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Research article

Influence of higher levels of NPK fertilizers on growth, yield, and profitability of three potato varieties in Surma, Bajhang, Nepal

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ABSTRACT

Potato is a crucial food and cash crop with high yield potential in many parts of the Bajhang district. However, achieving optimal yields can be hindered by inconsistent NPK fertilizer application rates and suboptimal potato variety selection, including instances where no fertilizers are used at all by the farmers. To address these challenges and determine the most effective NPK fertilizer rates and potato varieties, a field experiment was conducted in Surma rural municipality of Bajhang district. The experiment utilized a randomized complete block design (RCBD) with three replications, to evaluate the effects of four NPK fertilizer rates (0:0:0, 50:50:50, 100:100:60, and 150:150:90 kg NPK/ha) and three potato varieties (Khumal Seto, Cardinal, and Bajhang Local), on growth, yield, and economic profitability. Statistical analysis, including analysis of variance and Duncan's multiple range test (DMRT), indicated that the highest values for plant height, canopy diameter, number of leaves, number of main stems, tuber weight, fresh weight of leaves and stems, average tuber diameter and number of marketable tubers per hill were consistently observed higher in either the Khumal Seto or Bajhang Local potato varieties. Similarly, these results were particularly prominent with the application of 150:150:90 kg NPK/ha. Economic analysis demonstrated that the Khumal Seto variety showed superior performance in terms of gross benefit, net benefit, and benefit-to-cost ratio (NPR 1,805,714.29, NPR 1,306,168.83, and 3.61, respectively) when compared to other varieties. Similarly, the application of 150:150:90 kg NPK/ha resulted in higher economic returns (NPR 1,645,714.29, NPR 1,129,908.83, and 3.19). In conclusion, using higher levels of mineral fertilizers (150:150:90 kg NPK/ha) with high yielding and well adapted potato varieties such as Khumal Seto and Bajhang Local significantly enhances growth, yield, and profitability in potato cultivation, as demonstrated by the findings of this study.

1. Introduction

The potato (*Solanum tuberosum* L.) is an annual herbaceous plant belonging to the Solanaceae family. It is characterized by a chromosome count of (2n = 4X = 48) [1], and is globally recognized as one of the most important tuber crops [2]. Ranked as the fourth most crucial food crop worldwide after wheat, rice, and maize (corn), the potato is esteemed for its significant yield potential and high nutritional value [3]. Potatoes are renowned for their rich nutritive content, encompassing essential nutrients such as vitamins B1, B6, B9, and C, as well as macro- and microminerals like potassium, iron, copper, manganese, and phosphorus. Moreover, they provide

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dietary components such as fiber, high-quality protein, and carbohydrates (such as starch), further enhancing their nutritional profile and value [4].

In the Bajhang district, several potato varieties, notably Khumal Seto, Cardinal, and Bajhang Local, have traditionally been cultivated. According to farmers in Surma, potatoes represent a crucial source of income, second only to the risky Yarsagumba collection, motivating them to engage in potato farming. However, farmers in this region exhibit significant knowledge gaps regarding the major sources, rates, and methods of applying nitrogen, potassium, and phosphorus fertilizers. Evidence suggests that both deficiency and toxicity symptoms in potato fields result from either excessively low or high fertilizer application rates. Additionally, farmers are unaware of the importance of selecting suitable varieties to maximize yields; often planting whatever variety is available, missing out on potential profit from higher-yielding varieties. These factors contribute to the unsatisfactory potato yields in Surma, despite the area's considerable agricultural potential. Potato production and productivity in Bajhang (15.36 mt/ha) are below the national average (16.73 mt/ha) [5]. Potatoes are known for their high input-to-output ratio, with substantial yield increases driven by factors such as superior seed tubers, fertilizers, pesticides, and increased labor, which incentivize farmers to allocate more resources to potato cultivation compared to other crops [6]. However, the lack of well-adapted potato varieties poses a significant production challenge, contributing to these lower yields [7]. The response to nitrogen fertilizer application varies depending on the cultivar and soil type, emphasizing the need for careful consideration when selecting fertilization strategies for different cultivars in specific locations [8].

Potatoes, known for their inefficient use of nitrogen, require higher nitrogen (N) fertilizer rates to maximize growth [9]. Precise application of nitrogen (N) fertilizer, including selecting the right source, rate, timing, and placement, is crucial for effective nitrogen management. That's why the farmers should apply nitrogen only when necessary, calibrate application equipment for accurate placement, and adjust the source, rate, and timing to meet nitrogen requirements while minimizing potential harm to seeds or seedlings [8]. Split nitrogen applications is important to prevent losses through leaching, volatilization, denitrification, weed uptake, erosion, and sedimentation [10]. Nitrogen significantly influences two critical quality attributes: specific gravity (dry matter content) and reducing sugar content (glucose), both of which affect tuber quality. Varying nitrogen levels have diverse effects on tuber quality. Inadequate nitrogen results in very small tubers, high sugar levels, low dry matter content, overmature tubers, and increased susceptibility to infections. That's why it is important for the farmers to apply nitrogen in optimal and adequate rates which leads to well-shaped tubers with low sugar content, high dry matter, mature tubers, and improved disease resistance. Excessive nitrogen causes somewhat smaller tubers, higher sugar levels, moderate dry matter content, immature tubers, and heightened susceptibility to diseases and bruising [11–13].

Phosphorus (P) plays a crucial role in enhancing tuber yield and quality by influencing cell division, starch synthesis, and storage. It also increases concentrations of ascorbic acid, nitrogen (N), and protein in tubers, thereby impacting their size and dry matter content (specific gravity) [14]. This underscores the importance for farmers in Surma to apply phosphorus (P) in adequate rates to maximize tuber yield, solids content, nutritional quality, and resistance to specific diseases [15].

Potassium (K) holds significant importance as a crucial macronutrient for vegetable crops, especially potatoes. Among macronutrients, potassium is second only to nitrogen in terms of plant demand [16,17]. Potassium plays a vital role in photosynthesis by enhancing the translocation of photosynthates, increasing enzyme activities, and contributing to the synthesis of proteins, carbohydrates, and fats, thereby significantly boosting overall crop productivity [18]. It also helps plants withstand various biotic and abiotic stresses, such as pathogens, drought, and extreme temperatures [19]. Additionally, potassium is essential for maintaining photosynthesis [20] by facilitating CO_2 diffusion through the leaf mesophyll [21].

