



Effects of Different Rates of Nitrogen and Phosphorus Fertilizers on Growth and Yield of Potato (*Solanum tuberosum*) under Mechanized and Traditional Cultivation

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

In the present study, half of the land was cultivated mechanically by tractor using a two-bladed mould board plough and nine tine harrow. The other half was cultivated by a local farmer who used a bullock and wooden plough. A single seed variety (Marabel) was sown across the entire trial site. Four separate identical fertilizer treatments were used across both the mechanized and traditionally cultivated sites. Phosphorous was applied in the form of diammonium phosphate. Nitrogen was applied in the form of Urea. FAO's recommended rates for phosphorus (220kg/ha) and nitrogen (330kg/ha) were applied. In addition, additional rates below and above the FAO's recommendations were also applied, with phosphorous being applied at 0 kg/ha, 110 kg/ha (50% of recommendation) and 440 kg/ha (200% of recommendation). Nitrogen was applied at 0 kg/ha, 165 kg/ha (50% of recommendation) and 660 kg/ha (200% of recommendation). Results on average revealed that across all four fertilizer rates, mechanized cultivation produced 60% higher crop yields (average 32.83mt/ha) compared with traditional cultivation (average 20.5 mt/ha) which resulted in an average of 12.33mt/ha higher yield for mechanized cultivation over traditional cultivation. This yield difference was highly statistically significant ($P = 0.99$). Additionally, the average gross margin per

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hectare was 74% higher across the mechanized plots (US\$6,552/ha or 373,464AFN/ha) compared with the traditional plots (US\$3,772/ha or 215,004 AFN/ha). These figures confirm that use of mechanized cultivation and the application of phosphorus at 440 kg/ha and nitrogen at 660 kg/ha will increase the potato yield and produce a higher cash value and a higher gross margin per hectare.

Keywords: Mechanized; traditional; potatoes; urea and DAP fertilizers.

1. INTRODUCTION

Potato (*Solanum tuberosum* L.) is the major world's economic crop and also the third most important food crop in consumption in the world after rice and wheat [1-3]. The cultivation of potato exceeding globally to 19.34 million hectare of land with an estimated annual production of 364 million tons [4].

In Bamyan of Afghanistan, potato is the most important cash crop and plays a vital role in farm economy. Additionally, Bamyan produces more than 50 percent of Afghanistan's annual potato harvest [5]. However, the farming system in Bamyan is still traditional and mechanization systems have not been fully adopted yet. In addition, there are a number of production problems accounting for low yields of potato in Bamyan.

Current fertilizer guidelines for potatoes in Bamyan are not based on optimum fertility rates and potential yield. As with most crops, potatoes will respond to an increase in available nitrogen by maximising tuber growth and maintaining this growth throughout the growing season [1]. The authors however do not know the type and rate of fertilizers to be applied for individual crop species and cultivars for improving crop productivity. Application of Nitrogen and phosphorus fertilizers has shown good yield responses for different crops across different locations, indicating low nitrogen and phosphorus status of the soils [6,7].

Nevertheless and regardless of the soil fertility status of the soil and the types of cultivar, the FAO and Department of Agriculture & Livestock (DAIL) recommend 330 kg/ha Urea and 220 kg/ha Diammonium Phosphate (DAP) for potato production in Bamyan province. However, these recommended rates for nitrogen and phosphorus fertilizers by FAO and DAIL are higher than those used the study conducted by Zelalem et al. [8] on Vertisols of Debre Berhan in the highlands of central Ethiopia, where 207 kg N/ha as urea and 60 kg P/ha were applied in calcareous soils. Afghan soils are highly calcareous and calcareous soils make up some of the most

productive agricultural land in Bamyan province [9].

These rates are also higher than those used in the study conducted on Vertisols in the central highlands of Ethiopia (165 kg/ha Urea and 195 kg/ha DAP) being used for potato production in North Shewa [8]. However, adequate soil fertility is one of the requirements for profitable potato production as potatoes are mainly grown on sandy soils, and nitrogen is the most yield-limiting nutrient and phosphorus is the next most limiting nutrient in calcareous soils [10].

