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RESEARCH ARTICLE

DETERMINATION OF EFFECTIVE NITROGEN LEVEL TO OPTIMIZE YIELD AND QUALITY OF POTATO VARIETIES OF CONNECT AND MASAI

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ABSTRACT

Although the Department of Agriculture in Sri Lanka provides fertilizer recommendations for local potato cultivation, farmers do not comply with them. Fertilizer is overused mostly in up-country areas causing economic losses as well as health and environmental issues. There are high nitrogen (N) efficient potato varieties such as CONNECT and MASAI that produce optimum yield under lower N but show abnormalities such as secondary growth, tuber cracks, deformed or misshapen tubers and increased tuber rotting under higher N. A field experiment was conducted in Nuwara-Eliya, Sri Lanka to identify the effective N level to optimize yield and quality of potato varieties of CONNECT and MASAI. The experiment was arranged as a Randomized-Complete Block Design with five N levels (110, 150, 190, 230, and 270 kg ha^{-1}) and replicated thrice. Phosphorus (P, 100 kg ha^{-1}) and potassium (K, 250 kg ha^{-1}) levels were kept constant across treatments. N level had no significant (P>0.05) effect on tuber yield or dry matter content in both varieties confirming that the yield was not affected even by the lowest N level used in the study. In conclusion, the lowest N level of 110 kg ha^{-1} can be recommended for potato varieties of MASAI and CONNECT as it is an economically and environmentally sound option as it did not cause any yield or quality reduction in potato in the present study.

Keywords: Dry matter content, Fertilizer, Potato, Tuber yield, Tuber quality

INTRODUCTION

Potato (*Solanum Tuberosum* L.) is the third most important food crop in terms of global food consumption and it is highly recommended as a crop for food security given the food supply issue related growing population in the world (FAO, 2020). With regard to nutritional value, boiled potatoes on dry weight basis contains 1.9, 20.1, 0.1, 0.9 and 1.8% of protein, carbohydrates, fat, sugar and fibres, respectively (USDA, 2019) and therefore, it is ubiquitous.

Global potato production is more than 368 million metric tons each year (FAO, 2020). The potato crop was introduced to Sri Lanka in 1850, and ever since, with an average annual supply of 9 kg per person (Department of Census and Statistics, 2018a) It has been ranked as the country's second-largest root crop. In Sri Lanka, potato is widely planted in Nuwara-Eliya district (Upcountry Wet Zone) and Badulla district (Upcountry Intermediate Zone), while it is also successfully grown to a lesser level in Jaffna and Puttlam districts (Department of Agriculture, 2018).

Market supply of potato is from the local production (38%) and importation (62%). Potato also contributes by 33% to the total root crops available for consumption in the country (Department of Census and Statistics, 2018a). In 2016, total potato production in Sri Lanka was 80,458 metric tons and the covered

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land area was 5,092 ha. However, it has decreased to 52,998 metric tons in the year 2017 with a land cover of 3,333 ha (Department of Census and Statistics, 2018b). Reduction of potato production is attributed to high cost of production, intensive crop management practices, unavailability of seed potatoes and other inputs, high disease attack, extreme weather and poor storage conditions (Pavithira, 2018).

Nutrient supply is one of the most important agronomic practices and also a challenge in potato cultivation as it is directly related to the vegetative growth and final yield. In upcountry potato fields, almost all farmers use organic fertilizers such as poultry and cattle manures combining with inorganic fertilizers, especially during land preparation (Silva, 2019). Potato plants need an adequate supply of essential plant nutrients, particularly nitrogen (N), phosphorus (P), and potassium (K) which are largely removed with plants at harvesting. Among plant nutrients, N balances vegetative and reproductive growth of potato plants (Abewoy, 2024). Further, N is important in chlorophyll production and promotes rapid healthy growth of the plant. It is the nutrient that normally produces the greatest yield response in a crop (Kołodziejczyk, 2014).