Different fertilizer rates have a significant impact on potato yield, with the highest total tuber and tuber dry matter yield observed at the maximum NPK dose. Conversely, avoiding fertilizer application on the standard planting date typically results in the lowest tuber yield [22]. Dry matter accumulation is higher with the application of the highest NPK dose throughout all growth stages. Additionally, the efficiency of nitrogen (N), phosphorus (P), and potassium (K) fertilizers is significantly influenced by increasing levels of these nutrients. The highest optimal NPK dose results in higher soil nutrient levels, with maximum availability of N, P2O5, and K2O. This outcome is likely due to the higher fertilizer dose, leading to residual nutrient storage in the soil after meeting the potato's growth and yield requirements, influenced by nutrient uptake [23]. Plant height and other morphological characteristics are highly dependent on potato varieties due to genetic variations [24]. Higher production and a better benefit-cost ratio are observed at higher optimal rates of NPK fertilizers [23]. That's why it is very important for the farmers of Surma to start using higher NPK rates and high-yielding varieties.

Therefore, this study was conducted with the objective of determining the optimal and economically viable rates of nitrogen (N), phosphorus (P), and potassium (K) fertilizers, as well as identifying suitable and high-yielding potato varieties for Surma. The study aimed to evaluate the impact of increased levels of NPK fertilizers on the growth, yield, and profitability of various potato varieties in Surma rural municipality, Bajhang district.

2. Materials and methods

2.1. Description of the study area

The field experiment was conducted in Surma Rural Municipality-1, Daulichaur, Bajhang district, Sudurpaschim province. Surma is located in the Seti zone of the Far-western province of Nepal, within a sub-humid and sub-tropical zone at an elevation of 1867 m above sea level, covering a total area of 270.8 square kilometers. Potatoes are cultivated during the summer season in Surma due to favorable temperatures for potato growth at this time. The research was carried out from March 3, 2023, to July 23, 2023, over a duration of 140 days. The climatic conditions during the study period are presented in Fig. 1. The location of the experimental field is illustrated in Fig. 2.

2.2. Treatments and experimental design

A Randomized Complete Block Design (RCBD) was used for this experiment. The potato cultivars employed were Khumal Seto, Cardinal, and Bajhang Local. The tuber seeds were collected from the Prime Minister Agriculture Modernization Project (PMAMP), potato zone, Bajhang. In Bajhang, Khumal varieties such as Khumal Rato-2, Khumal Seto, and Khumal Ujjwal have a good reputation for high yield, a high number of marketable tubers, and overall performance [26]. Cardinal performed well in terms of tuber weight, while Bajhang Local, being a native variety, showed impressive growth parameters (number of main stems per hill, leaves and leaflet numbers, and canopy diameter) and some yield parameters (number of tubers per hill, tuber size) [27]. According to PMAMP, Bajhang, these three varieties have consistently outperformed others over the past few years in the potato zone of Bajhang. Although including more varieties would have provided a more comprehensive analysis, the selection of these three was based on their proven performance and availability at the time of the research.

The RDF of NPK for potatoes in Bajhang district is 100:100:60 kg/ha. The NPK rates used for this experiment were 0%, 50%, 100%, and 150% of the Recommended Dose of Fertilizers (RDF) for NPK. 100 % RDF is the recommended NPK fertilizer rate. First, the quantity for the 100% RDF was calculated, then it was halved to obtain the 50% RDF, and the quantity of the 100% RDF was increased by 1.5 times to achieve the 150% RDF of NPK fertilizers. Three potato varieties and four NPK rates resulted in a total of 12 treatments per replication.

Each individual plot measured 3.5 m in length and 1.25 m in breadth. The spacing was 70 cm between rows (RR) and 25 cm between plants (PP), resulting in five rows with five plants per row, totaling twenty-five plants per plot. In each plot, the border plants were not selected as sample plants, leaving nine plants in the middle. Among these nine, five sample plants were tagged and selected for data collection. The net experimental plot area was 4.375 m^2, with a plot-to-plot spacing of 30 cm and a 20 cm border around the research field. The field was organized into three blocks for three replications, with a replication-to-replication spacing of 50 cm. The total area for the research field was 219.65 m^2.

2.3. Soil sampling and analysis

Some physical and chemical properties of soil, collected from a depth of 0–30 cm before the application of fertilizer, were analyzed. The soil sample was sent to the Soil and Fertilizer Testing Laboratory in Sundarpur, Kanchanpur. According to the soil test results, the sandy-loam textured soil had a pH of 7.1 (neutral). The soil was rated as medium in fertility status, with organic matter at 4.64%, low in available nitrogen at 0.23%, low in available phosphorus at 23.84 kg/ha, and medium in potassium at 244.8 kg/ha, based on the laboratory's reference standards.

2.4. Data collection

2.4.1. Vegetative parameters

Germination percentage was calculated by counting the number of germinated plants per plot at 45 and 60 days after planting

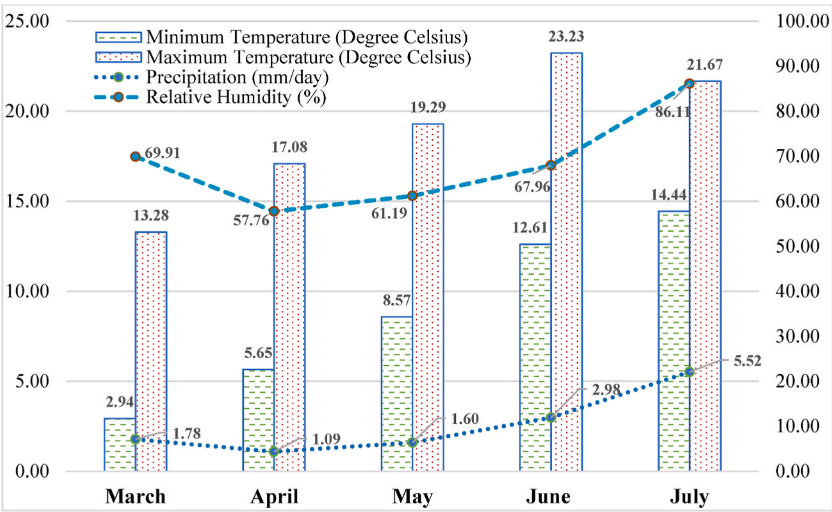

Fig. 1. Graph showing climate conditions during the study period
(Data source: [25]).

