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Economic analysis of potato cultivation as affected by sowing dates and plant spacing under split-plot design

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Abstract
The study aimed to evaluate the economic viability and yield performance of potato (*Solanum tuberosum* L.) as influenced by different sowing dates and plant spacings under a split-plot design. Conducted during Rabi 2023-24 in Dehradun, the experiment involved three sowing dates (15th October, 1st November, 15th November) and three spacing levels (45×15 cm, 60×20 cm, 60×25 cm), each replicated thrice. Results indicated that sowing on 1st November with a spacing of 60×20 cm (D2S2) produced the highest marketable tuber yield (34.2 t/ha) and maximum net returns (₹5.2 lakhs/ha), achieving a benefit-cost ratio of 6.48. The findings highlight that aligning planting with optimal climatic conditions and maintaining appropriate plant spacing enhances both productivity and profitability in potato cultivation.

Keywords: Potato cultivation, sowing dates, plant spacing, marketable yield, net returns, benefit-cost ratio, split-plot design, economic analysis, Rabi season, agro-climatic optimization, tuber yield, spacing efficiency, profitability

Introduction

Potato (*Solanum tuberosum L.*) stands as one of the most important staple crops globally, occupying a crucial place in global food systems due to its adaptability to diverse agro-climatic zones, short growth cycle, and high productivity per unit area (FAO, 2020) [5]. It is a rich source of carbohydrates, vitamins, and minerals, making it a valuable component in addressing food and nutritional security (Upadhya *et al*., 2018) [28]. Globally, it is cultivated in over 150 countries, and ranks fourth after maize, wheat, and rice in terms of production (Devaux *et al*., 2014) [4].

In India, potato is predominantly cultivated during the Rabi season in the northern Indo-Gangetic plains, particularly in states such as Uttar Pradesh, Bihar, and West Bengal (Haque *et al*., 2019; CPRI, 2022) [19, 3]. The crop's performance, however, is significantly influenced by a range of factors such as temperature, soil type, planting time, and crop management practices (Pandey *et al*., 2021) [19]. Among these, sowing date and plant spacing play a critical role in optimizing both yield and profitability.

The sowing time determines the environmental conditions during the crop's vegetative and tuberization stages. If sown too early or too late, the plant may experience sub-optimal temperature and photoperiod, negatively impacting growth and tuber formation (Singh *et al*., 2016) [25]. Optimum sowing ensures synchronization with favorable climatic windows, particularly temperature (15-25 °C) which is ideal for tuber initiation and development (Khurana & Pandey, 2004; Lal *et al*., 2015) [12, 17].

Similarly, plant spacing directly influences the plant population per unit area, thereby affecting the inter-plant competition for resources like nutrients, light, and water. Closer spacing may lead to overcrowding, resulting in reduced tuber size and higher disease incidence, whereas wider spacing can underutilize the land potential (Jatav *et al*., 2013; Kumar *et al*., 2020) [9, 21]. Therefore, balancing spacing with the crop's physiological needs is essential to maximize marketable tuber yield, which is a key parameter for commercial viability (Kumar & Rana, 2017) [13].

Economic analysis is another critical aspect often overlooked in agronomic trials. While biological yield provides a measure of productivity, net returns and benefit-cost ratio offer insights into the feasibility and profitability of the adopted practices (Tripathi *et al*., 2019) [27]. By evaluating both yield performance and economic returns, farmers and policymakers can make informed decisions for sustainable and profitable potato cultivation.

Therefore, this study is designed to systematically evaluate the influence of different sowing dates and plant spacings on marketable tuber yield and conduct a comprehensive economic analysis. The ultimate objective is to identify the most efficient and profitable combination of agronomic practices for enhanced productivity and farmer income under specific agro-climatic conditions.

2. Materials and Methods

Experimental Site and Soil Characteristics

The experiment was carried out at the Research Farm of Shivalik Institute of Professional Studies, Dehradun (30.3165° N, 78.0322° E) during Rabi 2023-24. The soil was loamy with pH 6.7, organic carbon 0.72%, available nitrogen 280 kg/ha, phosphorus 24 kg/ha, and potassium 310 kg/ha.

Treatments and Design

The study involved a split-plot design with three sowing dates (D1: 15th October, D2: 1st November, D3: 15th November) as main plot treatments and three spacings (S1: 45 cm × 15 cm, S2: 60 cm × 20 cm, S3: 60 cm × 25 cm) as subplot treatments. Each treatment was replicated thrice.

Table 1: Treatments and Experimental Design

Factor	Treatments	Treatment Codes
Sowing Dates	15th October	D1
	1st November	D2
	15th November	D3
Plant Spacing	45 cm × 15 cm	S1
	60 cm × 20 cm	S2
	60 cm × 25 cm	S3
Design	Split-plot design with sowing dates as main plot and spacings as subplot treatments	
Replications	Each treatment combination was replicated three times	

Economic analysis

Economic evaluation plays a crucial role in determining the profitability and sustainability of any agricultural practice. In the case of potato cultivation, where inputs are high and the crop is sensitive to both agronomic and climatic variables, an accurate economic assessment becomes essential for farmers to make informed decisions. The economic analysis in this study is based on standard financial parameters including Gross Returns (GR), Cost of Cultivation (CoC), Net Returns (NR), and the Benefit-Cost Ratio (B:C).

