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DRY MATTER PRODUCTION AND NUTRIENT UPTAKE OF POTATO (*Solanum tuberosum* L.) AS INFLUENCED BY N AND P APPLICATION ON NITISOLS OF WESTERN ETHIOPIA•

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ABSTRACT

The influence of different levels of N and P on haulm and tuber dry matter production, and nutrient uptake of two potato varieties, Tolcha and Menagesha, were evaluated at Bako Agricultural Research Center, western Ethiopia, during the years 2000 and 2002. The experiment was laid out in a split plot design having three replications with the two potato varieties assigned to the main plot while three levels of N (0, 69 and 138 kg N ha^{-1}) and four levels of P (0, 69, 138 and 207 kg P ha^{-1}) having factorial combinations to sub-plots. Soil samples were taken from 0 to 30 cm depth before and after treatment application to determine the selected soil physico-chemical properties. Highly significant ($P<0.01$) differences were noted for haulm and tuber dry matter between the varieties. Increasing N levels from 0 to 69 kg ha^{-1} significantly increased tuber dry matter on an average by 84%. On the contrary, the effect of P was non-significant ($P>0.05$) with respect to haulm and tuber dry matter. The variety and N interaction effect significantly ($P<0.01$) increased haulm and tuber dry matter. There were highly significant differences ($P<0.01$) between the two potato varieties with respect to haulm and tuber nutrient uptake. Nutrient uptake of the haulm and the tuber was significantly ($P<0.01$) enhanced due to N applications. The soil analyses showed that the soil of the experimental site was low in organic carbon and total nitrogen. The available P of the acidic Nitisols of Bako soil was estimated to be 7.48 ppm, which is below the critical level for potato production. The soil available P accounted only 4.3% for the variation of tuber dry matter. It was noted that 69 kg N ha^{-1} was found to be critical for potato production on Nitisols of western Ethiopia. Further studies on phosphorus nutrition in conjunction with organic amendments to improve phosphorus use efficiency need due consideration.

Key words: available P, dry matter, Nitisols, nutrient uptake, 'P' use efficiency

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INTRODUCTION

Potato is a major food crop grown in the highlands and mid-altitude areas of western Ethiopia. It has got vital importance as food and source of income to farmers. Because of its comparative advantage in terms of yield per unit area, maturity period for filling transitory food security gap and its short life cycle favouring double/multiple-cropping system, soil fertility maintenance or nutrient replenishment through use of inorganic or organic fertilizer for potato is essential to improve its production and productivity.

The three major essential plant nutrients, nitrogen, phosphorus and potassium, are increasingly in short supply in the soils of eastern, western and southern Africa (Rao et al., 1998). Particularly, nitrogen and phosphorus are deficient in many soils of tropical Africa, which might also be true for many Ethiopian soils (Murphy, 1968). In western Ethiopia, Nitisols, Acrisols and Alifisols are the dominant soil types with acidic properties. Under such conditions, the availability of plant nutrients, specifically phosphorus, is low (Alemayehu Tafesse, 1998). Soil fertility studies conducted on N and P fertilizers in western parts of Ethiopia indicated low N and P status of the soils (Tadesse Yohannis and Tolessa Debele, 1998). On the other hand, Osaki et al. (1991) noted potato to be a heavy feeder of K, N and P, in that order.

Crops vary in their nutrient requirements and their ability to accumulate and utilise nutrients. Yohannes Uloro and Richter (1999), reported differences in P use efficiency between varieties of *Phaseouls vulgaris* L. and *Sorghum bicolor* (L.) Moench and also within the varieties of the same species. Some plant and soil parameters affect the uptake of nutrients in plants (Sauerbeck and Helal, 1990) which included nutrient concentration in the soil solution, buffering capacity of the soil nutrient adsorbed on the solid phase and effective rate of nutrient diffusion. The plant parameters known to affect nutrient uptake rate are: rate of water influx into the root, total root length, average root radius and rate of root growth.