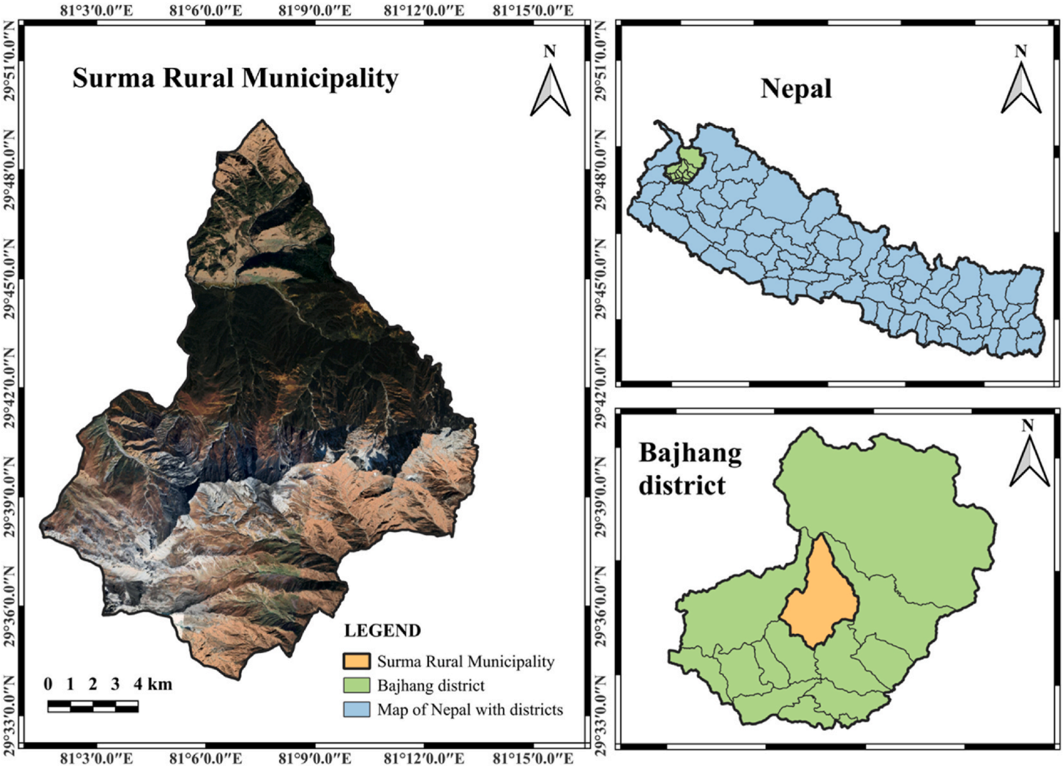

Fig. 2. Map showing the location of the experimental field.
(Created by using QGIS software, version: 3.36.0).

(DAP) and then converting this to a percentage, considering the total number of plants per plot was 25. The five tagged sample plants were used for collecting and recording data on plant height (cm), canopy diameter (cm), number of leaves per hill, and number of main stems per hill were recorded at 45, 60, 75, and 90 DAP. Plant height was measured from the ground surface to the tip of the main stem using a measuring tape. The number of stems emerging from the ground was counted for the five sample plants. Average shoot weight (grams per hill) was measured by cutting and weighing the shoot (stem, branch, and leaves) from the five sampled plants at physiological maturity, when the plants were fully developed and had practically ceased growing. The canopy diameter (distance across the potato plant's foliage at its widest point, from one edge to the opposite edge) was measured using a measuring tape, with averages per hill calculated for each parameter across all plots.

2.4.2. Yield parameters

At harvest, data was collected from the five tagged sample plants in each plot. The recorded parameters included the number of tubers per hill (both marketable and non-marketable), weight of tubers per hill (kg), and average tuber diameter (cm). The tubers were weighed and graded as marketable (>25 g) and non-marketable (<25 g). Both categories were counted separately, and an average was taken. Tuber diameter was measured by placing a measuring tape around the broadest part of the tuber and the reading was noted.

2.4.3. Economic analysis

The cost of cultivation includes all the tentative working costs incurred in potato cultivation, calculated in terms of NPR per hectare. The cost of cultivation was similar for all varieties. However, it was significantly higher for fields with NPK treatment (50%, 100%, and 150% RDF) compared to non-treated conditions (0% RDF, control) due to the extra cost incurred on urea, DAP (Diammonium Phosphate), and MOP (Muriate of Potash) fertilizers.

The economic analysis of potato cultivation was conducted based on yield, and was carried out in two sections. In the first section, the details regarding the total cost of production were calculated and in the second section, total revenue (gross return) and B:C ratio (Benefit to cost ratio) was calculated for each treatment. The total monetary value of the major product (Potato tuber) obtained from the crop is called gross return. The rate per unit of all the input was based upon current market rate in the Surma area of Bajhang district, with the price of potato being fixed at NPR 40 per kg. The cost of the chemical fertilizers were calculated based on input price during the experimental period. The total cost of cultivation was worked out by summing up the fixed (general) cost of cultivation and variable cost. The B: C ratio was calculated by using the equations given below:

Gross return (Total revenue) = Yield (kg/ha) x price per kg.

Total cost = Cost of inputs, labor, machines, etc.

Net return = Gross return - Total cost.
B: C ratio = Gross return/Total cost.

2.5. Data analysis and softwares/tests used

All the data were recorded and calculated by arranging systematically treatment-wise under three replications based on various observed parameters by using Microsoft Excel. Analysis of variance (ANOVA) was conducted using RStudio (version: 2024.04.2 + 764). Linear model assumptions for descriptive statistics, skewness and kurtosis were confirmed to be acceptable by using the R-package 'gvlma'. No outlying or missing data were found during the analysis. The main purpose of the ANOVA was to do mean comparisons among treatments by using Duncan's Multiple Range Test (DMRT) via RStudio, facilitated by the R-package 'agricolae'. This test was done at a confidence interval of 95 % (0.05 level of significance, $\alpha = 0.05$) and 22 degree of freedom. Results from these tests were tabulated, interpreted, and discussed in the results and discussion section. Given the fact that there were no local meteorological stations available in Bajhang district, the climate data was collected from Ref. [25] and Fig. 1 was prepared with the help of this data by using MS Excel. Fig. 2 was generated by using appropriate shape files with the help of QGIS software (version: 3.36.0).

3. Results and discussion

3.1. Vegetative parameters

3.1.1. Plant height as impacted by potato varieties and NPK rates

Analysis of variance (ANOVA) indicates a significant influence of potato varieties (at 60, 75, and 90 DAP) and NPK rates (at 75 and 90 DAP) on the height of the potato crop, as detailed in Table 1. Khumal Seto (47.16 cm at 75 DAP) and Bajhang Local (24.68 cm at 60 DAP and 60.23 cm at 90 DAP) exhibited the tallest plant heights, while Cardinal consistently showed the lowest height across all observation days. This variation in plant height among potato varieties aligns with findings from Ref. [7] highlighting significant differences in plant height among potato varieties. The superior performance of Bajhang Local and Khumal Seto in terms of plant height may be attributed to genetic variations influencing morphological characteristics. Environmental factors and additive genetic mechanisms also play significant roles in regulating traits like plant height, as noted in previous studies by Refs. [24,28].

150% RDF (50.04 cm at 75 DAP and 70.22 cm at 90 DAP) resulted in the highest plant height, whereas the lowest plant height was found in 0% RDF (38.71 cm at 75 DAP and 45.36 cm at 90 DAP). Increasing NPK rates significantly enhanced plant height. High doses of nitrogen [29], phosphorus [30] and potassiuum [31,32] applications contributed to robust plant growth and taller plants. This effect is likely due to the pivotal role of nitrogen, phosphorus, and potassium in promoting cell division, growth, and stem elongation, supporting increased plant height, as observed in previous study by Ref. [33].

