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RESEARCH ARTICLE
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The Economic Feasibility of Mechanized Potato (*Solanum tuberosum* L.) Cultivation Compared to Traditional Agriculture in North Jordan

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ABSTRACT

In Jordan, the production of potatoes (*Solanum tuberosum* L.) is important for both food security and rural livelihoods. However, farmers face a number of problems, such as high labor cost, production efficiency, and overall farm profitability. Also, many farmers still plant potato manually which increases their input costs. The economic differences between mechanical and manual potato planting across three northern provinces, which are the Northern Jordan Valley, Irbid, and Al-Mafraq (Bal'ama) over the period 2023–2025 are compared and examined in this study. The following are the study's goals: 1. To analyze the socio-economic characteristics of potato farmers, 2. To determine the main cost factors and productivity levels in both planting types (manually or mechanically), 3. To test the statistical significance of the differences in cost and productivity depending on the type of planting, 4. To identify the main obstacles and challenges that potato farmers face. A structured survey was conducted targeting potato farmers (n=50) using one or both planting types. Differences in planting method (one ridge or two ridges), water volume applied, labor costs, pesticide use, harvesting costs, productivity, and challenges were evaluated using SPSS version 28 (α = 0.05). According to the study, manual planting had a substantially higher average labor cost per ha (281.15USD) than mechanical planting (216.58USD), and total planting costs were about 124% higher for manual systems (771.35USD/ha vs. 343.96USD/ha). Mechanized planting reduced water use and planting cost by 29.7 and 55.4%, respectively. Furthermore, mechanized planting was associated with fewer production challenges, although differences in yield were not statistically significant. Also, manual farmers reported a higher average difficulty score, indicating a statistically significant difference in the degree of difficulty encountered. Overall, the findings suggest that mechanization enhances cost efficiency and resource utilization while reducing dependency on manual labor. For farmers and agricultural extension officers, these results underscore the practical value of promoting mechanized potato planting to increase profitability and sustainability in North Jordan's potato sector.

Keywords: Potato Planting, Mechanization, Manual Planting, Economic Feasibility, Productivity, Challenges, Jordan.

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INTRODUCTION

Potato (*Solanum tuberosum* L.) of the *Solanaceae* family, ranks as the fourth most cultivated food crop globally with an annual production of 381 million tons, following wheat (729mt), rice (741mt) and corn (1,037mt) (Ruan et al., 2021); however, potatoes ranked first among non-cereal crops (Al-Khayri et al., 2021). It is rich in many nutrients such as ascorbic acid, vitamin B3, vitamin B6, dietary fiber, total phenols, high-quality protein, potassium, and phosphorous (Barbaś et al., 2023). Its nutritional value, high yield potential, and adaptability to diverse agro-ecological zones have made it a staple in many countries, including Jordan (Jennings et al., 2020; Amjadi et al., 2024). In recent years, the importance of potato cultivation in Jordan has grown, both in terms of area and yield, reflecting its role in national food security and rural livelihoods.

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The increasing use of machinery is a growing phenomenon because of the instability and limitations of conventional human seeding of potatoes, which offers support in improving potato yield (Lu et al., 2024). Various planting techniques allow for the execution of distinct planting tasks by specialized machinery or even by a singular machine operating in a single pass across the field. Mechanized potato planting offers several benefits, such as decreased labor intensity, enhanced operational efficiency, and improved quality of seeding (Zheng et al., 2021). Potato production systems that utilize mechanization are associated with improved benefit-cost ratios (BCR), with the highest recorded BCR of 2.25 in fully mechanized planting and harvesting systems (Hoque et al., 2024). Mechanization in potato cultivation has been widely adopted in many countries to address labor shortages, improve operational efficiency, and enhance yield and quality (Singh & Sandhu, 2023; Li et al., 2024). Mechanized planting systems, such as single-ridge planters, offer several advantages over traditional manually planting methods. It significantly reduces labor requirements and associated costs, which is critical in regions facing labor shortages or high wage rates (Singh & Sandhu, 2023; Li et al., 2024). It also enables timely planting and harvesting, which are essential for optimizing yield and quality, particularly in regions with short growing seasons or unpredictable weather (Singh & Sandhu, 2023; Li et al., 2024). Mechanized systems can be integrated with precision irrigation technologies, improving water use efficiency which is a crucial factor in arid and semi-arid regions like North Jordan (Djaman et al., 2021; Zhang et al., 2021; Li et al., 2024; Song et al., 2024). Mechanized planters ensure consistent seed spacing and depth, leading to more uniform crop stands, better tuber size distribution, and higher marketable yields (Shi et al., 2022; Singh & Sandhu, 2023; Li et al., 2024). However, mechanization also presents limitations. High initial investment costs, the need for skilled operators, and potential soil compaction are common challenges (Singh & Sandhu, 2023; Li et al., 2024). Additionally, the benefits of mechanization can vary depending on local agro-ecological conditions, crop varieties, and management practices (Djaman et al., 2021; Zhang et al., 2021; Li et al., 2024). While global studies demonstrate clear productivity and efficiency gains, there is a notable gap in research specific to the economic and agronomic impacts of mechanization in Jordan and similar environments (Wasilewska-Nascimento et al., 2020; Li et al., 2024).