The limited information available in Ethiopia pertaining to the N and P needs of potato mainly focused on fresh tuber yield. The dry matter content of tuber is also an important measure of quality specifically for processing as it influences processing efficiency, product yield and oil absorption (Storey and Davies, 1992). Also, it was reported that the dry matter content is the main determinant of quality for both processing as well as cooking. This is because the high dry matter content with less sugar accumulation and water content is desirable (Nelson and Shaw, 1976). It was further noted that the tuber dry matter content is influenced by a wide range of factors that affect the growth and development of the crop. Of these, soil fertility is regarded as the prominent one in western Ethiopia.

According to Osaki et al. (1991), tubers accounted for more than 70 percent of the nutrient removal of potatoes. They further noted that as a result of high harvest index, tubers actively removed nutrient elements from the leaves and stems and therefore, the accumulation and distribution of N, P and K were the key factors that determined the productivity. Storey and Davies (1992) noted nitrogen applications tended to delay early tuber growth rates and crop maturity, which might also indirectly influence percent dry matter if foliage growth was curtailed. Schippes (1968) found that the applied N and K usually reduced tuber dry matter but the effects were not always consistent and the dry matter changes, however, were usually small over the range of fertilizer levels used to give optimum yield.

In western Ethiopia, there is scanty information pertaining to the influence of N and P both on dry matter yield and nutrient uptake of potatoes. Therefore, this study was designed to fill this gap, which is important to improve potato production in the region.

MATERIALS AND METHODS

Description of the experimental site and design

The experiment was conducted at Bako Agricultural Research Center in 2000 and 2002 in the subhumid agro-ecological zone of Western Ethiopia during the main cropping season. The soil of the area is reddish brown Nitisol, which is acidic with a pH of 4.6. The experiment was laid out in a split plot design with three replications. Two improved potato varieties viz., Menagesha and Tolcha were assigned to the main plot while NP factorial combinations were considered the sub-plot treatments in a plot size of 9 m^2. The fertilizer treatments comprised of three levels of N at 0, 69 and 138 kg N ha^{-1}, as urea, and four levels of P at 0, 69, 138 and 207 kg P ha^{-1}, as triple superphosphate. Well-sprouted potato tubers averaging 75 g were planted on June 6 and 19 in 2000 and 2002, respectively.

They were spaced 75 x 30 cm between rows and plants, respectively. Recommended cultural practices were followed for potato production. Half the quantity of N was applied in band on the ridge and incorporated into the soil at the time of planting while the remaining half N was side-dressed 5 cm around the root zone at one and a half months after planting. The entire quantity of P was applied at the time of planting in band on the ridge and incorporated into the soil.

Soil and plant tissue sampling and analysis

Twelve soil samples were collected at a depth of 0–30 cm from different locations of the experimental site before planting to form one composite sample. Further, 24 soil samples were also collected from each treated plot replication-wise after harvesting to appraise some soil physico-chemical properties (Table 1).

The collected soil samples were air-dried and ground to <2 mm for analysis. Particle size distribution was determined by Bouyoucos hydrometer method (Day, 1965). The soil pH at 1:2.5 soil-water ratio was measured by using a digital pH meter (Page, 1982). The organic matter content of the soil was detrmined by Walkley and Black method (Dewis and Freitas, 1970). Total nitrogen was estimated by micro-Kjeldahl method (Dewis and Freitas, 1970), available K by flame photometry (FAO, 1984) and soil cation exchange capacity (CEC) and basic exchangeable cations (Ca, Mg, K and Na) determined by ammonium acetate method (Chapman, 1965). The available and total soils P were estimated following standard procedure (Olsen and Dean, 1965). Percentage base saturation was calculated by dividing total exchangeable base by CEC of the soil and multiplied by 100.

Total fresh and dry weights (g) of haulms and tubers were recorded on five randomly sampled plants per harvestable plots at maturity. The samples were washed, chopped and dried in a forced air circulation oven at $70^{O}C$ for 72 hours until constant-weight for estimating dry matter. Representative oven dried haulm and tuber samples were ground to <1 mm for determination of total N, P and K contents. Total nitrogen content of haulm and tuber was determined by micro-Kjeldahl method (Dewis and Freitas, 1970) and that of potassium content by flame photometry (FAO, 1984). Total P of the plant tissue was determined according to Olsen and Dean (1965). Total N, P and K uptake in haulms and tubers were computed as the products of dry weights of parts and their respective N, P and K contents.