Apparently, the level of fertilizer application in upcountry is higher than that of the recommendation of the Department of Agriculture. Farmers do not comply with the recommendations though certain fertilizer recommendations are available for potatoes (Ariyapala and Nissanka, 2006). Excessive use of fertilizers leads to many ecological issues, abnormalities in plant morphology and yield; it also increases cost of production in potato cultivation. Currently, the organizations related to environment conservation encourage potato breeders to produce new varieties that produce maximum yield under low N fertilizer levels. According to the breeders, both CONNECT (Den Hartigh Potatoes, 2021a) and MASAI (Den Hartigh Potatoes, 2021b) varieties can produce greater yield under relatively low N fertilizer applications. Besides, CONNECT is also recommended for organic cultivations. However, with usual fertilizer practices, these N-efficient varieties show many abnormalities. For example, CONNECT variety shows relatively lengthy succulent stems, rotting and plant lodging, whereas MASAI variety shows a high percentage of cracked tubers specially under high N level. Because of these reasons, some farmers are reluctant to cultivate these CONNECT and MASAI varieties with the current fertilizer practices.

The objective of the present study was to introduce a proper fertilizer schedule and to identify the effective N level which could optimize yield and quality of potato varieties; CONNECT and MASAI.

MATERIALS AND METHODS

Experiment site

The study was carried out in a farmer field (*Maha* season 2021) in Nuwara Eliya district (6°56'41.0" N 80°46'40.6" E), Sri Lanka where the elevation is 1,889 m above mean sea level. Average annual temperature and annual rainfall of the area are 19.1°C and 2,550 mm, respectively. Major soil type of the area was Red Yellow Podzolic (Typic Hapludults).

Agronomic practices

Primary and secondary tillage operations were done and representative soil samples were collected from 10-15 places in the field (0-15 cm depth) and analysed for available N, P, and exchangeable K contents before planting. Lime was applied to adjust the pH to optimum level recommended for potato cultivation (5.5 -6.5) (Department of Agriculture, Sri Lanka, 2021). Fungicide treatment (Thiophanatemethyl 50%, Thiram 30% solution; 2 g L^{-1} each) were applied for seed potatoes before planting. Inter-ridge and intra-ridge spacing were 45 and 25 cm, respectively.

Planting materials

Potato varieties; CONNECT and MASAI were used in this study. CONNECT is a medium late table variety with yellow flesh which is bred and distributed by Den Hartigh potatoes, the Netherland. This variety has been introduced to Sri Lanka by Hayleys

Agro Farms (Pvt.) Ltd. in 2015. The most important trait of this variety is high tolerance to late blight disease (Den Hartigh potatoes, 2021a), the major problem of Sri Lankan potato farmers. MASAI is also a medium late potato variety bred by Hartigh potatoes, the Netherland. It is a high yielding variety with very smooth red skin, large size tubers, and nice yellow flesh (Den Hartigh potatoes, 2021b). Both varieties require relatively less N compared to others (Den Hartigh potatoes, 2021a; Den Hartigh potatoes, 2021b).

Experimental set-up and procedure

The experiment was set up according to Randomized Complete Block Design (RCBD). Five N levels (110, 150, 190, 230, and 270 kg ha^{-1}) were replicated thrice with a constant amount of P_2O_5 (100 kg ha^{-1}) and K_2O (250 kg ha^{-1}). There were 36 plants per replicate (plot). The N level 230 kg ha^{-1} was the recommended total N requirement for potato cultivation according to the Agriculture Research and Development Centre, Department of Agriculture, Seetha-Eliya. The N levels 110, 150, and 190 kg ha^{-1} were selected according to the recommendations of the seed potato breeder and the supplier, Den Hartigh potatoes, the Netherlands. The N level of 270 kg ha^{-1} was selected according to farmers' fertilizer application rates in the area. For both varieties, 2/3 of total N (Urea) fertilizer requirement was applied as basal application, and the remaining 1/3 was applied as top-dressing. Total P fertilizer (TSP) dosage was applied with the basal application. Half of the K fertilizer (MOP) was applied as the basal application and the other half of K fertilizer was applied with the top-dressing application.