3.1.2. Canopy diameter as impacted by potato varieties and NPK rates

Analysis of variance (ANOVA) indicates that both potato varieties (at 45, 75, and 90 DAP) and NPK rates (at 60, 75, and 90 DAP) significantly affect the canopy diameter of potato plants, as detailed in Table 2. Khumal Seto exhibited the widest canopy diameter

Table 1
Plant height (cm) as influenced by potato varieties and NPK rates.

Treatment	Plant height (cm)			
	45DAP	60DAP	75DAP	90DAP
Varieties				
- Khumal Seto	9.65^{a}	23.80^{ab}	47.16^{a}	59.43^{a}
- Cardinal	9.15^{ab}	21.35^{b}	38.43^{b}	49.55^{b}
- Bajhang local	7.98^{b}	24.68^{a}	46.34^{a}	60.23^{a}
LSD ($\alpha = 0.05$)	1.41	2.56	3.20	4.26
SEM (±)	0.48	0.87	1.01	1.45
F-test ($\alpha = 0.05$)	NS.	S*	S***	S***
NPK rates				
– 50% RDF	9.11^{a}	22.98^{ab}	41.71^{c}	53.51^{b}
– 100% RDF	9.22^{a}	23.47^{ab}	45.44^{b}	56.53^{b}
– 150% RDF	9.31^{a}	25.02^{a}	50.04^{a}	70.22^{a}
– 0% RDF	8.07^{a}	21.64^{b}	38.71^{c}	45.36^{c}
LSD ($\alpha = 0.05$)	1.62	2.95	3.69	4.92
SEM (±)	0.55	1.01	1.26	1.68
F-test ($\alpha = 0.05$)	NS	NS	S***	S***
CV (%)	18.59	12.98	8.58	8.93

Note: Treatment means that share a common letter(s) within a column are not statistically different from one another, according to DMRT at the 5 % level of significance. NS, non-significant; S*, significance at 0.05 level of significance; S**, significance at 0.01 level of significance; S***, significance at <0.01 level of significance; DAP, Days After Planting; LSD, Least significant difference; CV, Coefficient of Variation; SEM, Standard error of mean; RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium.

(70.69 cm at 75 DAP and 80.44 cm at 90 DAP). At 45 DAP, the largest canopy diameter was observed in Bajhang Local (25.51 cm). Conversely, Cardinal showed the smallest canopy diameter at 45 DAP (21.10 cm) and 90 DAP (72.86 cm), while Bajhang Local had the smallest at 75 DAP (59.35 cm). Varietal differences in canopy diameter, with Khumal Seto having the widest and Cardinal the narrowest, may be attributed to specific traits such as branch angle and leaflet shape that influence canopy coverage [34]. The genetic basis of these traits, influenced by complex interactions of genetic, physiological, and environmental factors, contributes to the observed variability in canopy architecture among potato varieties, which is consistent with previous researches by Refs. [34,35].

At 60, 75, and 90 DAP, the highest canopy diameter was observed in plots treated with 150% RDF (55.41 cm at 60 DAP, 75.44 cm at 75 DAP, and 90.83 cm at 90 DAP). Conversely, the lowest canopy diameter was recorded in plots with 0% RDF (45.13 cm at 60 DAP, 57.34 cm at 75 DAP, and 60.24 cm at 90 DAP). Increased nitrogen, potassium, and phosphorus rates promoted canopy development, evident in the significantly larger canopy diameter of plants treated with 150 % RDF. These findings are consistent with previous studies by Refs. [15,36,37]. The enhanced canopy development in plots treated with 150 % RDF can be attributed to several factors. Nitrogen boosts leaf area index and chlorophyll content, phosphorus stimulates lateral stem production, leaf length, and overall leaf area, thereby promoting canopy growth. Additionally, potassium enhances water uptake, root permeability, enzymatic processes, and increases shoot weight and photosynthetic pigments, contributing to broader stem anatomy and larger canopy diameters. These physiological effects are well-documented in the works by Refs. [38,39–43].

3.1.3. Number of leaves per hill as impacted by potato varieties and NPK rates

Analysis of variance (ANOVA) indicates that both potato varieties and NPK rates significantly influence the number of leaves per hill throughout the observation period, as shown in Table 3. Khumal Seto exhibited the highest number of leaves per hill at 45 (18.53), 75 (67.83), and 90 DAP (97.38). Conversely, Bajhang Local had the highest number of leaves per hill at 60 DAP (43.81). Cardinal consistently showed the lowest number of leaves per hill across all observation days. The variation in leaf number among varieties such as Khumal Seto, Bajhang Local, and Cardinal underscores the complex relationship between genetic traits, leaf development, and canopy area. Leaf characteristics, including size and number, are strongly influenced by genetic factors inherent to each variety. Traits like leaf area index and flag leaf area play crucial roles in determining leaf numbers in potato crops. These findings align with previous studies by Refs. [44–46].

Furthermore, the highest and lowest numbers of leaves per hill were observed in plots treated with 150% RDF and 0% RDF, respectively, across all observation days. This pattern reflects the direct impact of NPK application rates on leaf development, consistent with previous researches by Refs. [37,47]. Potassium, in particular, regulates nitrogen metabolism and osmotic adjustment, which are critical for leaf development and growth. Additionally, potassium enhances shoot growth and chlorophyll content, contributing to increased leaf numbers. Similar outcomes have been reported in experiments carried out by Refs. [48,49].

3.1.4. Number of main stems per hill as impacted by potato varieties and NPK rates

Analysis of variance (ANOVA) reveals a significant effect of potato varieties (at 60, 75, and 90 DAP) and NPK rates (45, 75, and 90 DAP) on the number of main stems per hill in the potato crop, as illustrated in Table 4. The highest number of main stems per hill was found in Bajhang Local at all days of observation. Cardinal had the lowest number of main stems per hill at 75 (4.42) and 90 DAP (4.48). However, at 60 DAP, the lowest number of main stems per hill was found in Khumal Seto (5.01). There were significant

Table 2
Canopy diameter (cm) as influenced by potato varieties and NPK rates.