The effects of variety, and N and P and their interactions on haulm and tuber dry matter were determined by analysis of variance using MSTAT C Software (M-Stat, 1990). The variables were tested for normality before the individual year or combined data were analysed. The relationship between dry matter production and its related traits was evaluated by simple correlation matrix. The effect of applied N and available P on tuber dry matter was estimated by simple regression matrix as per the statistical procedures outlined by Gomez and Gomez (1984) and means were compared using least significance difference (LSD).

RESULTS AND DISSCUSION

Effect of soil extractable P on dry matter

Soil extractable P was non-significantly correlated (r=0.21) with tuber dry matter (Table 6). Simple regression analysis evidently showed that soil available P accounted for only 4.3% of the variation in tuber dry matter production (Table not shown). Only 0.4% of the total P that existed in the experimental site was available for plant use which is reflected in the low uptake of P both by haulm and tubers (Tables 1 and 6). The available soil P of the experimental site was estimated to be 7.48 ppm (Table 1), which is the best indication of crop yield response and P uptake under different situations (Tekalign Mamo and Haque, 1991).Thus, despite the use of the recommended P extraction method, the available P of the test soil was below critical level for potato production.

Table 1. Physico-chemical characteristics of Nitisols of experimental site before any nutrient application.

pH	EC	Sand (%)	Silt (%)	Clay (%)	CEC	Bas.S	T.N (%).	O.C (%)	Phosphorus (ppm)		Av.K (ppm)
									Av.P	T.P	
4.55	0.02	40	26	34	22.6	35	0.154	1.74	7.48	1740	105

EC= electric conductivity, CEC= cation exchange capacity, Bas.S = base saturation,
T.N = total nitrogen, O.C = organic carbon, Av.P = available phosphorus,
T.P = total phosphorus, Av.K = available potassium; ppm= parts per million

Dry matter

Highly significant (P<0.01) differences were noted with respect to haulm and tuber dry matter between the two potato varieties. Menagesha produced 77% and 80% higher haulm and tuber dry matter, respectively, over Tolcha (Table 2). The superior performance of Menagesha as compared to Tolcha is attributed to its vigorous vegetative growth and longer foliage duration as evidenced by higher values of plant height, stem number and days to maturity (Table 2), conducive to higher dry matter accumulation.

Table 2. Mean dry matter (kg ha^{-1}) and some other agronomic parameters of potato as influenced by the main effects of nitrogen, phosphorus and variety

Source of variation	PH (cm)	SN	DM	HDM	TDM
Variety					
Tolcha	30.71	4.30	104.11	703.06	3202.634
Menagesha	55.28	5.13	111.36	1265.47	5445.88
LSD (0.05)	5.11	NS	1.35	106.30	1079.00
N (kg ha-$^{-1}$)					
0	37.28	4.17	106.83	716.50	2774.54
69	42.93	5.00	106.88	912.51	4744.62
138	48.79	4.98	109.50	1323.78	5453.61
LSD (0.05)	2.75	0.69	2.27	49.65	851.5
P (kg ha^{-1})					
0	41.03	4.66	108.94	892.43	4312.52
69	40.97	4.27	107.11	980.78	4441.62
138	44.79	5.07	106.67	972.23	4331.44
207	45.20	4.87	108.22	1091.60	4229.46
LSD (0.05)	3.17	ns	ns	57.33	ns

PH=plant height in cm; SN=stem number per plant; DM= days to maturity; HDM=haulm dry matter; TDM=tuber dry matter; ns=not significant

Such condition probably arises from differences in genotypic potential (Saluzzo et al., 1999) that could be manifested in variations in root physiology and development and the plant's ability to translocate and utilise the given nutrient (Epstein and Jefferies, 1964). Burton (1966) further reported that dry matter production of early maturing cultivars is usually lower than that of late maturing ones. This could explain the behaviour of Menagesha as it was found to be late maturing (Table 2).