Gross Returns (GR)

Gross Returns refer to the total income earned from the sale of marketable potato tubers per hectare. It is calculated by multiplying the marketable yield (in tonnes per hectare) with the average market price of potatoes.

Gross Returns (GR) = Marketable Yield (t/ha) × Market Price

Cost of Cultivation (CoC)

The Cost of Cultivation includes all expenses incurred in growing potatoes over one hectare. This encompasses costs related to seed tubers, land preparation, fertilizers, irrigation, labour, pesticides, and machinery usage.

In this study, the CoC is assumed to be a fixed amount of ₹95,000 per hectare, based on prevailing input costs and agricultural cost norms in potato-growing regions such as Uttar Pradesh, Bihar, and Punjab. This approximation provides a uniform baseline for economic comparison across different treatments.

Cost of Cultivation (CoC) = Fixed at ₹95,000/ha (based on local cost norms)

Net Returns (NR)

Net Returns represent the actual profit earned by the farmer after deducting all cultivation costs from the total gross income. It reflects the economic viability of a particular sowing date and spacing treatment.

Net Returns (NR) = *GR - CoC*

Benefit-Cost Ratio (B:C Ratio)

The Benefit-Cost Ratio is an important indicator of economic efficiency. It denotes the return per rupee invested in the production process. A B:C ratio greater than 1 suggests that the operation is profitable, while a ratio less than 1 indicates a loss.

Benefit-Cost Ratio (B:C) = GR / CoC

Results and Discussion

Yield Performance

The experimental data revealed that the sowing date and plant spacing significantly influenced the yield of potato (*Solanum tuberosum L.*). Among all the treatment combinations, the D2S2 treatment (1st November sowing with 60 × 20 cm spacing) yielded the highest marketable tuber production of 34.2 t/ha. This was closely followed by D2S3 (33.0 t/ha) and D2S1 (32.6 t/ha). Conversely, the lowest yield was observed in D3S1 (25th November with 45 × 15 cm spacing), which recorded only 24.3 t/ha. The. These findings indicate that early November sowing offers optimal environmental conditions such as moderate temperature, better solar radiation, and sufficient soil moisture, all of which contribute positively to tuber development and bulking. The results are supported by the studies of Kumar *et al*. (2021) [14] and Gauraha *et al*. (2017) [6], who also reported enhanced productivity with timely sowing and moderate spacing, which allows for better canopy development, nutrient utilization, and aeration.

Economics of potato affected by date of sowing and spacing

The influence of different treatment combinations on the economic returns was substantial. The Gross Returns (GR), Net Returns (NR), and Benefit-Cost (B:C) Ratio were computed using a fixed Cost of Cultivation (CoC) of ₹95,000/ha and a market price of ₹1,800 per quintal.

Table 2: Effect of Different Treatment Combinations on Yield, Gross Return, Net Return, and Benefit-Cost Ratio of the Crop

Treatment	Yield (t/ha)	GR (₹/ha)	NR (₹/ha)	B:C Ratio
D1S1	29.8	5,36,400	4,41,400	5.65
D1S2	31.0	5,58,000	4,63,000	5.87
D1S3	30.4	5,47,200	4,52,200	5.76
D2S1	32.6	5,86,800	4,91,800	6.18
D2S2	34.2	6,15,600	5,20,600	6.48
D2S3	33.0	5,94,000	4,99,000	6.25
D3S1	24.3	4,37,400	3,42,400	4.60
D3S2	25.6	4,60,800	3,65,800	4.85
D3S3	26.1	4,69,800	3,74,800	4.94

Thus, D2S2 was the most economical treatment with a B:C ratio of 6.48. Late sowing (D3) was associated with lower returns due to suboptimal growing conditions, supporting earlier findings by Sharma *et al.* (2018) [22] and Mitra & Ghosh (2015) [18].

Among all treatments, D2S2 emerged as the most economically viable option. It provided the highest gross returns of ₹6.15 lakh/ha, net returns of ₹5.20 lakh/ha, and a benefit-cost ratio of 6.48, indicating significant profitability. The economic advantage can be attributed to enhanced yield and efficient resource utilization. On the other hand, late sowing treatments (D3 series) resulted in reduced yields and subsequently lower economic returns, likely due to shortened growth duration and exposure to terminal heat stress or frost conditions.

These results are in alignment with the findings of Sharma *et al.* (2018) [22] and Mitra & Ghosh (2015) [18], who also concluded that delayed sowing negatively affects potato yields due to less favorable temperature and light conditions during the critical tuber bulking stage.

Interpretation and Agronomic Implications

From an agronomic perspective, sowing potatoes during the first week of November ensures that the critical phases of tuber initiation and bulking coincide with favorable weather conditions. The 60 × 20 cm spacing facilitated better canopy architecture, allowing for optimal sunlight interception, minimized intra-plant competition, and improved air circulation—all of which are essential for high tuber yield and quality.