Data collection and analysis

Plant height, number of compound leaves, and number of stems were recorded weekly. Leaf petiole N content was determined 45 days after planting (DAP) using Kjeldahl method. Leaf greenness was measured twice (45 and 60 DAP) using SPAD 502 chlorophyll meter (Minolta Camera Co. Ltd., Osaka, Japan). Yield per unit land area, number of tubers per plant, tuber size distribution, number of cracked tubers, number of rotten tubers, number of deformed tubers, and number of marketable tubers were evaluated at the harvesting time (3.5 months after planting). Dry matter content of the potatoes was measured using underwater weight method (Tiemens-Hulscher *et al.*, 2013) and accordingly, following equation was used to estimate the dry matter content of tubers.

Percentage dry matter =
$(0.0493 \times \text{under water weight}) + 1.95$

Data were subjected to analysis of variance (ANOVA) using Minitab 17 statistical software and the means were compared following Tukey's test at $P = 0.05$.

RESULTS AND DISCUSSION

Growth Parameters

The results of the present study revealed that the treatment application did not significantly (P>0.05) affect the plant height (Figure 1),

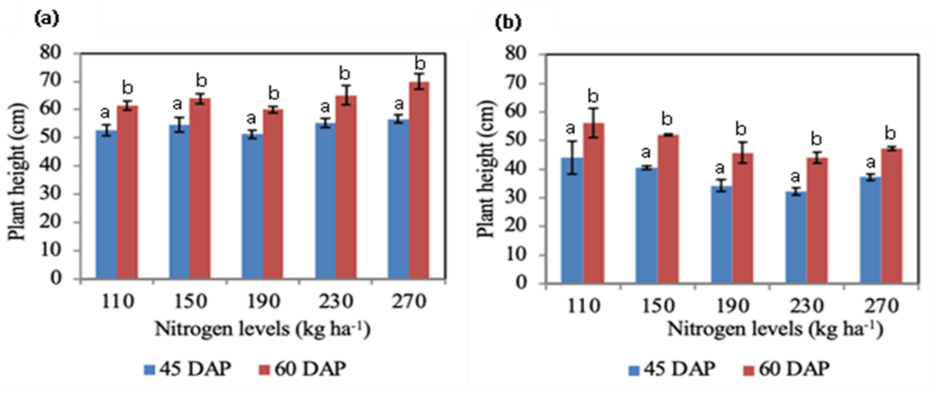

Figure 1: Effect of N level on plant height (cm): (a) CONNECT and (b) MASAI.
Means with same letters are not significantly different at P = 0.05. DAP- Days After Planting.

seedling emergence, and stolon development of CONNECT and MASAI varieties (Table 1). However, Banjare *et al*. (2014) have observed an increasing trend on growth parameters with increased N levels.

Table 1: Number of compound leaves, number of stems, seedling emergence, and number of stolons under different N levels.

Variety	N level (kg ha^{-1})	Number of compound leaves plant^{-1}		Seedling emergence (15 DAP)	Number of stolons plant^{-1}	Number of stems plant^{-1} (60 DAP)
		45 DAP	60 DAP			
CONNECT	110	46.8±2.5	54.2±0.8	26.0±3.1	3.6±0.2	34.3±4.9
	150	45.6±2.4	53.7±2.3	22.3±2.3	3.3±0.3	22.3±3.2
	190	42.3±2.8	49.7±1.0	27.3±4.1	2.9±0.1	39.7±6.2
	230	45.8±1.3	53.4±1.8	30.0±2.0	3.4±0.5	40.3±1.3
	270	46.3±0.4	52.8±2.3	26.7±4.8	3.8±0.2	35.3±5.2
MASAI	110	32.5±0.9^{a}	39.4±0.9	23.0±2.7	2.3±0.2	22.0±6.7
	150	29.2±1.4^{abc}	37.1±4.3	21.7±3.2	2.2±0.2	13.3±1.2
	190	26.2±1.6^{bc}	32.9±4.3	13.7±2.8	2.0±0.2	10.3±2.3
	230	24.3±0.5^{c}	31.2±1.4	13.3±0.9	1.6±0.1	17.7±3.5
	270	31.6±0.3^{ab}	37.6±2.2	17.3±1.3	2.1±0.1	13.7±1.2
***P* Value**						
CONNECT		0.61	0.49	0.68	0.07	0.25
MASAI		0.01	0.22	0.07	0.15	0.19

Values are mean±SEM. Means with different letters are significantly different at $P = 0.05$.