One of the major problems resulting in lower potato productivity in Bamyan is inadequate agronomic practices often associated with inadequate fertilizer rate recommendations for the local conditions. To address this problem this study was initiated with the major objective of investigating the effects of different rates of nitrogen (as urea) at the rates (0, 165, 330 and 660 kg/ ha) and phosphorus (as DAP) at the rates of (0, 110, 220 and 440 kg/ ha) on the total yield and yield components of potato under mechanized and traditional cultivation systems in the Yakawlang district of Bamyan. Yakawlang is the second largest potato producing district after Bamyan Center. Yakawlang district is located in the north-western part of Bamyan province.

2. RESEARCH METHODOLOGY

2.1 Land Preparation

The trial was situated on land owned by one of the farmers' cooperative members Sayed Abdul Hamid from Nayak cooperative in Yakawlang. The soil type was silty clay. Fifty percent of the land (comprising Site B) (Mechanized Cultivation) (refer Fig. 2) was prepared mechanically by tractor using a two-bladed mould board plough and nine tine harrow. The remaining 50% of the trial (comprising Site A) (Traditional Cultivation) (Fig. 1) was prepared by a local farmer who used a bullock and wooden plough.

A single seed variety (Marabel) was sown across the entire trial site and the crop husbandry used

on both the mechanized and traditional sites strictly followed the FAO's Good Practice Guide for Potatoes. Randomized Complete Block Design (RCBD) was deployed for this research trial.

2.2 Farm Yard Manure (FYM) and Ash Application

Five metric tonnes of farm yard manure (sheep manure), combined with one metric tonne of

wood ash, and were applied equally to both site A and site B, 20 days prior to cultivation.

As farmers are unable to purchase this important soil nutrient in Afghanistan, because of its possible use in bomb making, the only option was to use wood ash to overcome some of the potassium deficiency in the soil. The land was irrigated before FYM application and sowing in order to let the FYM to fully penetrate the soil.



Fig. 1. Land preparation for Site A using a bullock pulled wooden plough



Fig. 2. Land preparation for site B using a 2 bladed mouldboard plough

2.3 Sowing Rate and Cultivation Method

The sowing rate and spacing was the same for both sites; 789 kg of potato, 25 cm spacing between each seed and 70 cm between furrows was replicated across both Sites A and B (refer Fig. 3). The seed was treated with Thiram fungicide prior to sowing in order to control both early blight and late blight, which are common in Bamyan potato fields. There were eight treatments with Randomised Complete Block Design (RCBD) being deployed for this research trial.

2.4 Irrigation and Fertilizer Application

For both sites (mechanized and traditional), the Float Method ($Q = A \times V$) was used to estimate the amount of water applied, where Q is the volume of water in cubic metres per second, V is velocity of water in liters per second and A is the size of the water channel supplying the trial site. The total time to irrigate Site A and Site B was recorded and the total volume of water applied determined. Both Sites were irrigated 14 times before harvesting using the float method of measuring water. The application of water on 14 separate occasions was more than what a typical Bamyan farmer would do, which is usually 8 to 9 times. The timing of water application for this trial was based on crop cycle requirements.

Four separate identical fertilizer treatments were used across both the mechanized and traditionally cultivated sites. Phosphorous was applied in the form of DAP. While nitrogen was applied in the form of Urea. FAO's recommended rates for phosphorus (220 kg/ha) and nitrogen (330 kg/ha) were applied. In addition, additional rates below and above the FAO's

recommendations were also applied, with phosphorous being applied at 0 kg/ha, 110 kg/ha (50% of recommendation) and 440 kg/ha (200% of recommendation). Nitrogen was applied at 0 kg/ha, 165 kg/ha (50% of recommendation) and 660 kg/ha (200% of recommendation). Each treatment was triplicates across both cultivation methods such that the trial comprised of 8 different treatments with 24 plots across both sites.

Once germination had reached 80%, half of the DAP and Urea was mixed together and applied. This took place on 31 May (refer Fig. 4). The remaining 50% of the fertilizer was applied when the germination was 100%. This application took place on 10 June and the ridges were then 'earthed up' (refer Fig. 5).

2.5 Observations Recorded before Harvesting

Four separate observations were recorded throughout the trial; germination percentage, number of branches, flowering percentage and plant height. Observations commenced on 26 May when the germination percentage was 30%. 100% germination percentage was recorded on 2 June for both sites. For Site A the average number of branches was 8.1 and for Site B the average number of branches was 8.9. The average plant height for Site A and Site B were 43.5cm and 50.5cm respectively. There was no difference in flowering percentages between the sites, however for both sites the plots which had the 200% fertilizer treatment flowering was delayed by 6 days and the plant height increased by 37 cm. The trial reached 100% flowering percentage 23 days after the final fertilizer application (Fig. 6).