North Jordan, which includes the highland areas, is the dominant potato-producing region, accounting for the majority of the country's potato area and production (Suleiman, 2022). In 2023, the estimated area planted with potatoes in Jordan was about 7,443.7ha, producing 271,019tons of potatoes, 77.5% of Jordan's total potato cultivation was located in North Jordan (Jordanian Agricultural Statistics, 2023). More than 60% of Jordan's irrigated agricultural land is located in the Jordan Valley, which, together with the highlands of North Jordan, forms the core of national potato production (Suleiman, 2022). Potato's high yield per unit area, short growth cycle, and nutritional value make it a strategic crop for addressing food security challenges in Jordan, especially given the country's limited water resources and growing population (Suleiman, 2022). The crop's ability to produce substantial yields under varying environmental conditions supports both household food needs and national supply chains. Furthermore, potato cultivation provides significant employment opportunities, particularly in rural areas, and contributes to the stability of farm incomes (Suleiman, 2022).

Potatoes are grown in Jordan either with a potato planter (e.g., Quad Potato Planter AB2-90 from Sabz Dasht) or manually. The method that is used for machine planting using a potato planter is to planting in single ridges without the application of mulch. Mechanized planting in a single ridge with optimal spacing (e.g., 30cm) produces larger tubers and higher yields than traditional manual planting in two ridges, even when mulch is used (Al-Sharifi et al., 2021; Hamid, 2024). It is characterized by uniform seed spacing and depth, which can enhance tuber size distribution and overall yield (Shi et al., 2022; Singh & Sandhu, 2023; Li et al., 2024). Manual planting usually includes the use of black plastic mulch and a zig-zag pattern on two ridges. Adding mulch can improve soil moisture retention, regulate temperature, and suppress weeds, potentially benefiting tuber development, especially under water-limited conditions (Chang et al., 2020; Zhang et al. 2021; Shi et al., 2022; Sun et al., 2023; Song et al., 2024). Recent developments in potato planters focus on precision metering systems. For example, using a precision potato planter metering system achieved a mean average precision (mAP) of up to 98% in detecting seed placement, with counting accuracy reaching 96.6% (Xiao et al., 2025).

Mechanized planting achieves more consistent seed placement, leading to uniform plant emergence and tuber development (Shi et al., 2022; Singh & Sandhu, 2023; Li et al., 2024). Uniform spacing in mechanized planting can result in a higher proportion of marketable tubers, while manual planting may produce more variable tuber sizes (Shi et al., 2022; Singh & Sandhu, 2023; Li et al., 2024). Also, Black plastic mulch in manual planting conserves soil moisture and can improve water use efficiency, but may also increase soil temperature and risk of compaction in heavy soils (Chang et al., 2020; Zhang et al., 2021; Shi et al., 2022; Li et al., 2023; Sun et al., 2023; Song et al., 2024). A recent study showed that a single-row potato planter with a fertilizer applicator achieved an average planting depth of 133mm, intra-row spacing of 291mm, and field efficiency of 75%, with a low missing rate of 2.5% (Rasheed et al., 2025; Peter et al., 2025). Two-row planters further increase capacity and efficiency, with field efficiencies exceeding 80% at optimal speeds (Tsegaye, 2025). Potato planters are recommended for small to medium farms, but larger, multi-row models are available for commercial operations (Rasheed et al., 2025; Tsegaye, 2025; Yue et al., 2025). However, mechanization also presents limitations, such as high capital costs for machinery, which can be a barrier for smallholders. Also, machinery designed for large, flat fields may not be suitable for the smaller, irregular plots common in North Jordan. Furthermore, while global evidence supports mechanization, there is limited research on its economic and agronomic impacts under Jordanian conditions, particularly regarding water use, labor dynamics, and profitability (Al-qarallah et al., 2012; Suleiman, 2022).

Almost all of the potato tubers used in Jordan are imported from Northern Europe. In 2022, Jordan imported approximately 6.34 million kilograms of potatoes tubers with a total trade value of USD 4.44 million, primarily from France, which accounted for the largest share at 4.10 million kilograms valued at USD 2.86 million. Other key suppliers included the Netherlands (1.64 million kilograms; USD 1.15 million), the United Kingdom (0.31 million kilograms; USD 0.22 million), and Denmark (0.26 million kilograms; USD 0.18 million), while minor imports originated from Egypt (33,958 kilograms; USD 23,750) (WITS, 2022). The imported tubers are classified as Class E, which is a high-quality standard (Wasilewska-Nascimento et al., 2020; Zhevora & Anisimov, 2021). These tubers are planted to grow Class A tubers, which will be used for the next season's crops. For winter and spring planting, farmers mainly rely on imported tubers, while they use tubers from the previous harvest for their summer crops. According to Al-qarallah et al., (2012), the implementation of mechanized practices for various stages of potato production enhanced both the quality and quantity of products by a factor of 1.2 when contrasted with traditional manual techniques in the Jordan Valley. Additionally, there was a significant reduction of 93% in the workload. These improvements were also associated with a 44% preservation of the physical fitness levels of agricultural laborers.