Treatment	Canopy Diameter (cm)			
	45DAP	60DAP	75DAP	90DAP
Varieties				
- Khumal seto	22.73^{ab}	51.71^{a}	70.69^{a}	80.44^{a}
- Cardinal	21.10^{b}	48.41^{a}	69.28^{a}	72.86^{b}
- Bajhang local	25.51^{a}	47.93^{a}	59.35^{b}	79.66^{a}
LSD (α = 0.05)	2.96	4.73	4.68	5.47
SEM (±)	1.01	1.61	1.6	1.87
F-test (α = 0.05)	S*	NS	S***	S*
NPK rates				
– 50% RDF	23.11^{a}	48.29^{b}	63.31^{c}	75.76^{c}
– 100% RDF	23.46^{a}	48.58^{b}	69.67^{b}	83.78^{b}
– 150% RDF	24.20^{a}	55.41^{a}	75.44^{a}	90.83^{a}
– 0% RDF	21.68^{a}	45.13^{b}	57.34^{d}	60.24^{d}
LSD (α = 0.05)	3.42	5.46	5.40	6.32
SEM (±)	1.16	1.86	1.84	2.15
F-test (α = 0.05)	NS	S**	S***	S***
CV (%)	15.11	11.31	8.32	8.32

Note: Treatment means that share a common letter(s) within a column are not statistically different from one another, according to DMRT at the 5 % level of significance. NS, non-significant; S*, significance at 0.05 level of significance; S**, significance at 0.01 level of significance; S***, significance at <0.01 level of significance; DAP, Days After Planting; LSD, Least significant difference; CV, Coefficient of Variation; SEM, Standard error of mean; RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium.

Table 3
Number of leaves per hill as influenced by potato varieties and NPK rates.

Treatments	Number of leaves per hill			
	45DAP	60DAP	75DAP	90DAP
Varieties				
- Khumal seto	18.53[a]	38.69[ab]	67.83[a]	97.38[a]
- Cardinal	14.92[b]	36.15[b]	52.68[b]	78.43[b]
- Bajhang local	17.93[a]	43.81[a]	61.79[ab]	89.83[ab]
LSD (α = 0.05)	2.82	6.05	10.28	14.20
SEM (±)	0.96	2.06	3.51	4.84
F-test (α = 0.05)	S*	S*	S*	S*
NPK rates				
– 50% RDF	16.82[ab]	32.65[b]	62.77[a]	86.13[b]
– 100% RDF	17.60[ab]	35.68[b]	59.66[ab]	86.78[b]
– 150% RDF	19.41[a]	57.98[a]	70.62[a]	104.49[a]
– 0% RDF	14.67[b]	31.89[b]	50.02[b]	76.80[b]
LSD (α = 0.05)	3.26	6.98	11.87	16.40
SEM (±)	1.11	2.38	4.05	5.59
F-test (α = 0.05)	S*	S***	S*	S*
CV (%)	19.46	18.06	19.98	18.94

Note: Treatment means that share a common letter(s) within a column are not statistically different from one another, according to DMRT at the 5 % level of significance. NS, non-significant; S*, significance at 0.05 level of significance; S**, significance at 0.01 level of significance; S***, significance at <0.01 level of significance; DAP, Days After Planting; LSD, Least significant difference; CV, Coefficient of Variation; SEM, Standard error of mean; RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium.

differences in number of main stems among the varieties with highest in Bajhang Local and lowest in Cardinal. Similar results were also observed by Refs. [7,50]. This is because the number of main stems per hill in potato varieties is influenced by various factors, including seed quality, soil conditions, and planting techniques, which interact differently across different varieties. This complexity is also reflected in the study by Ref. [51].

Regarding NPK rates, the highest and lowest numbers of main stems per hill were observed in plots treated with 150% RDF and 0% RDF, respectively, across all observation days. This is because increase in NPK rates help in significant increase in the number of main stems per hill which is similar to the results obtained by Refs. [30,32]. This might be due to the fact that nitrogen has significant impact on vigorous plant growth and increasing carbohydrate synthesis, which in turn leads to an increase in the number of main stems. Phosphorus helps in increasing the level of endogenous abscisic acid and indole-3-acetic acid, which are key hormones helping in increasing the main stem number. Potassium also functions to maintain osmotic potential, enhancing water uptake, and regulating enzymatic processes enhancing number of main stems. These findings are similar to the results obtained by Refs. [52–55].

Table 4
Number of main stems per hill as influenced by potato varieties and NPK rates.

Treatment	Number of main stems per hill			
	45DAP	60DAP	75DAP	90DAP
Varieties				
- Khumal seto	3.98[a]	5.01[b]	5.14[b]	5.48[a]
- Cardinal	3.64[a]	5.12[b]	4.42[b]	4.48[b]
- Bajhang local	3.97[a]	6.08[a]	6.21[a]	5.91[a]
LSD (α = 0.05)	0.62	0.87	0.78	0.60
SEM (±)	0.21	0.30	0.27	0.20
F-test (α = 0.05)	NS	S*	S***	S***
NPK rates				
– 50% RDF	4.02[a]	5.24[b]	4.49[b]	5.14[b]
– 100% RDF	4.11[a]	5.16[b]	5.98[a]	5.61[b]
– 150% RDF	4.26[a]	6.27[a]	6.43[a]	6.76[a]
– 0% RDF	3.07[b]	4.96[b]	4.13[b]	3.64[c]
LSD (α = 0.05)	0.72	1.00	0.90	0.69
SEM (±)	0.24	0.34	0.31	0.23
F-test (α = 0.05)	S**	NS	S***	S***
CV (%)	19.10	18.97	17.60	13.33

Note: Treatment means that share a common letter(s) within a column are not statistically different from one another, according to DMRT at the 5 % level of significance. NS, non-significant; S*, significance at 0.05 level of significance; S**, significance at 0.01 level of significance; S***, significance at <0.01 level of significance; DAP, Days After Planting; LSD, Least significant difference; CV, Coefficient of Variation; SEM, Standard error of mean; RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium.

3.2. Yield parameters

3.2.1. Germination percentage, tuber diameter (TD), and number of marketable (MNT) and non-marketable tubers (NMNT) per hill as impacted by potato varieties and NPK rates

Analysis of variance (ANOVA) indicates that the use of potato varieties and NPK rates did not significantly affect the germination percentage of the potato crop, as shown in Table 5. All potato varieties exhibited statistically similar germination percentages, consistent with findings from Ref. [56]. Similarly, increasing NPK rates also showed statistically similar germination percentages, as reported by Refs. [29,57,58].

ANOVA reveals that the use of potato varieties significantly influenced the tuber diameter of the potato crop, as depicted in Table 5. Khumal Seto exhibited the largest tuber diameter (5.53 cm), while Bajhang Local had the smallest (4.56 cm). Variations in tuber size and shape are primarily varietal characteristics, with significant differences observed in tuber length, breadth, mass, and volume among different potato varieties, as supported by Refs. [59–61].

However, there was no significant effect of NPK rates on the tuber diameter of the potato crop, consistent with findings from Refs. [62,63]. In contrast, ref. [64] reported that an increase in nitrogen and potassium application decreased the number of small tubers and increased the number of medium and large tubers. These contrasting results suggest that while nitrogen and potassium may influence tuber size distribution, further research is needed to validate these findings and understand the underlying mechanisms.