According to Table 1, N level had a significant effect ($P<0.05$) on the number of compound leaves in MASAI variety, only at 45 DAP (Table 1) but the number of stems per plant (60 DAP) did not show any significant ($P>0.05$) difference under different N levels. It is in agreement with the findings of Banjare *et al*. (2014) with respect to 45 and 60 DAP.

The petiole N content of both varieties was significantly ($P<0.05$) affected by N levels (Figure 2). In CONNECT, the percentage of petiole N gradually increased with an increasing amount of N applied to the soil whereas in MASAI, the value gradually increased only up to 230 kg ha^{-1} N level. Accordingly, in CONNECT, the highest petiole N was observed at 270 kg ha^{-1} N level while the lowest was observed under 110 kg ha^{-1} N level (Figure 2).

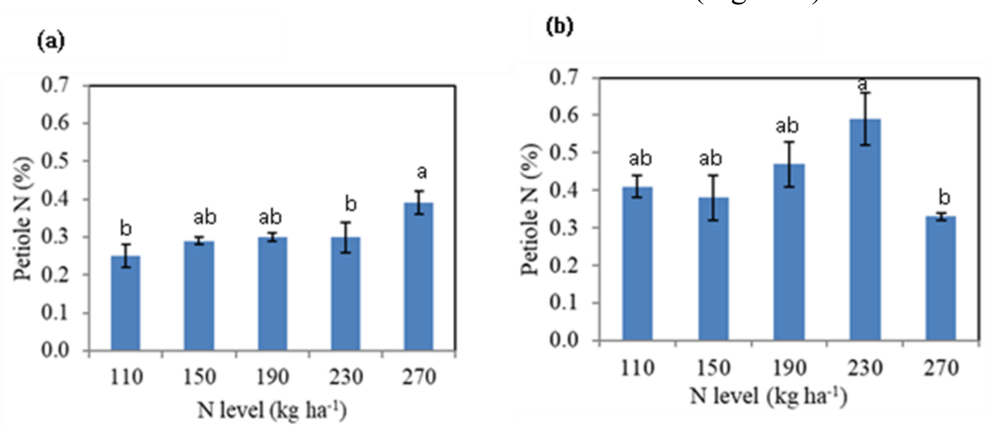

Figure 2: Effect of different levels of N on petiole N concentration (%): (a) CONNECT and (b) MASAI.

Values are means. Means with different letters are significantly different at $P = 0.05$.

In MASAI, the highest petiole N was recorded under 230 kg ha^{-1} N level and the lowest was observed at the highest N level (270 kg ha^{-1}). It could be presumed that the excess N added to the soil might not be available to plants due to losses nor absorbed much by roots.

Previous studies have shown that N supply has a significant impact on greenness represented by the measured SPAD value in leaves (Zhang *et al*. 2020). However, there was no significant (P>0.05) effect of level of N applied on leaf greenness in both varieties in this study (Figure 3).

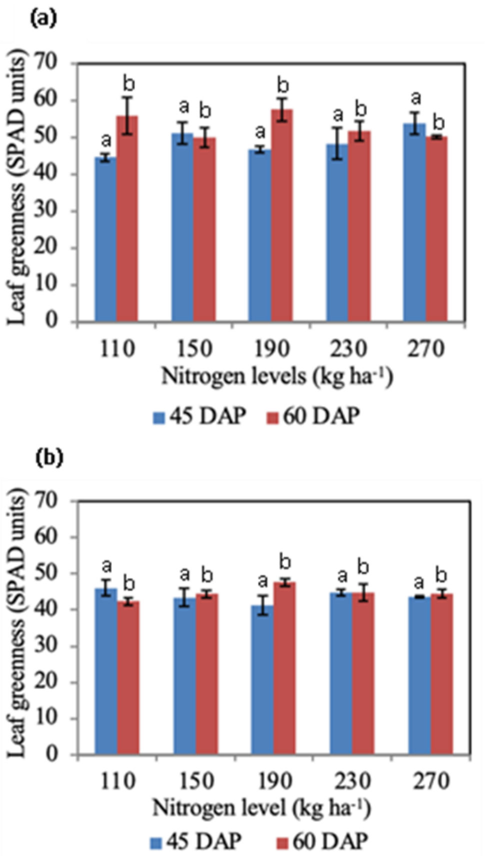

Figure 3: Effect of different levels of N on leaf greenness (SAPD meter units): (a) CONNECT and (b) MASAI.
Values are means. Means with different letters are significantly different at P = 0.05.