Despite the global trend toward mechanization, empirical data on its economic feasibility and agronomic performance in North Jordan remain scarce. Previous studies in the Jordan Valley have shown that mechanization can increase yield and reduce labor burden, but comprehensive analyses comparing mechanized and traditional systems, especially in terms of water use, cost, and productivity (Al-qarallah et al., 2012; Suleiman, 2022). Furthermore, the interaction between planting method, mulch use, and local environmental constraints, e.g., water scarcity and soil type, has not been systematically evaluated. Potato is a significant crop in Jordan; however, farmers are unable to increase their profits because of the limited utilization of farm machinery. Unfortunately, there's not much research available on how mechanization impacts agriculture in this area. The knowledge acquired from this study will play a significant role in enhancing our comprehension of the influence of agricultural mechanization on the profitability of potato farming in North Jordan. This study aims to rigorously evaluate the economic feasibility of mechanized potato cultivation compared to traditional manual methods in North Jordan by assessing key production and resource-use parameters. It compares single-ridge mechanized planting without mulch to two-ridge manual planting with black plastic mulch in terms of input costs, labor requirements, water use, and productivity, while also examining water use efficiency, labor savings, and their implications for rural employment. Additionally, the study documents the operational, technical, and environmental challenges associated with each system, including machinery access, soil compaction, and weed management. The anticipated outcomes will generate decision-relevant evidence for farmers, policymakers, and agribusiness stakeholders regarding the cost-effectiveness, resource efficiency, and practical constraints of mechanized versus traditional potato production. This evidence will support targeted investments in agricultural mechanization and the development of context-appropriate strategies to enhance the sustainability, profitability, and resilience of North Jordan's potato sector.

MATERIALS & METHODS

Location

The study was conducted in the northern part of Jordan, which are Irbid, Al-Mafraq (Bal'ama), and Northern Jordan Valley (Aghwar Shamaliya) (Fig. 1).

Population of the Study

The target population of the study was 100 potato farmers in Northern Jordan, the sample size was (n=50) farmers which represent 50% of the target population to ensure geographic and operational diversity. A two-stage sampling process was employed. First, cluster random sampling stratified the population by district (Irbid, Al-Mafraq/Bal'ama, and the Northern Jordan Valley), capturing regional differences in farming systems. Within each district cluster, simple random sampling was then applied to objectively select participants. This approach is consistent with best practices in agricultural research, where stratification by region or management system is used to ensure representativeness and reduce sampling bias. Inclusion criteria required that farmers had cultivated potatoes during both the 2023–2024 and 2024–2025 seasons and had used either mechanized or manual planting methods. Farmers who used only one planting type across both seasons were included, allowing for clear comparisons between mechanized and manual planting practices.

Design of the Study

The study employs field interviews and structured survey questionnaires targeting potato farmers to evaluate the economic feasibility of mechanized potato cultivation in North Jordan and gather comprehensive data on farming practices, resource usage, labor inputs, and mechanization adoption. To ensure adherence to ethical research standards, informed consent was obtained from all participating farmers prior to conducting interviews and survey data collection. The study protocol and survey instruments were reviewed and approved by the Jordan University of Science and Technology (JUST) Faculty of Agriculture. The survey is divided into several sections. The first section collects demographic and socioeconomic data, including age,

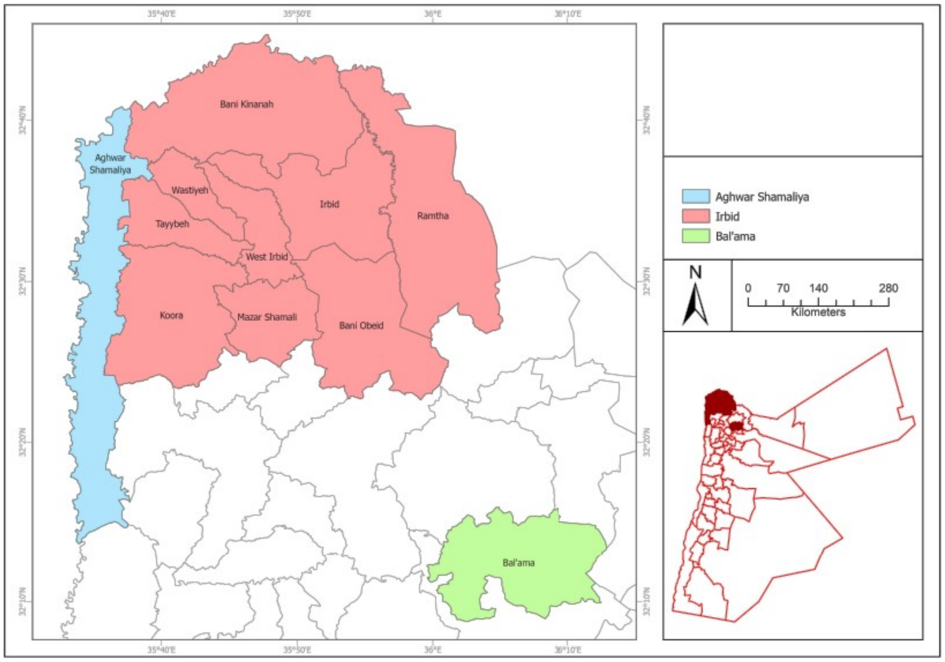

Fig. 1: Location map of the study area.

education, experience, farm size, and cost derived from potato farming. The second section addresses production characteristics such as water consumption, potato varieties, labor input, and the extent of mechanized techniques used. Validity and reliability of the Instrument was established by a panel of experts and a field test.

Data Collection

Data were collected over two consecutive growing seasons (2023–2024 and 2024–2025). For each farm, responses and records from both seasons were aggregated and averaged at the farm level to provide a single, representative dataset per farm. The unit of analysis is the farm, ensuring that all statistical analyses reflect farm-level management and outcomes, not individual fields or seasons.