Analysis of variance (ANOVA) reveals that the use of potato varieties has a significant effect on the number of marketable tubers per hill of the potato crop, while NPK rates do not show a significant effect, as shown in Table 5. Khumal Seto exhibited the highest number of marketable tubers per hill (9.42), whereas Cardinal had the lowest (7.04).

However, regarding the number of non-marketable tubers per hill of the potato crop, both the use of potato varieties and NPK rates demonstrate significant effects. The highest number of non-marketable tubers per hill (10.30) was observed in Bajhang Local, while the lowest (5.94) was found in Cardinal. Specifically, the highest number of non-marketable tubers per hill occurred in the 0% RDF treatment (9.21), whereas the lowest number was recorded in the 100 % RDF treatment (7.14), which was statistically similar to the 150% RDF treatment (7.28).

Significant interaction effects of potato varieties and NPK rates on the number of non-marketable tubers per hill were observed, as shown in Table 6. The highest number of non-marketable tubers per hill was found in the Bajhang Local x 50% RDF interaction (11.47), while the lowest number was found in the Khumal Seto x 50% RDF interaction (5.13), which was statistically similar to the Khumal Seto x 150% RDF interaction (5.61).

The variation in tuber numbers among different varieties can be attributed to differences in tuber shape, which may vary between cultivars and even across different batches grown in the same location in a given year. Similar observations have been reported by Refs. [7,65]. Additionally, physiological factors such as crop age influence the timing of tuber formation, the total number of tubers produced, and the distribution of tuber sizes, as supported by findings in the research by Ref. [66].

NPK rates did not significantly affect the number of marketable tubers, which is consistent with findings from Refs. [30,64]. However, there was a significant difference in the number of non-marketable tubers due to NPK rates, which aligns with results

Table 5
Germination percentage, average tuber diameter, number of marketable tubers per hill, and number of non-marketable tubers per hill influenced by potato varieties and NPK rates.

Treatments	Germination Percentage (%)		ATD (cm)	NMTPH	NNMTPH
	45 DAP	60 DAP			
Varieties					
- Khumal seto	69.33^{a}	77.67^{a}	5.53^{a}	9.42^{a}	7.11^{b}
- Cardinal	71.67^{a}	82.00^{a}	5.10^{b}	7.04^{b}	5.94^{b}
- Bajhang local	73.00^{a}	82.67^{a}	4.56^{c}	8.79^{a}	10.30^{a}
LSD (α = 0.05)	9.60	10.16	0.27	1.39	1.22
SE (±)	3.27	3.46	0.09	0.47	0.42
F-test (α = 0.05)	NS	NS	S***	S**	S***
NPK rates					
– 50% RDF	73.33^{a}	79.11^{a}	5.10^{a}	8.66^{a}	7.51^{b}
– 100% RDF	68.00^{a}	84.44^{a}	5.11^{a}	9.15^{a}	7.14^{b}
– 150% RDF	69.33^{a}	75.56^{a}	4.96^{a}	8.36^{a}	7.28^{b}
– 0% RDF	74.67^{a}	84.00^{a}	5.08^{a}	7.51^{a}	9.21^{a}
LSD (α = 0.05)	11.09	11.73	0.32	1.61	1.41
SE (±)	3.78	4.00	0.11	0.55	0.48
F-test (α = 0.05)	NS	NS	NS	NS	S*
CV (%)	15.90	14.85	6.37	19.51	18.53

Note: Treatment means that share a common letter(s) within a column are not statistically different from one another, according to DMRT at the 5 % level of significance. NS, non-significant; S*, significance at 0.05 level of significance; S**, significance at 0.01 level of significance; S***, significance at <0.01 level of significance; DAP, Days After Planting; LSD, ATD, Average Tuber Diameter; Least significant difference; CV, Coefficient of Variation; SEM, Standard error of mean; RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium; NMTPH, Number of marketable tubers per hill, NNMTPH, Number of non-marketable tubers per hill.

Table 6
The number of non-marketable tubers per hill influenced by the interaction effect of potato varieties and NPK rates.

Treatments		
Varieties	NPK rates	Non- Marketable Number of tubers per hill
Khumal Seto	50% RDF	5.13[b]
	100% RDF	5.91[b]
	150% RDF	5.61[b]
	0% RDF	11.80[a]
Cardinal	50% RDF	5.92[b]
	100% RDF	6.39[b]
	150% RDF	5.91[b]
	0% RDF	5.55[b]
Bajhang Local	50% RDF	11.47[a]
	100% RDF	9.11[a]
	150% RDF	10.33[a]
	0% RDF	10.27[a]
LSD (α = 0.05)		2.44
SEM (±)		0.83
F-test (α = 0.05)		S***
CV (%)		18.53

Note: Treatment means that share a common letter(s) within a column are not statistically different from one another, according to DMRT at the 5 % level of significance. NS, non-significant; S*, significance at 0.05 level of significance; S**, significance at 0.01 level of significance; S***, significance at <0.01 level of significance; DAP, Days After Planting; LSD, Least significant difference; CV, Coefficient of Variation; SEM, Standard error of mean; RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium.

reported by Refs. [32,67]. The influence of NPK rates on tuber numbers varied across studies, showing significant effects in some cases and non-significant effects in others, as documented in existing literature. Further investigation is warranted to explore the reasons behind this variability.

3.2.2. *Weight of tuber per hill (kg) and shoot fresh weight per hill (kg) as impacted by potato varieties and NPK rates*

Analysis of variance (ANOVA) reveals that both potato varieties and NPK rates significantly affect the average tuber weight of the potato crop, as indicated in Table 7. The greatest tuber weight per hill was observed in Khumal Seto (0.79 kg), whereas the smallest tuber weight per hill was found in Cardinal (0.51 kg). Various potato varieties exhibited distinct tuber weights per hill. Similar findings were reported by Ref. [7]. The observed variation in tuber weight among varieties may be attributed to genotype-specific responses to environmental conditions, with certain genotypes demonstrating superior performance in specific regions, as discussed by Ref. [68].

The treatment receiving 150% RDF exhibited the maximum tuber weight per hill (0.72 kg), while the treatment receiving 0% RDF

Table 7
Weight of tubers per hill and shoot fresh weight per hill as influenced by potato varieties and NPK rates.