It could be observed for the MASAI variety that the greenness of leaves increased with their growth at other nitrogen N levels, except at the lowest N level 110 kg ha^{-1}. Since both potato varieties used in the study have high N sensitivity it can be inferred that the plants have utilized absorbed N to produce their potential amount of chlorophyll according to the genetic traits of both varieties.

Yield Parameters

In this study, the N level did not show a significant (P>0.05) effect on total tuber yield in both varieties (Figure 4). Conversely, some previous studies report that increasing the level of N application can significantly increase total yield of potato (Alfred *et al.* 2000; Banjare *et al*. 2014; El-Hadidi *et al.* 2017). In the present study, the potato yield ranged from 22.54 to 25.67 t ha^{-1} in CONNECT and 13.62 to 19.66 t ha^{-1} in MASAI (Figure 4). Importantly, the results of the present study showed a statistically similar yield even at the lowest N level (110 kg ha^{-1}) applied.

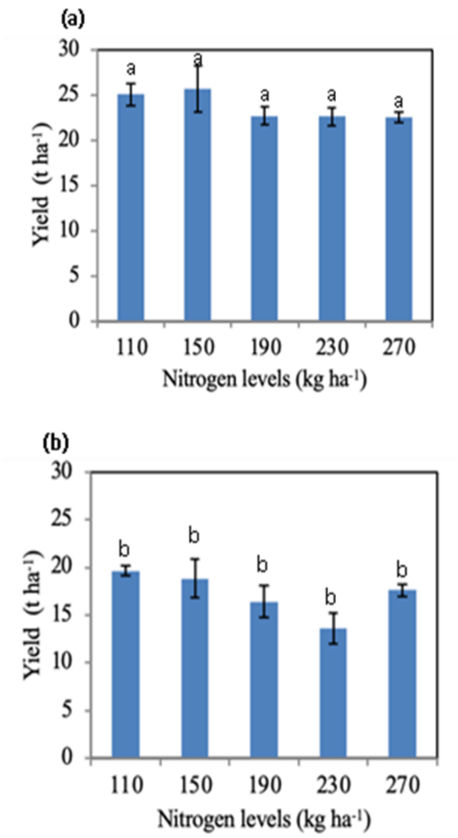

Figure 4: Effect of different levels of N on yield (t ha^{-1}): (a) CONNECT and (b) MASAI.
Values are means. Means with different letters are significantly different at P = 0.05.

This may be due to the lower N requirement of these two varieties according to the variety description provided by the breeder. Also, both potato varieties have given the average yield recorded in the area. These findings support the fact that the high N application is not necessarily linked with high tuber yields of CONNECT and MASAI varieties and thus, it emphasizes importance of providing only the required amount of N to the plant. By considering the increasing trend of petiole N content with the increasing habit of plant height and decreasing habit of final yield (although the difference was insignificant at P=0.05) in CONNECT, absorbed N has been allocated more to vegetative growth but has not been efficiently converted to tuber production. However, the higher vegetative growth in CONNECT with high N application is undesirable due to lodging.

According to El-Hadidi *et al.* (2017), variation in number of tubers per plant has been significant due to the effect of N rates. In the current study, the N level had no significant (P>0.05) effect on the number of tubers per plant in CONNECT but the MASAI showed a significant (P<0.05) effect (Figure 5). In MASAI, 110 kg ha^{-1} of N recorded the highest number of tubers per plant (6.5), and 230 kg ha^{-1} recorded the lowest (4.1).