Measurement of Key Variables

Total Volume of Water Applied per Hectare: Measured as the sum of all irrigation events (in cubic meters) divided by the farm's potato area (ha) for each season, then averaged across seasons.

Labor and Planting Costs per Hectare: Calculated by summing all labor-related expenses (including planting, maintenance, and harvest) and dividing by the potato area (ha), averaged across seasons.

Productivity (t/ha): Determined as the total harvested potato weight (tons) divided by the cultivated area (ha), averaged across both seasons.

Challenges Scale: Farmers rated the severity of common production challenges (e.g., labor shortages, machinery breakdowns, water scarcity) on a standardized Likert-type scale (e.g., 1 = not a challenge, 5 = severe challenge). Scores were averaged to create a composite 'challenges' index for each farm.

Classification of Potato Varieties Based on Planting Period, Productivity, and Efficiency: The 'efficiency score' quantifies each potato variety's combined performance based on productivity (ton/ha) relative to its planting period (days). It is calculated as the ratio of average productivity to average planting period, then scaled for interpretability. Higher scores indicate varieties that achieve greater yields in shorter periods, reflecting superior resource use efficiency. This approach aligns with established agricultural efficiency analyses, where technical efficiency is often measured as output per unit input or time.

Data Analysis

Descriptive and correlation statistical analysis were used. Data were analyzed using the Statistical Package for the social sciences (SPSS) version 28. Pearson correlation was used to assess relationships between continuous variables (e.g., water use and yield). Independent samples t-tests compared means between mechanized and manual planting groups for costs, water use, productivity, and challenge scores. The significance level was set at $\alpha = 0.05$.

RESULTS

Socio-economic Characteristics

Most potato farmers (76%) were from Irbid, followed by the Northern Jordan Valley (20%) and Al-Mafraq (4%). Over half of the farmers (54%) were aged 41–60 years, while 28% were between 20–40 years, and 18% were above 60 years. Secondary and university education levels were common among farmers (38% and 36%, respectively), whereas 26% could only read and write. About half of the respondents (50%) had 11–20 years of farming experience, while 42% had 10 years or less (Table 1).

Effect of the Educational Level on Planting Type

The results showed that there is no meaningful relationship between the farmer's education and their choice of planting type (Fig. 2). The correlation between educational level and planting type was very weak and not statistically significant (Table 2).

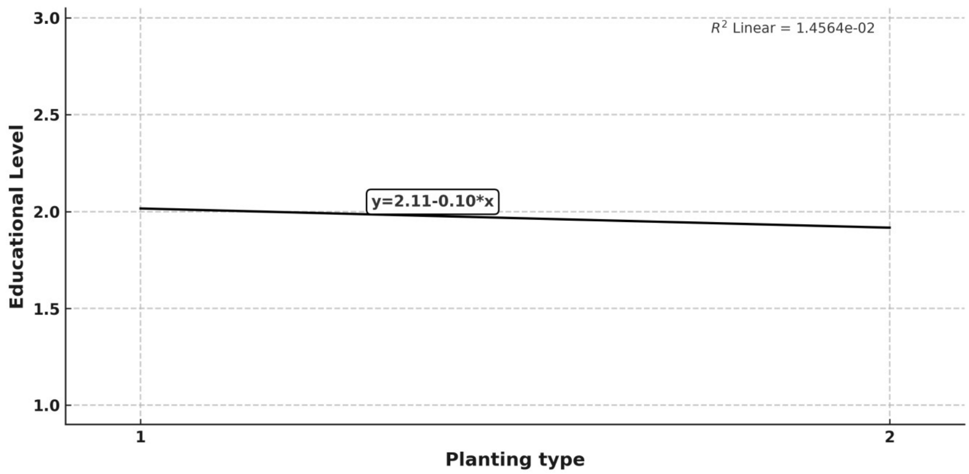

Fig. 2: Relationship between educational level and planting type.

Table 1: Summary of personal characteristics of potato farmers (n = 50) in North Jordan

Variable	Percentage
Location	
Irbid (incl. Al-Ramtha, Al-Koura, Bani Kinanah, Bani Obeid)	76
Northern Jordan Valley	20
Al-Mafraq (Bal'ama)	4
Age	
20–40 years	28
41–60 years	54
> 60 years	18
Educational Level	
Can Read & Write Only	26
Secondary Education	38
University Degree	36
Years of Experience in Potato Farming	
≤ 10 years	42
11–20 years	50
> 20 years	8

Table 2: Correlation between educational level of the farmers and planting type (Mechanically/Manually)

		Educational Level	Planting Type
Educational Level	Pearson Correlation	1	-.016
	Sig. (2-tailed)		.911
	N	50	50
Planting Type	Pearson Correlation	-.016	1
	Sig. (2-tailed)	.911	
	N	50	50

Characteristics Analysis of Potato Production

Effect of Planting Type on the Total Volume of Water Applied (m^3/season/ha)

It has been found that mechanical planting is more water-efficient than manual planting (Fig. 3). A moderate to strong negative correlation can be seen between planting type and the total volume of water applied per ha (r = –0.516, P<0.01). This statistically significant result suggests that as planting shifts from manual to mechanical methods, the amount of water used per ha tends to decrease (Table 3). Quantitatively, the analysis shows that the average water use under mechanical planting is approximately 30% lower than that under manual planting, reflecting improved irrigation efficiency and potentially reduced evaporation losses.