Similar outcomes have been documented by Rana *et al.* (2020) [21] and Borah *et al.* (2014) [2], who emphasized the importance of timely sowing and adequate spacing in optimizing yield potential. Additionally, Patel *et al.* (2022) [20] highlighted that agronomic interventions, such as the use of appropriate spacing and sowing time, not only improve productivity but also enhance the economic viability of potato farming in commercial settings.

Discussion

Optimal sowing around early November appears to be highly beneficial for potato cultivation, particularly because it aligns the crop's critical growth phases—especially tuber initiation and bulking—with favorable environmental conditions such as moderate temperatures and ideal photoperiods. These climatic factors during early November promote physiological activities like photosynthesis and assimilate partitioning, which are crucial for optimal tuber development. The cooler nights and mild day temperatures prevalent during this time frame enhance the synthesis and translocation of carbohydrates towards the developing tubers, thus supporting higher yields. Such synchronization with the crop's growth rhythm minimizes environmental stress and maximizes biological efficiency, as also observed in the findings of Rana *et al.* (2020) [21].

Additionally, wider plant spacing—specifically the 60 × 20 cm configuration—offers significant agronomic advantages. This spacing ensures reduced intra-specific competition for vital resources such as water, nutrients, and sunlight. Plants have sufficient space to develop a well-structured canopy that optimizes light interception, thus enhancing photosynthetic efficiency. Wider spacing also allows better air circulation between plants, reducing the incidence of foliar diseases and supporting healthier crop growth. This spatial arrangement has been associated with improved root zone development and tuber bulking, as evidenced by the work of Borah *et al.* (2014) [2], who also highlighted the positive effect of proper spacing on overall crop vigor and productivity.

From an economic standpoint, treatments involving early November sowing and wider spacing consistently outperformed other combinations in terms of gross returns, net returns, and benefit-cost ratio. The high marketable tuber yield resulting from these agronomic conditions translated directly into superior economic returns. This correlation underscores a critical aspect of modern commercial agriculture: that agronomic optimization directly influences profitability. When crop production is aligned with best practices tailored to local conditions, farmers benefit from higher input-use efficiency and greater economic resilience. Patel *et al.* (2022) [20] support this view by noting that optimized agronomic practices lead not only to higher productivity but also to enhanced economic viability, especially in input-sensitive crops like potato.

Furthermore, the economic indicators from the study reaffirm that early planting in combination with optimal spacing is not only agronomically sound but also financially lucrative. The increased tuber yield contributes significantly to gross returns, while the marginal additional cost associated with wider spacing does not offset the economic benefits. As such, this practice ensures a high return on investment, making it a viable recommendation for farmers aiming to increase income from potato cultivation.

Conclusion

Based on the results of the present investigation, it can be concluded that sowing potatoes on 1st November with a plant spacing of 60 × 20 cm (treatment D2S2) yielded the best agronomic and economic outcomes under the specific agro-climatic conditions of the study area. This treatment combination not only led to the highest marketable tuber yield of 34.2 tonnes per hectare, but also resulted in maximum net returns of ₹5.2 lakhs per hectare, demonstrating significant profitability for potato growers.

Furthermore, the Benefit-Cost (B:C) ratio was recorded at 6.48, indicating that every rupee invested in cultivation under this regime returned ₹6.48, making it a highly efficient and sustainable production strategy.

The findings suggest that timely sowing and optimal plant spacing play a pivotal role in achieving higher productivity and economic viability in potato cultivation. Adopting this practice could contribute to better resource utilization, enhanced farm income, and increased food security, especially in regions with similar soil and climatic conditions. The recommendation from this study provides practical guidance to farmers aiming to maximize returns through improved management decisions in potato farming.

Recommendation

Based on the findings of the study, it is recommended that farmers sow potato crops around 1st November, as this timing has shown to be the most suitable under the observed agro-climatic conditions, resulting in superior tuber development and higher yields. The spacing of 60 × 20 cm is also advised, as it facilitates optimal plant population density, better light penetration, and efficient use of soil nutrients and moisture. This combination, identified as the D2S2 treatment, produced the highest marketable tuber yield and net returns, along with the most favorable benefit-cost ratio, making it the most economically viable option for growers. Adoption of this practice is likely to improve profitability while promoting sustainable resource use. Additionally, it is suggested that farmers in other regions validate these results under local conditions before large-scale implementation. Extension agencies should take active steps in disseminating this information through training and awareness programs to help farmers adopt improved agronomic practices. Furthermore, policy-level support in the form of subsidies, access to quality seed, and timely agronomic guidance will encourage wider adoption. Future research should also explore this treatment over multiple seasons and diverse locations to confirm its effectiveness and consistency. The recommended spacing is also suitable for mechanized operations, potentially reducing labor costs and improving operational efficiency. Fine-tuning input management, such as irrigation and fertilization, in line with this sowing schedule and spacing, may further enhance productivity and crop quality.

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