Fig. 3. Potato sowing and cultivation method



Fig. 4. First fertilizer application on 31 May in site A



Fig. 5. The second and final fertilizer application on 10 June



Fig. 6. Flower stage 23 days after final fertilizer application in site B and site A

2.6 Harvesting Method

The trial was harvested on 30 September using a bullock (refer Fig. 7). Maximum effort was undertaken to make sure that no single potato remained on the land. At harvest time, a calibrated standard balance was used to weigh the total potatoes harvested from each of the 24 plots (refer Fig. 8).

2.7 Statistical Analysis

Data were analyzed using the KyPlot 4.0 program (Kyens Lab Inc., Tokyo, Japan). Crop data underwent an analysis of F- test and Student's t-test for pairwise comparisons.

3. RESULTS AND DISCUSSION

Yield results from the various plots are shown below in Table 1.

As an average across all four fertilizer rates, mechanized cultivation produced 60% higher crop yields (average 32.83mt/ha) than traditional cultivation (average 20.5 mt/ha) which resulted in an average of 12.33mt/ha higher yield for mechanized cultivation over traditional cultivation. This yield difference was highly statistically significant ($P = 0.99$)¹. A deeper planting depth may provide more favourable environment for potatoes to develop more extensive roots and mature tubers than a shallow planting depth [11, 12].

Furthermore, greater application of fertilizer increased the yield by a similar amount in both mechanized and traditional treatments. Importantly, analysis of the variance within treatments in resultant yield increases showed that there was no statistically significant difference in responsiveness to fertilizer between the two cultivation methods (F value = 0.5855)².

Greater yield was obtained from the mechanized treatments compared with the traditional treatments across all four fertilizer rates (refer Fig. 9). These results highlight that farmers who remained with traditional cultivation could potentially be US\$6,491/ha (369,987 AFN/ha) better off by applying phosphorous and nitrogen at twice the recommended FAO rates. Concerning factors regarding shallow planting depths may include reduced early season

moisture to plants and lower marketable yields [13]. Those farmers who use mechanized cultivation and also applied phosphorous and nitrogen at twice the recommended FAO rates could receive an extra US\$10,307/ha (587,499AFN/ha).

The average gross margin per hectare was 74% higher across the mechanized plots (US\$6,552/ha or 373,464AFN/ha) over the traditional plots (US\$3,772/ha or 215,004 AFN/ha). These figures confirm that use of mechanized cultivation and the application of phosphorus at 440kg/ha and nitrogen at 660kg/ha will increase the potato yield and produce a higher cash value and a higher gross margin per hectare.

Additionally, farmers who use mechanized cultivation and apply phosphorus at 440kg/ha and nitrogen at 660kg/ha could increase the value of their production up to US\$10,307/ha, whilst farmers who remained with the traditional method of cultivation and did not apply chemical fertilizers would receive only US\$2,334/ha. This will result in a US\$7,973/ha (454,461 AFN/ha) increase in income – over 300% more.

Application of phosphorus at 440kg/ha and nitrogen at 660 kg/ha also delayed the onset of flowering by 6 days, increased the average plant height by 37 cm and produced a greater number of marketable tubers. Higher tuber uniformity was obtained in Site B (mechanized cultivation) compared with Site A (traditional cultivation).

These results also confirmed that farmers who use mechanized cultivation with fertilizer application at twice the FAO recommended rates, will produce higher potato yields, higher cash value, and obtain a higher gross margin per hectare. This result is supported by previous researchers who concluded that application of 207kg nitrogen per hectare delayed the days to flowering and maturity by between four and nine days and also increased the plant height and marketable tuber weight [8,14]. These authors also concluded that the application of 60kg phosphorus increased days to flowering by a further two days, and increased the plant height and number of marketable tubers. This is in conformity with the findings of Lauer [15] and Ojala et al. [16] who observed that high N levels promoted excessive vegetation growth and delayed flowering.

