T3 also indicated minimal infestations of insects and diseases throughout the crop's growth period, which might have reduced stress to plants, contributing to increased grain yield. Besides, all the yield attributing traits as well as plant growth were significantly better than all other treatments leading to the highest grain yield at 60 kg phosphorous when combined with PSB. A positive trend in grain yield was evident with the increasing phosphorus levels in combination with PSB, ranging from 0 kg P₂O₅ + PSB/ha to 60 kg P₂O₅ + PSB/ha. However, the grain yield exhibited a slight decline as the phosphorus levels with PSB increased further, ranging from 90 kg P₂O₅ + PSB/

ha to 120 kg P₂O₅ + PSB/ha (in Table 4). These results suggested that the phosphorus application at the rate of 60 kg in combination with PSB was found to be the optimal dose for achieving higher grain yield production. Amanullah & Khan (2015) observed highest grain yield of maize at 75 kg P₂O₅ + PSB/ha which was statistically similar with treatment 60kg P₂O₅ + PSB/ha. Bai et al. (2020) also reported highest grain yield at 75 kg P₂O₅ with combination of PSB among different levels of phosphorus which was very close to the findings of this research.

Biological Yield

The biological yield of spring maize was also significantly affected by different doses of phosphorus with combination of PSB. The highest biological yield (16.43 mt/ha) was found in T₃ (60 kg P₂O₅ + PSB/ha) which was statistically similar with T₆ (60 kg P₂O₅/ha) i.e. 16.14 mt/ha. Very less infestation of insect pests as well as disease in T₃ (60 kg P₂O₅ + PSB/ha) compared to other treatments during field experiment might have reduced plant stress leading to the higher biological yield. The lowest biological yield (13 mt/ha) was recorded in T₁ (0 kg P₂O₅ + PSB/ha). The biological yield of spring maize was increased with increasing phosphorus levels from T₁ (0 kg P₂O₅ + PSB/ha) to T₃ (60 kg P₂O₅ + PSB/ha), might be due to increased plant height, leaf number accompanied by the longer cob size and number of grains per cob. This finding indicated that, 60 kg P₂O₅ + PSB/ha could be optimum dose for the better cell formation, growth, development and yield performance throughout the crop growth period which results in high production of biological yield. This finding is similar with the findings from Bai et al. (2020) and Amanullah & Khan (2015) in which they concluded that, the biological yield was significant at 75kg kg P₂O₅ with PSB treated seed over other treatments.

Table 4

Performance of yield and yield attributing traits of spring maize under different levels of phosphorous with PSB at Botechaur, Surkhet, 2023

Treatments	Cob length (cm)	Number of grains/cob	Thousand grain weight (g)	Grain yield (t/ha)	Biological yield (mt/ha)
T ₁ (0 kg P ₂ O ₅ + PSB/ha)	15.82 ^c	284.53 ^b	301.50	3.37 ^c	13.00 ^c
T ₂ (30 kg P ₂ O ₅ +PSB/ha)	16.52 ^{bc}	297.74 ^b	323.75	4.29 ^{bc}	13.31 ^{bc}
T ₃ (60 kg P ₂ O ₅ + PSB/ha)	18.00 ^a	377.74 ^a	357.75	5.71 ^a	16.43 ^a
T ₄ (90 kg P ₂ O ₅ +PSB/ha)	16.85 ^{abc}	301.26 ^b	347.00	4.69 ^{ab}	15.150 ^{ab}

T5(120 kg P ₂ O ₅ +PSB/ha)	16.60 ^{bc}	300.27 ^b	326.25	4.37 ^{bc}	15.12 ^{abc}
T6(60 kg P ₂ O ₅ /ha)	17.12 ^{ab}	347.80 ^{ab}	331.75	4.71 ^{ab}	16.14 ^a
Grand Mean	16.82	318.16	331.33	4.52	14.91
SEm (±)	0.41	0.21	13.57	0.42	0.74
F-test	*	*	ns	*	*
CV (%)	4.95	13.40	8.19	19.00	9.93