Treatments		
Varieties	Weight of tuber per hill (kg)	Shoot fresh weight per hill (kg)
- Khumal seto	0.79[a]	0.63[a]
- Cardinal	0.51[c]	0.51[b]
- Bajhang local	0.64[b]	0.60[b]
LSD (α = 0.05)	0.09	0.08
SE (±)	0.029	0.028
F-test (α = 0.05)	S***	S*
NPK rates		
– 50% RDF	0.65[a]	0.59[a]
– 100% RDF	0.70[a]	0.59[a]
– 150% RDF	0.72[a]	0.67[a]
– 0%RDF	0.53[b]	0.47[b]
LSD (α = 0.05)	0.10	0.09
SEM (±)	0.034	0.032
F-test (α = 0.05)	S**	S**
CV (%)	15.60	16.66

Note: Treatment means that share a common letter(s) within a column are not statistically different from one another, according to DMRT at the 5 % level of significance. NS, non-significant; S*, significance at 0.05 level of significance; S**, significance at 0.01 level of significance; S***, significance at <0.01 level of significance; DAP, Days After Planting; LSD, Least significant difference; CV, Coefficient of Variation; SEM, Standard error of mean; RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium; Kg, Kilograms.

showed the minimum tuber weight per hill (0.53 kg). Increased NPK levels significantly enhanced tuber yield. Similar outcomes were reported by Refs. [30,32,69]. The higher tuber weight due to fertilizer treatment can be attributed to enhanced growth, increased foliage and leaf area, and greater photosynthate supply, all contributing to the formation of larger tubers and higher yields. Nitrogen and potassium applications have also been noted to prolong canopy duration, thereby extending tuber bulking. Potassium is crucial for enhancing potato tuber quality and yield by influencing various physiological and biochemical processes such as improving water uptake, root permeability, enzymatic processes, and reducing physiological disorders, thereby enhancing shelf life. These findings are consistent with those reported by Refs. [8,64,67,70].

Analysis of variance (ANOVA) reveals that potato varieties and NPK significantly influence the average shoot weight of the potato crop, as shown in Table 7. The highest average shoot weight was recorded in Khumal Seto (0.63 kg), while Cardinal exhibited the lowest average shoot weight (0.51 kg). Variability in shoot weight among potato varieties is attributed to differences in above-ground biomass, influenced by factors such as canopy spectral saturation, crop height, and growth stage. Additionally, the response of potato growth to growth regulators varies across varieties, affecting lateral stem growth differently among them. These findings align with similar observations reported by Ref. [38] and are consistent with views discussed by Ref. [71].

The highest average shoot weight was observed in the 150 % RDF treatment (0.67 kg), while the lowest average shoot weight was recorded in the 0% RDF treatment (0.47 kg). NPK fertilization exerted a significant influence on the biomass of different potato cultivars, with higher application rates correlating with increased total biomass. Similar findings were reported by Ref. [72]. The increase in the stem's fresh weight due to NPK application is a result of its association with the plant's metabolic activities, leading to enhanced growth [38]. Nitrogen, in particular, plays a critical role in the vegetative development and yield of potatoes, enhancing phosphorus availability in the soil and altering phosphorus metabolism within the plant. These insights are supported by Refs. [73,74].

Nitrogen fertilizers are highly susceptible to leaching and runoff, posing significant environmental risks such as nutrient runoff and water pollution. These issues can lead to eutrophication, oxygen depletion, and soil and air contamination as mentioned by Refs. [75,76]. To mitigate these problems, urea was applied in split doses, aiming to enhance nitrogen use efficiency and reduce nutrient runoff [77]. Research by Ref. [78] indicated a 43% reduction in tile nitrate loss with split applications, underscoring their effectiveness. Additionally, Ref. [79] demonstrated that optimizing the timing of split applications could decrease regional nitrogen loads by 28%.

3.3. Economic analysis

The details of the cost components and respective cost calculation for each treatment is shown in Tables 8–11. The evaluated results of gross benefit (revenue), cultivation cost, net return, and B:C ratio are given in Table 12.

The gross margin achieved with Khumal Seto and Bajhang Local was higher by 55% and 25.49%, respectively, compared to Cardinal (NPR 1,165,714.29 ha^{-1}). Similarly, the gross margin with 50%, 100%, and 150 % RDF increased by 22.64%, 32.08%, and 35.85%, respectively, compared to 0% RDF (NPR 1,211,428.57 ha^{-1}).

Net return, representing gross return minus cultivation costs, was 96.07% higher with Khumal Seto and 44.60% higher with Bajhang Local compared to Cardinal (NPR 666,168.83 ha^{-1}). Likewise, net return with 50%, 100%, and 150% RDF increased by 37.77%, 53.06%, and 58.72%, respectively, compared to 0% RDF (NPR 711,883.12 ha^{-1}).

The benefit-cost (B: C) ratio, which reflects return per rupee invested, ranged from 2.33 to 3.61 across various varieties and NPK rates (Table 12). Khumal Seto and 150% RDF showed the highest gross and net returns per hectare, leading to a higher B: C ratio. This indicates these treatments could significantly enhance farm income at the household level of the farmers of Surma.

The highest gross and net returns, along with the most favorable benefit-cost ratios, were particularly evident at optimal NPK fertilizer rates as mentioned by Refs. [23,80]. This outcome is attributed to enhanced nutrient availability in the soil, promoting robust plant growth and higher tuber yields, thereby increasing profitability as discussed by Ref. [81].

4. Conclusion

The experiment yielded valuable insights into the vegetative growth parameters, phenological characteristics, and yield of potato varieties in response to increased NPK rates. Khumal Seto and 150% RDF demonstrated the highest values across various parameters including plant height, canopy diameter, number of leaves, number of main stems, tuber diameter, tuber weight, and shoot weight per hill. Bajhang Local showed statistically similar or close performance to Khumal Seto in most aspects. In contrast, Cardinal and control treatments consistently exhibited the lowest values. The interaction effect between Khumal Seto and 150% RDF resulted in the least number of non-marketable tubers, further highlighting their combined efficacy. Economic analysis revealed that Khumal Seto and 150% RDF treatments offered the highest benefit-cost ratio and gross returns compared to other treatments, with Bajhang Local closely following Khumal Seto. Therefore, 150% RDF emerged as the optimal NPK dose, and Khumal Seto as the optimal variety among the treatments for maximizing growth and yield performance. These findings suggest that potato farmers in Surma would benefit significantly from adopting Khumal Seto or Bajhang Local varieties with 150% RDF of NPK to achieve higher yields and profits.

5. Limitations of the study and suggestions for future research

This study focused exclusively on one soil type within a specific agricultural domain. Therefore, it is recommended to investigate the agronomic and economic impacts of varying NPK rates and different potato varieties across diverse soil types. Conducting experiments over multiple years and at different locations is essential for reliable and generalizable agronomic evaluations. The study site, situated at an altitude exceeding 1800 m, presents unique pedological and climatic conditions that may limit the extrapolation of

Table 8
Details of cost components for Khumal Seto, Cardinal, Bajhang Local or 0 % RDF.