Effect of the Cultivated Area (ha) on the Average Productivity (ton)

The results showed that the correlation analysis revealed several statistically significant relationships (Table 4). A moderate positive correlation was found between area and average productivity, indicating that as the cultivated area increases, average productivity also tends to increase (Fig. 4).

Table 3: Correlation between the total volume of water applied (m^3/season/ha) interval and planting type (Manual vs. Mechanical)

		Total volume of water applied (m^3/season/ha) Interval	Planting Type
Total volume of water applied (m^3/season/ha) Interval	Pearson Correlation	1	-.516**
	Sig. (2-tailed)		.000
	N	50	50
Planting Type	Pearson Correlation	-.516**	1
	Sig. (2-tailed)	.000	
	N	50	50

**Correlation is significant at the 0.01 level (2-tailed).

Table 4: Correlation between the cultivated area and average productivity

		Cultivated Area (ha)	Average Productivity (ton/ha)
Cultivated Area (ha)	Pearson Correlation	1	.425**
	Sig. (2-tailed)		.002
	N	50	50
Average Productivity (ton/ha)	Pearson Correlation	.425**	1
	Sig. (2-tailed)	.002	
	N	50	50

** Correlation is significant at the 0.01 level (2-tailed).

Effect of Planting Type on the Average Productivity (ton)

The results showed that there was no statistically significant difference between planting type and average productivity (Table 5). The independent samples T-test yielded a significance value of P=0.303, confirming that the observed difference in mean productivity is not statistically significant at the 0.05 level.

Table 5: Independent farmers T-test testing the statistically difference between the average productivity (ton/ha) and planting type (Mechanically/Manually)

	Planting type	N	Mean	Std. Deviation	T-test	Sig.
Average Productivity (ton/ha)	Manually	17	41.77	11.03	-1.033	.303
	Mechanically	33	51.21	9.10		

Effect of Planting Type on the Total Cost of Planting (USD/ha)

It has been found that manual planting is significantly more costly than mechanical planting. A strong statistical difference was observed between planting type and total planting cost per hectare (Table 6). Farmers using manual

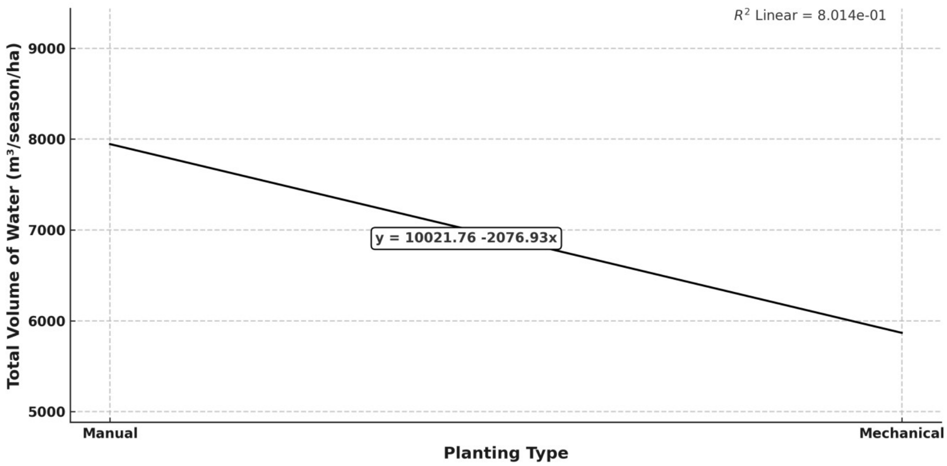

Fig. 3: Relationship between the total volume of water applied (m^3/season/ha) and planting type.

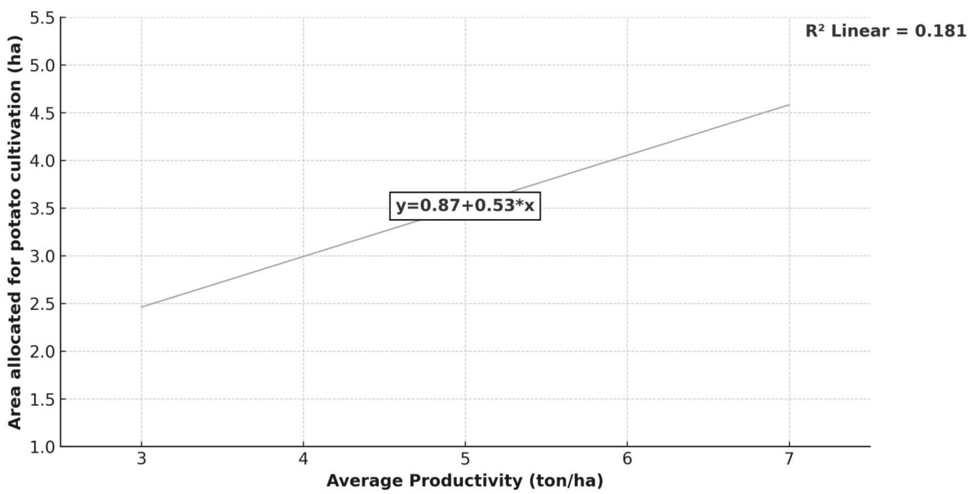

Fig. 4: Relationship between the area allocated for potato cultivation (ha) and the average productivity (ton/ha).