Note. LSD: Least significant difference, SEm: Standard error of mean, CV: Coefficient of variation, ns: non-significant, ‘*’ Significant at 0.05 levels of significance

Harvest Index

The data showed non-significant difference in the harvest index among the treatments at 5% level of significance. However, T3 (60 kg P₂O₅ + PSB/ha) recorded the highest value (0.34) while the lowest value (0.26) was noted in T1 (0 kg P₂O₅ + PSB/ha). Although grain yield and biological yield were statistically significant, the harvest index did not exhibit as such. This suggests that the variation in grain yield was not distinctly from the variation in biological yield.

Table 5

Harvest index of spring maize under different levels of phosphorous with PSB at Botechaur, Surkhet, 2023

Treatments	Harvest index
T1(0 kg P ₂ O ₅ + PSB/ha)	0.26
T2(30 kg P ₂ O ₅ +PSB/ha)	0.32
T3(60 kg P ₂ O ₅ + PSB/ha)	0.34
T4(90 kg P ₂ O ₅ +PSB/ha)	0.30
T5(120 kg P ₂ O ₅ +PSB/ha)	0.29
T6(60 kg P ₂ O ₅ /ha)	0.29
Grand Mean	0.30
SEm (±)	0.03
F-test	Ns
CV (%)	22.16

Note. LSD: Least significant difference, SEm: Standard error of mean, CV: Coefficient of variation, ns: non-significant

Economic Analysis

The highest cost of cultivation was recorded for T5 and the lowest cost of cultivation for T1 whereas the highest gross return was recorded in T3 and lowest gross return in T1. Similarly, the highest net return was found in T3 followed by T6 and the lowest net

return was recorded in T1, due to lesser grain yield. Highest benefit cost ratio of 1.64 was found in T3, indicating it to be the most profitable treatment. The BC ratios of 1 for the agricultural sector has been reported as economically viable ones (Ghimire et al., 2016). Hence, combination of 60 kg phosphorous with PSB is cost effective choice for generating higher incomes from maize cultivation in the similar context of soil and climate.

Table 6

Gross return, cost of cultivation, net return and BC ratio of spring maize under different levels of phosphorous with PSB at Botechaur, Surkhet, 2023

Treatments	Cost of cultivation (NRs/ha)	Gross return (NRs/ha)	Net return (NRs/ha)	B:C Ratio
T1 (0 kg P ₂ O ₅ + PSB/ha)	172222.2	238980	66757.77	1.38
T2 (30 kg P ₂ O ₅ +PSB/ha)	182600	295560	103033.33	1.61
T3 (60 kg P ₂ O ₅ + PSB/ha)	194722.2	320666.7	125944.45	1.64
T4 (90 kg P ₂ O ₅ +PSB/ha)	205966.7	309000	103033.33	1.49
T5 (120 kg P ₂ O ₅ +PSB/ha)	217222.22	317266.7	100044.44	1.45
T6 (60 kg P ₂ O ₅ /ha)	191388.9	314713.3	123324.45	1.63

Conclusion

Application of 60 kg/ha phosphorus with phosphate-solubilizing bacteria (PSB) maximized maize yield, yield-attributing traits, and economic return. Higher phosphorus levels up to 120 kg/ha improved growth traits but did not surpass yield and profitability at 60 kg/ha. Thus, 60 kg/ha P₂O₅ with PSB is recommended as the optimal dose for spring maize (Arun-2) in Surkhet.

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Author's Contribution

Binod Prasad Shah, under the supervision of Asst. Prof. Raksha Sharma, designed and carried out the research, accomplished the experiment, analyzed the data and prepared the report. Niranjana Kushwaha collected the data and helped in analysis. Satya

Niraula prepared the manuscript. Raksha Sharma guided in all aspects including the write-up of the manuscript.

Conflicts of Interest

The authors have no any conflict of interest to disclose.

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