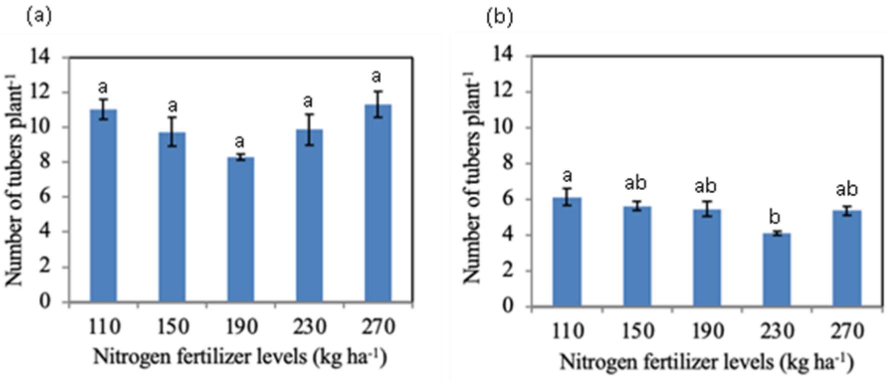

Figure 5: Effect of different levels of N on number of tubers per plant: (a) CONNECT and (b) MASAI.
Values are means. Means with different letters are significantly different at P = 0.05.

The results of this study revealed that the treatment effect was not significantly different (P>0.05) for the tuber size distribution of both varieties, except for the size range 28-35 mm in CONNECT (Table 2). According to Gray and Hughes (1978), high quantities of applied

Table 2: Tuber size distribution under different N levels. Values are mean±SEM.

Variety	N level (kg ha^{-1})	Tuber size distribution (number of tubers plant^{-1}) <28 mm	28-35 mm	35-55 mm	>55 mm
CONNECT	110	1.91±0.50	1.52±0.19^{a}	5.23±0.26	1.65±0.20
	150	1.55±0.17	1.19±0.16^{ab}	4.62±0.60	1.97±0.20
	190	0.78±0.05	0.73±0.12^{b}	4.45±0.03	1.65±0.11
	230	1.51±0.20	1.09±0.25^{ab}	5.19±0.04	1.55±0.28
	270	1.97±0.32	1.11±0.44^{ab}	5.41±0.50	1.72±0.00
MASAI	110	0.39±0.07	0.62±0.76	3.38±0.44	1.29±0.11
	150	0.16±0.03	0.51±0.08	2.98±0.16	1.39±0.17
	190	0.33±0.13	0.65±0.15	2.87±0.17	1.12±0.35
	230	0.20±0.03	0.43±0.20	2.22±0.28	0.84±0.19
	270	0.14±0.11	0.52±0.06	3.00±0.18	1.32±0.16
***P* Value**					
CONNECT		0.15	0.04	0.30	0.48
MASAI		0.32	0.81	0.17	0.51

Means with different letters are significantly different at P = 0.05.

N and irrigation, but low levels of K, increase the length of potato tubers compared to their width.

Quality Parameters

The net marketable tubers differed significantly ($P<0.05$) in both varieties (Table 3).

No cracked tubers were found in CONNECT variety under all applied N levels, which suggest that the relationship of the MASAI variety with tuber cracking does not significantly depend on the amount of N applied. Further, the results of this study revealed that the treatment effect was not

Table 3: Number of cracked tubers, number of rotten tubers, number of deformed tubers, and number of marketable tubers under different N levels.

Variety	N level (kg ha^{-1})	*Cracked tubers plant^{-1}	Rotten tubers plant^{-1}	Deformed tubers plant^{-1}	Marketable tubers plant^{-1}
150	-	0.12±0.05	0.25±0.08	9.2±0.7^{ab}	
190	-	0.39±0.15	0.22±0.03	7.6±0.2^{b}	
230	-	0.20±0.14	0.22±0.03	9.3±0.8^{ab}	
270	-	0.09±0.04	0.35±0.09	10.9±0.8^{a}	
MASAI	110	0.13±0.04	0.19±0.02	0.01±0.01	5.8±0.5^{a}
	150	0.17±0.03	0.30±0.06	0.10±0.05	5.1±0.3^{ab}
	190	0.15±0.03	0.22±0.03	0.03±0.03	5.1±0.4^{ab}
	230	0.12±0.08	0.16±0.04	0.04±0.04	3.8±0.2^{b}
	270	0.10±0.06	0.15±0.06	0.03±0.01	5.1±0.4^{ab}
***P* Value**					
CONNECT		-	0.47	0.76	0.04
MASAI		0.884	0.28	0.19	0.03

Values are mean±SEM. Means with different letters are significantly different at $P = 0.05$.