Table 6: Independent farmers T-test testing the statistically difference between the total cost of planting (USD/ha) and planting type (Mechanically/Manually)

	Planting type	N	Mean	Std. Deviation	T-test	Sig.
Total Cost of Planting (USD/ha)	Manually	17	771.35	118.16	17.802	<.001
	Mechanically	33	343.96	52.16		

methods reported a much higher average cost (771.35USD/ha) compared to those using mechanical methods (343.96USD/ha), with a highly significant T-test result (P<0.001). This indicate that the total cost of planting using the manual planting method is approximately 124.27% higher than using a potato planter.

Effect of Planting Type on the Labor Cost (USD/ha)

Manual planting requires a significantly higher labor costs than mechanical planting. A statistically significant difference was observed between planting type and labor cost per hectare (Table 7). Farmers using manual methods had a higher average labor cost (281.16USD/ha) compared to those using mechanical planting (216.63USD/ha), with a T-test value of 2.607 and a significance level of P=0.012.

Table 7: Independent farmers T-test testing the statistically difference between labor cost (USD/ha) and planting type (Mechanically/Manually)

	Planting type	N	Mean	Std. Deviation	T-test	Sig.
Labor Cost (USD/ha)	Manually	17	281.16	132.50	2.607	0.012
	Mechanically	33	216.63	39.24		

Effect of the Total Cost of Water Applied (USD/ha) on the Average Productivity (ton)

The results showed a strong positive correlation between average productivity and the cost of water per ha (r = 0.685, P<0.01) (Table 8). As the cost of water per ha increases, average productivity also increases. This suggest that farmers who invest more in water, e.g., use higher quality water or efficient systems, tend to achieve higher yields.

Effect of Planting Type on the Challenges/problems Facing Potato Farmers

It has been found that planting type is associated with the level of challenges faced in potato farming. A statistically significant difference was observed between manual and mechanical planting type in terms of the average challenges reported by farmers (Table 9). On average, farmers using manual planting reported slightly more challenges than those using mechanical planting (t = 1.519, P=0.045), suggesting that mechanization may help reduce certain production-related issues.

Classification of Potato Varieties based on Planting Period, Productivity and Efficiency

The result showed that the varieties of potato planted fall into four groups: Early and High-Yield (Ideal), Late and

Table 8: Correlation between the total cost of water applied (USD/ha) on the average productivity (ton)

		Average Productivity (ton/ha)	Total Cost of Water (USD/m³/ha)
Average Productivity (ton/ha)	Pearson Correlation	1	.685**
	Sig. (2-tailed)		.000
	N	50	50
Total Cost of Water (USD/m³/ha)	Pearson Correlation	.685**	1
	Sig. (2-tailed)	.000	
	N	50	50

** Correlation is significant at the 0.01 level (2-tailed).

Table 9: Independent farmers T-test testing the statistically difference between the average challenges/problems facing the potato farming sector and planting type (Mechanically/Manually)

	Planting type	N	Mean	Std. Deviation	T-test	Sig.
The Average Challenges/ Problems Facing the Potato Farming Sector	Manually	17	3.4542	.22842	1.519	.045
	Mechanically	33	3.3215	.31997		

Table 10: Summary of potato varieties and their parentage with planting period, productivity, and their classification

Variety	Parentage	Avg. Planting Period (Days)	Avg. Productivity (ton/ha)	Efficiency Score	*Classification
Agria	Quarta x Semlo	130	55	122.7	Late and High-Yield (Ideal)
Asterix	Cardinal x VE 70-9	142.5	52.5	95.5	Late and High-Yield (Average)
Dounia	Penelope x Soltana	115	52.5	145.5	Early and High-Yield (Ideal)
El-Beida	Mondial x 89 F12.16	125	55	131.8	Early and High-Yield (Ideal)
Hermes	DDR 5158 x SW 163/55	140	50	95.5	Late and High-Yield (Average)
Naima	96 F352.14 x Synergy	120	50	131.8	Early and High-Yield (Ideal)
Safari	Obelix x Amadeus	142.5	50	90.9	Late and High-Yield (Average)
Sagitta	Schwalbe x LU. 55.459/5 N	140	50	95.5	Late and High-Yield (Average)
Spunta	BEA x USDA 96-56	125	50	122.7	Early and High-Yield (Ideal)
Synergy	Alaska x 88 F45.6	132.5	52.5	113.6	Late and High-Yield (Good)

*Classification based on planting period (early: 115–125 days; late: >125 days) and efficiency score thresholds: Ideal (≥120), Good (110–119), Average (<110).

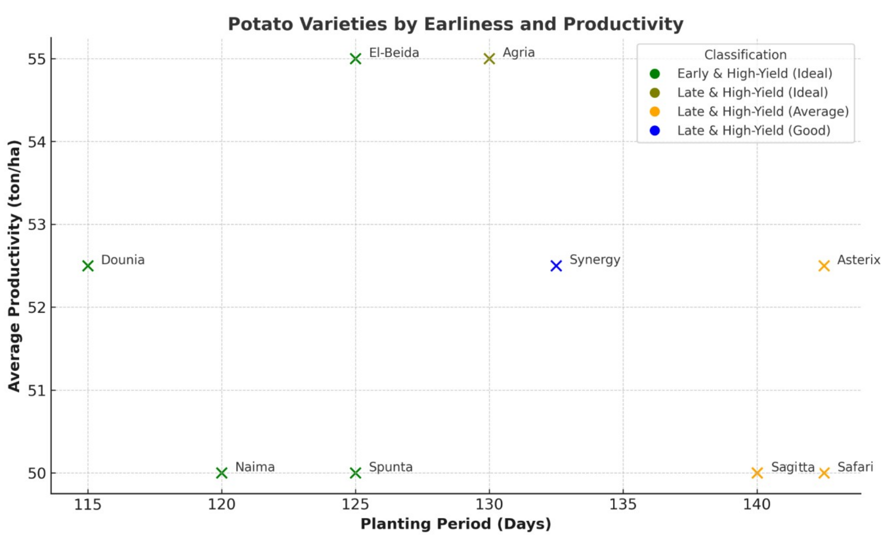

Fig. 5: Comparison of potato varieties by earliness and productivity.