¹Paired t-test

²F-test



Fig. 7. Potatoes being harvested using the bullock



Fig. 8. Weighing potatoes

Table 1. Yakawlang potato trail research yield results

Treatments	Yield (kg)	Average Yield (Kg)	Area (m ²)	Area (ha)	Yield (mt)	Yield (mt/ha)	Average Yield (mt/ha)
Site B (Mechanized)							
N0P0	248		114	0.0114	0.248	22.323	
N0P0	267	255.0	117	0.0117	0.267	22.421	22.325
N0P0	250		116	0.0115	0.261	22.231	
N1P1-50%NP	377		119	0.0119	0.377	31.539	
N1P1-50%NP	298	324.5	128	0.01275	0.298	25.473	27.601
N1P1-50%NP	299		126	0.0126	0.299	25.790	
N2P2-100%NP	435		132	0.0132	0.435	32.917	
N2P2-100%NP	398	409.8	120	0.012	0.398	33.158	33.139
N2P2-100%NP	397		119	0.0119	0.397	33.341	
N3P3-200%NP	551		126	0.01255	0.551	46.704	
N3P3-200%NP	499	550.0	122	0.0122	0.499	45.609	48.384
N3P3-200%NP	600		114	0.01135	0.600	52.840	
Treatments	Yield (kg)	Average Yield (Kg)	Area (m ²)	Area (ha)	Yield (mt)	Yield (mt/ha)	Average Yield (mt/ha)
Site A (Traditional)							
N0P0	135		112	0.0112	0.135	12.054	
N0P0	103	113.67	104	0.0104	0.1025	9.856	10.955
N0P0	104		105	0.0102	0.1023	10.223	
N1P1-50%NP	205		112	0.0112	0.205	18.304	
N1P1-50%NP	235	223.33	112	0.0112	0.235	20.982	19.643
N1P1-50%NP	230		113	0.0113	0.23	20.354	
N2P2-100%NP	278		126	0.0126	0.2775	22.024	
N2P2-100%NP	257	261.50	129	0.0129	0.2565	19.884	20.954
N2P2-100%NP	251		126	0.0126	0.2505	19.881	
N3P3-200%NP	387		120	0.012	0.387	32.250	
N3P3-200%NP	362	369.67	126	0.0126	0.3615	28.690	30.470
N3P3-200%NP	361		127	0.0127	0.3605	28.386	

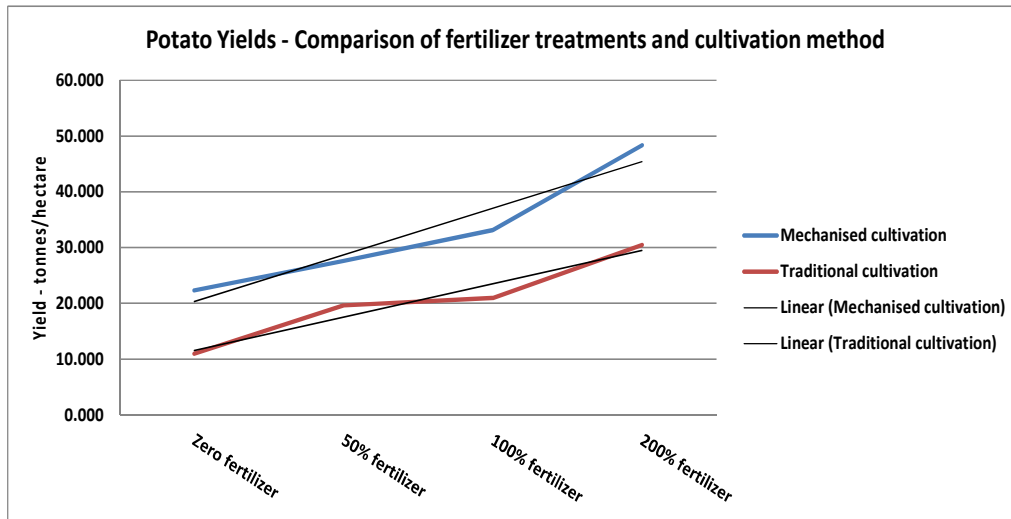


Fig. 9. Comparison of fertilizer treatments and cultivation methods

Table 2. Financial analysis of mechanized and traditional treatments with different fertilizer application rates