* No crack tubers were found in CONNECT variety.

In CONNECT, the highest value was recorded under 270 kg ha^{-1} but it was statistically similar to 110 kg ha^{-1}. N level of 110 kg ha^{-1} recorded the highest value for MASAI. The N level had no significant ($P>0.05$) effect on the number of cracked, deformed, and rotten tubers (Table 3).

significantly ($P>0.05$) different for tuber dry matter content of both varieties (Figure 6). Previous studies on the effect of N level on starch content, specific gravity, and dry matter content of tubers showed mixed responses. For instance, El-Hadidi *et al*. (2017) showed that there is a positive and significant effect of

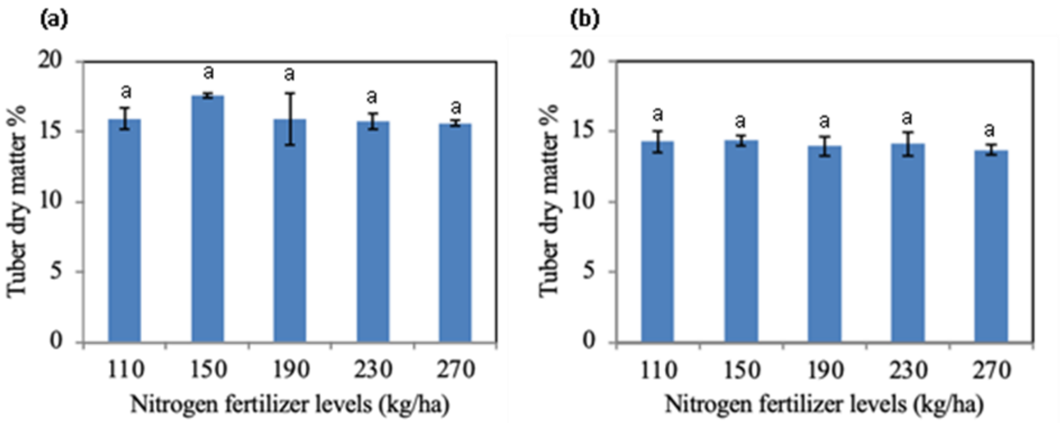

Figure 6: Effect of different levels of N on tuber dry matter content (%): (a) CONNECT and (b) MASAI.

Values are means. Means with different letters are significantly different at $P = 0.05$.

varying levels of N on starch content, specific gravity, and dry matter content of tubers. The opposite effect was reported by Ahmed *et al*. (2009). According to the varietal description provided by the breeder, the dry matter content of CONNECT is about 20.9% and, in MASAI about 18.7%. In this study, the dry matter content was lower than the average value for both potato varieties (Figure 6). This can be attributed to the effect of occasionally heavy rain during the tuber bulking stage and the influence of other macro and micro plant nutrients.

CONCLUSIONS

In this study, a statistically similar yield was given by all N levels including the lowest level (110 kg ha^{-1}) which is similar to the average yield recorded in the area. Compared to the highest N level 270 kg ha^{-1}, the use of 110 kg ha^{-1}, which is the lowest N level, is important to reduce addition of excess amounts of synthetic N to the field by less than half and correspondingly it reduces the cost for fertilizers. Therefore, the lowest N level (110 kg ha^{-1}) can be recommended for MASAI and CONNECT potato varieties as it is an economically and environmentally sound option that does not cause any yield or quality reduction. The breeder has also identified that these two CONNECT and MASAI potato varieties can be grown under relatively low N conditions and according to the current study, similar results are obtained under the local soil and climatic conditions of the area. The yield obtained in this study is satisfactory in quality, and it was found that the quality of the tubers of both potato varieties did not essentially depend on the level of N applied. The N content of the plant tissues depends significantly on the amount of N applied but does not significantly affect the overall growth of the plant.

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AUTHOR CONTRIBUTION

HW conceived of the presented idea. HW, SH and CR developed the methodology. CD carried out the experiment. CD and CR performed the formal analysis. CD and CR prepared the original draft and SH, CR and HW reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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