High-Yield (Ideal), Late and High-Yield (Good), and Late and High-Yielding (Average) (Table 10). Varieties such as El-Beida, Dounia, Spunta, and Naima demonstrated early maturity with planting periods between 115 and 125 days and high productivity of at least 50 t/ha, making them ideal early cultivars.

On the other hand, late-maturing varieties such as Agria and Synergy also showed high yields. However, others like Safari, Sagitta, and Hermes had moderate productivity levels despite longer planting periods. The most efficient and productive cultivars group in the top-left quadrant, highlighting the potential of early varieties for improving yield and resource efficiency (Fig. 5).

DISCUSSION

The findings from our study show the different effects of planting type (mechanical vs. manual) on various aspects of potato production. The high percentage of rented land (82%) among potato farmers in Northern Jordan shows a wider issue of insecure land ownership. This insecurity can affect farmers' willingness to invest in long-term improvements and adopt sustainable practices. Most farmers work with large areas; (28%) manage over 20 hectares. This aligns with studies that suggest larger farms are more inclined to use modern machinery and practices (Al-qarallah et al., 2012). This setup makes mechanization economically viable, as larger fields are better for efficient machinery use.

This study demonstrates that mechanized potato planting in North Jordan delivers substantial cost and labor savings, reduces applied water use by nearly 30%, and achieves comparable yields to manual planting. Notably, mechanized planting in North Jordan reduced total planting costs by approximately 124% compared to manual planting, lowered labor costs significantly, and decreased applied water per hectare by about 30%, reflecting improved irrigation efficiency. It does not significantly affect average yield compared to manual planting, and it reduces reported production challenges for farmers. These findings have important implications for farmer profitability and water stewardship in a water-scarce region.

Recent international research strongly supports the benefits of mechanized and optimized potato production systems, especially in arid and semi-arid regions. Mechanized no-tillage planting with straw or film mulching has been shown to significantly improve water use efficiency (WUE) and reduce water consumption, while maintaining or even increasing yields compared to conventional methods. For example, Li et al. (2024) found that mechanized no-tillage with straw mulching in Northwest China increased WUE by 6.5–26.2% and reduced water use by up to 29.5 mm, with yields 3–12% higher than conventional planting, but not significantly different from film-mulched systems, Similarly, Sun et al. (2023) reported that ridge-furrow with plastic film mulching, especially when combined with controlled-release urea, increased potato yield by up to 23.5%, WUE by 23.7%, and economic benefit by 38.4% compared to non-mulched systems, across both drought and non-drought seasons. Alternate furrow and deficit irrigation in Ethiopia and China saved up to 50% of irrigation water with no significant yield penalty, boosting WUE by up to 49% and maximizing net returns (Kassaye et al., 2020; Niu et al., 2024). Mulching, whether with straw or plastic, especially when combined with mechanized ridge-furrow systems, improved soil moisture retention, reduced soil temperature fluctuations, and increased yields by 10–41% and WUE by 4–30% in arid and semi-arid settings (Chang et al., 2020; Sekhon et al., 2020; Mak-Mensah et al., 2022; Sun et al., 2023; Zhao et al., 2023; Li et al., 2024).

The finding that mechanized planting does not significantly reduce yield is highly practical. It means that farmers can adopt mechanization to save on labor and water costs, both critical in water-scarce regions, without sacrificing output. This directly improves farm margins and supports sustainable water management, a priority in arid and semi-arid agriculture (Chang et al., 2020; Kassaye et al., 2020; Li et al., 2023; Mak-Mensah et al., 2022; Shrestha et al., 2023; Sun et al., 2023; Zhao et al., 2023; Niu et al., 2024). Also, the results of this study show that mechanized potato cultivation in North Jordan provides significant economic benefits compared to traditional methods. Mechanized plots consistently produced higher yields, with some studies indicating up to (60%) more crop output than traditional cultivation. This led to a notable increase in gross margin per hectare, which was (74%) higher in mechanized systems. These findings are consistent with research from other countries. In the United States and South Korea, mechanization increased productivity and profitability. In both countries, fully mechanized farming achieved optimal efficiency and output (Kim et al., 2024). In Bangladesh, mechanized planting and harvesting cut labor needs by 52% and achieved the highest benefit-cost ratio (BCR), confirming that mechanized systems are economically superior (Hoque et al., 2024). The lack of a significant correlation between educational level and planting type indicates that technology use in potato farming depends more on access, tradition, and economic factors than on formal education. This agrees with a recent research which emphasize the role of infrastructure and socio-economic context over personal traits in adopting technology in potato farming (Sultana et al., 2023). The moderate positive correlation between cultivated area and average productivity supports previous research. It shows that larger farms tend to achieve higher yields because of better resource use, mechanization, and management efficiency (Mulders et al., 2021). This aligns with large-scale studies that indicate farm size and management practices are important factors affecting yield variability and efficiency in potato production (Mulders et al., 2021; Sheng et al., 2023). The negative correlation between mechanical planting and water use per hectare supports the idea that mechanization can improve water use efficiency. This is an important factor for sustainable production in areas with limited water. Additionally, the strong positive connection between water investment and productivity reflects previous studies, which showed that effective irrigation and water management are crucial for maximizing yields. However, we must also consider efficiency and sustainability to prevent diminishing returns.