Traditional Treatments	Cost in AFN/HA	Cost in USD/HA	Benefit (MT/HA)	Benefit (AFN)	Benefit (USD/HA)	Gross Margin (USD/HA)
Zero fertilizer	15,000	263	10.955	133,021	\$ 2,334	\$ 2,071
50% fertilizer	26,875	471	19.64	238,520	\$ 4,185	\$ 3,713
100% fertilizer	35,863	629	20.95	254,439	\$ 4,464	\$ 3,835
200% fertilizer	58,252	1,022	30.47	369,996	\$ 6,491	\$ 5,469
Mechanized Treatments						
Zero fertilizer	5,000	88	22.33	271,089	\$ 4,756	\$ 4,668
50% fertilizer	20,010	351	27.60	335,151	\$ 5,880	\$ 5,529
100% fertilizer	26,195	460	33.14	402,397	\$ 7,060	\$ 6,600
200% fertilizer	49,519	869	48.38	587,524	\$ 10,307	\$ 9,439

*AFN= Afghanistan money; USD= US dollar; HA= hectare

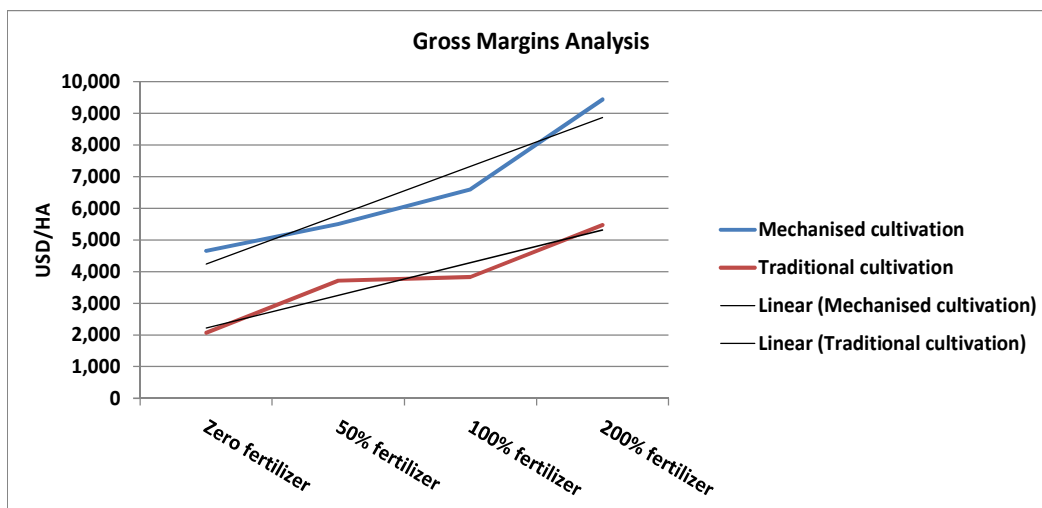


Fig. 10. Gross margin analysis of mechanized and traditional cultivation with different fertilizers application rates

The use of mechanization and fertilizer application at twice the FAO recommended rates not only produces higher yield and higher financial benefit but also reduces crop competition from weeds. The trial also suggested that the DAP and Urea fertilizers should be applied together in two separate occasions.

4. CONCLUSION

There was a significant difference in the yield of potato in Site B (mechanized cultivation) as compared to Site A (traditional cultivation). Higher application rates of fertilizer resulted in higher crop yields in both mechanized and traditional systems. Mechanized cultivation resulted in an average yield increase of 12.33mt/ha, which equates to US\$4655.75/ha. Higher production value was obtained in the mechanized method as compared with the traditional method across all the treatments. Meanwhile, higher gross margin per hectare was obtained in mechanized treatments compared with traditional treatments.

5. RECOMMENDATIONS

The results of this trial support the following recommendations:

1. Apply farm yard manure (FYM) 20 days ahead of cultivation in order to let the manure get the maximum fixation within the soil.
2. The correct use of mechanization will dramatically improve potato yields. Deeper ploughing of land, which can only be obtained using a tractor and mouldboard plough, allows the potato tubers root to penetrate deeper into the ground and develop more.
3. Treat the potato seed with fungicide (Thyram) before planting in order to control or decrease the early blight and late blight diseases which are common in Bamyán potato fields.
4. The ratio of DAP and Urea fertilisers should be correctly calculated and rates of 440 kg/ ha phosphorous and 660 kg/ha nitrogen are recommended.
5. Two separate DAP and Urea applications should be applied at the same time when the germination percentage is between 50% and 80% and the remaining 50% when the germination percentage has reached 100%.
6. After applying urea irrigate the land to reduce losses from volatilization.

7. It is important to measure the timing and amount of water going to the field and irrigate the field more, but we recommend light irrigation over heavy watering (i.e. apply water more frequently but less heavily).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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