SN	Particulars	Unit	Quantity	Rate/unit (NPR)	Cost (NPR/220m^2)
(A)	Land Preparation & labour costs				
1.	Mini tiller (3 ploughs)	hr	1.25	1000	1250
2.	levelling and ridge preparation	man-hr	10	100	1000
3.	Planting potato tuber seed	man-hr	6	100	600
4.	Intercultural operations	man-hr	12	100	1200
5.	pesticide application	man-hr	2	100	200
6.	Irrigation	hr	3	500	1500
(B)	Seed tuber				
1.	Khumal seto or Cardinal or Bajhang local	kg	36	70	2520
(C)	Fertilizer & Pesticides				
1.	FYM (Farmyard Manure)	kg	400	0.8	320
2.	Pesticides (Mancozeb 75% WP)	packets	1	150	150
(D)	Harvesting & Packaging				
1.	Harvesting & packaging	man-hr	10	100	1000
2.	Sacs	no.	15	50	750
(E)	Rental value of land				500
				Total (NPR/220m^2)Total (NPR/220m^2)	10990
				Total (NPR/ha)	499545.4545

Table 9
Details of cost components for 50 % RDF.

SN	Particulars	Unit	Qty	Rate/unit (NPR)	Cost (NPR/220m^2)
(A)	Land Preparation & labour costs				
1.	Mini tiller (3 ploughs)	hr	1.25	1000	1250
2.	levelling and ridge preparation	man-hr	10	100	1000
3.	Planting potato tuber seed	man-hr	6	100	600
4.	Intercultural operations	man-hr	12	100	1200
5.	pesticide application	man-hr	2	100	200
6.	Irrigation	hr	3	500	1500
(B)	Seed tuber				
1.	Khumal seto or Cardinal or Bajhang local	kg	36	70	2520
(C)	Fertilizer & Pesticides				
1.	FYM (Farmyard Manure)	kg	400	0.8	320
2.	Urea	kg	1.458	22	32.065
3.	DAP (Diammonium Phosphate)	kg	2.387	25	59.675
4.	MOP (Muriate of Potash)	kg	1.1	25	27.5
5.	Pesticides (Mancozeb 75% WP)	packets	1	150	150
(D)	Harvesting & Packaging				
1.	Harvesting & packaging	man-hr	10	100	1000
2.	Sacs	no.	15	50	750
(E)	Rental value of land				500
				Total (NPR/220m^2)	11109.24
				Total (NPR/ha)	504965.4545

findings to other regions with different environmental characteristics. Thus, additional trials in diverse environmental settings are needed.

While higher NPK applications showed favorable responses in potato crops, exceeding optimal rates can lead to toxicity, diminishing both vegetative and reproductive performance, thus becoming economically disadvantageous. Further research should be done to explore the upper thresholds of NPK application for potato varieties, identifying the point where benefits peak and economic returns are maximized. This research included only three potato varieties, and there may be others that outperform those studied here. Therefore, future studies should expand varietal trials to encompass a broader range of potato cultivars to identify superior performers across different environmental conditions. Additionally, while employing the split application method in this experiment helps mitigate nutrient runoff and associated environmental hazards to a certain extent, further research should focus on identifying, refining, and implementing additional methods to effectively manage and minimize these environmental impacts associated with higher NPK rates.

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Table 10
Details of cost components for 100 % RDF.

SN	Particulars	Unit	Qty	Rate/unit (NPR)	Cost (NPR/220m^2)
(A)	Land Preparation & labour costs				
1.	Mini tiller (3 ploughs)	hr	1.25	1000	1250
2.	levelling and ridge preparation	man-hr	10	100	1000
3.	Planting potato tuber seed	man-hr	6	100	600
4.	Intercultural operations	man-hr	12	100	1200
5.	pesticide application	man-hr	2	100	200
6.	Irrigation	hr	3	500	1500
(B)	Seed tuber				
1.	Khumal seto or Cardinal or Bajhang local	kg	36	70	2520
(C)	Fertilizer & Pesticides				
1.	FYM (Farmyard Manure)	kg	400	0.8	320
2.	Urea	kg	2.915	22	64.13
3.	DAP (Diammonium Phosphate)	kg	4.774	25	119.35
4.	MOP (Muriate of Potash)	kg	2.2	25	55
5.	Pesticides (Mancozeb 75% WP)	packets	1	150	150
(D)	Harvesting & Packaging				
1.	Harvesting & packaging	man-hr	10	100	1000
2.	Sacs	no.	15	50	750
(E)	Rental value of land				500
				Total (NPR/220m^2)	11228.48
				Total (NPR/ha)	510385.4545

Table 11
Details of cost components for 150 % RDF.

SN	Particulars	Unit	Quantity	Rate/unit (NPR)	Cost (NPR/220m^2)
(A)	Land Preparation & labour costs				
1.	Mini tiller (3 ploughs)	hr	1.25	1000	1250
2.	levelling and ridge preparation	man-hr	10	100	1000
3.	Planting potato tuber seed	man-hr	6	100	600
4.	Intercultural operations	man-hr	12	100	1200
5.	pesticide application	man-hr	2	100	200
6.	Irrigation	hr	3	500	1500
(B)	Seed tuber				
1.	Khumal seto or Cardinal or Bajhang Local	kg	36	70	2520
(C)	Fertilizer & Pesticides				
1.	FYM (Farmyard Manure)	kg	400	0.8	320
2.	Urea	kg	4.373	22	96.195
3.	DAP (Diammonium Phosphate)	kg	7.161	25	179.025
4.	MOP (Muriate of Potash)	kg	3.3	25	82.5
5.	Pesticides (Mancozeb 75% WP)	packets	1	150	150
(D)	Harvesting & Packaging				
1.	Harvesting & packaging	man-hr	10	100	1000
2.	Sacs	no.	15	50	750
(E)	Rental value of land				500
				Total (NPR/220m^2)	11347.72
				Total (NPR/ha)	515805.4545

Table 12
Calculated results of gross benefit, cultivation cost, net return, and B:C ratio.

Treatments	Total yield (t ha^{-1})	Gross Benefit (NPR ha^{-1})	Cultivation cost (NPR ha^{-1})	Net return (NPR ha^{-1})	B:C ratio
Varieties					
- Khumal Seto	45.14	1805714.29	499545.45	1306168.83	3.61
- Cardinal	29.14	1165714.29	499545.45	666168.83	2.33
- Bajhang local	36.57	1462857.14	499545.45	963311.69	2.93
NPK rates					
– 50% RDF	37.14	1485714.29	504965.45	980748.83	2.94
– 100% RDF	40.00	1600000.00	510385.45	1089614.55	3.13
– 150% RDF	41.14	1645714.29	515805.45	1129908.83	3.19
– 0% RDF	30.29	1211428.57	499545.45	711883.12	2.43

Note: RDF, Recommended dose of fertilizers; cm, centimeters; %, percentage; NPK, Nitrogen Phosphorus Potassium; NPR ha^{-1}, Nepalese rupee per hectare; B:C ratio, Benefit to cost ratio; t ha^{-1}, tons per hectare.

Data availability statement

Data included in supp. material/referenced in article.

CRediT authorship contribution statement

Rijwan Sai: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Shobha Paswan:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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