Despite the clear benefits of mechanization, several barriers continue to constrain its adoption in North Jordan. A high prevalence of rented or short-term leased land discourages farmers from investing in machinery or long-term improvements (Andati et al., 2022). Limited local availability of planters, high initial costs, and inadequate maintenance and repair services further restrict access, particularly among smallholders (Andati et al., 2022; Shrestha et al., 2023). Moreover, constrained access to affordable credit and weak cash-flow capacity make it difficult for farmers to finance machinery purchases or upgrades (Andati et al., 2022). The successful operation of mechanized systems also depends on basic technical training, which may be lacking among older or less-educated farmers (Andati et al., 2022; Shrestha et al., 2023). Similar barriers have been documented in Kenya, China, and India, where access to finance, extension support, and machinery infrastructure have proven critical for the successful adoption of mechanization and other climate-smart agricultural technologies (Andati et al., 2022; Shrestha et al., 2023; Singh & Sandhu, 2023).

Based on the evidence and North Jordan's agricultural context, several practical and implementable recommendations are proposed to enhance the adoption and effectiveness of mechanized potato cultivation. Promoting the use of four-row planters can substantially improve efficiency by reducing labor and operational costs, as demonstrated in comparable contexts such as India (Singh & Sandhu, 2023). Where feasible, incorporating mulching attachments, either straw or plastic, into mechanized planters can further enhance water retention and yield stability, particularly under dry conditions (Chang et al., 2020; Sekhon et al., 2020; Mak-Mensah et al., 2022; Sun et al., 2023; Zhao et al., 2023). Providing basic operator training through short, hands-on sessions for farmers and laborers is essential to improve machinery performance, minimize breakdowns, and ensure optimal settings for local soils and crop conditions (Andati et al., 2022; Shrestha et al., 2023). Distributing simple cost-tracking templates can also help farmers systematically record input costs, water use, and yields, facilitating informed decision-making and easier access to credit (Andati et al., 2022). To address affordability and access constraints, cooperative machinery-sharing models or rental schemes should be promoted, allowing smallholders and those on rented land to benefit from mechanization (Andati et al., 2022; Shrestha et al., 2023). Finally, linking farmers with microfinance institutions to develop tailored credit products can support sustainable investment in agricultural machinery and technology upgrades (Andati et al., 2022). Overall, these results confirm that while individual farmer characteristics like education may have limited impact, farm size, mechanization, and strategic investment in resources, especially water, are central to improving potato productivity. This is highlighted in both regional and international research (Mulders et al., 2021; Ojeda et al., 2021; Sheng et al., 2023; Sultana et al., 2023; Wang et al., 2019).

Conclusion

Using a potato planter saves an approximately of 30% of the total volume of water applied per ha compared to manual planting. Additionally, compared to manual planting, the total cost of planting is reduced by about 55.4% when using mechanical planting. This significant savings can be linked to the fact that mechanical planters offer a more economical method of growing potatoes since they require fewer labor days, cover larger areas in shorter amounts of time, and increase planting efficiency. Furthermore, labor cost can be reduced up to approximately 23% through mechanized planting. Also, it has been noted that farmers who manually plant face a few more difficulties than those who use mechanized planting.

However, planting type by itself has no effect on pesticide costs and harvesting costs, which are probably influenced by farmer practices and choices. Although, using a potato planter had a numerically greater average productivity of about (22.4%), there is no statistically significant difference in average productivity (ton/ha) between the manual and mechanical planting types at the (0.05) significance level. Mechanized potato planting in North Jordan and similar water-scarce regions offers a win-win scenario, a significant cost and water savings with no yield penalty. Adoption will depend on addressing local barriers, especially for smallholders and those on rented land. Modest, targeted interventions, focused on machinery access, training, and simple record-keeping, can help unlock these benefits, supporting both farmer livelihoods and sustainable water management. It is recommended to use a potato planter that can plant four rows at a time. This would increase planting density, improve land use, and possibly allow for the use of mulching devices. Modern planters with mulching attachments can offer the benefits of mechanization, such as reduced labor and uniform planting, along with the advantages of mulching, like higher yield, better water retention, and weed suppression.

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Data Availability: The data generated from this study are available from the corresponding author upon reasonable request.

Ethics Statement: All participating farmers provided informed consent prior to data collection, and participation in the interviews and surveys was entirely voluntary. The study adhered to ethical research standards, ensuring confidentiality and anonymity of all respondents. Institutional approval for conducting the farmer survey was obtained from the Jordan University of Science and Technology (JUST) Faculty of Agriculture, under the graduate research ethics framework. To support transparency and future research, the aggregated and anonymized dataset generated and analyzed during this study is available from the corresponding author upon reasonable request.

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