The applied N significantly ($P<0.01$) increased haulm and tuber dry matter contents (Table 2). Increasing N levels from 0 to 138 kg N ha^{-1} significantly increased haulm dry matter production on an average by 85%. Similar findings on N fertilization increasing dry matter accumulation in the canopy was reported by various workers (Yibekal Alemayehu, 1998; Saluzzo et.al., 1999). This is probably due to increase in new leaf formation and extended activity of older leaves due to high N levels. Tuber dry matter also increased in response to applied N levels (which increased by 97% when N level increased from 0 to 138 kg ha^{-1}) (Table 2). Simple regression analysis indicated that applied N contributed by 51% to the variation in tuber dry matter (Table not shown). This implied that the soil of the test site was inherently poor in N status to support good crop growth and hence external supply of in-organic N fertilizer perhaps is required to boost plant growth and crop production. Soil analysis corroborates low organic carbon and total nitrogen contents of the soil (Table 6). Talley (1983) reported that dry matter yields and total N percentages of potato tubers increased with increasing rates of N fertilizer for potato plants. High dry matter yield of potato tuber obtained by increasing nitrogen, phosphorus and potassium application rates have been reported by Eppendorfer et al. (1979).

The main effect of applied P in this experiment, however, was non-significant ($P>0.05$) with respect to haulm and tuber dry matter (Table 2), which is against the findings of Yibekal Alemayehu (1998) and Saluzzo et al. (1999). It may be largely attributed to the possible behaviour of native and applied P under the influence of acidic (4.6) soil reaction of the test location (Table 5) with regard to P availability to crop needs. Archer (1988) and Foy (1992) reported that at soil pH below 5.5, plant growth is likely to be inhibited by one or more of the acidic soil infertility factors. The emphasis on use of P arises due to the fact that its concentration in many soils appeared very low and the possibilities of different chemical reactions rendering it unavailable to plants (Tisdale et al., 1995). It is, hence, of prime importance to improve P use efficiency of acid soils through use of organic amendments like farmyard manure and compost as well by applying lime. Such an approach also appears to be significant from the point of view of interaction in terms of crop growth and yield when inadequate supply of one nutrient prevents the crop from making full use of others (FAO, 1979).

The variety and N interaction effect manifested significant ($P<0.01$) influence on haulm and tuber dry matter (Table 3). However, the variety x P, N x P and variety x N x P interactions were non-significant (Table 4). Significantly higher tuber dry matter was recorded in Menagesha at 69 kg N ha^{-1} as compared to no N application. However, the levels 69 and 138 kg N ha^{-1} were statistically at par while 0 to 138 kg N ha^{-1} gave linear increase in tuber dry matter in Tolcha. In view of this, 69 kg N ha^{-1} appears critical for tuber dry matter production in Menagesha (Table 3). Nevertheless, high N level applied (138 kg N ha^{-1}) favoured higher haulm dry matter at the expense of partitioning of dry matter to tubers in Menagessha in contrast to the trends in Tolcha (Table 3), probably due to varietal differences in dry matter production, accumulation, and partitioning among different organs (Eppenderfer et al., 1979; Saluzzo et al., 1999). This emphasises the need for developing separate N recommendations for each variety based on behaviour of growth morphology and tuber dry matter production aspects.

Table 3. Mean haulm and tuber dry matter (kg ha^{-1}) as influenced by variety and nitrogen interaction in potato.

	HDM			TDM		
N (kg a^{-1})	Tolcha	Menagesha	Mean	Tolcha	Menagesha	
0	494.18	938.82	716.50	2122.00	3429.00	2775.50
69	713.77	1111.25	912.51	3190.00	6294.00	4742.00
138	901.22	1746.34	1323.78	4290.00	7552.00	5921.00
LSD (0.05)			200.10			2132.00

HDM=haulm dry matter and TDM=tuber dry matter

The haulm dry matter was positively and significantly correlated with tuber dry matter ($r=0.79^{xx}$) (Table 5). This implied that tuber yield increments resulted from higher haulm dry matter production under the influence of N levels facilitating higher interception of more photo-synthetically active radiation, efficient radiation use, more dry matter accumulation and partitioning to tubers (Saluzzo et al., 1999). This is corroborated by the fact that tuber dry matter production was also significantly associated with N uptake (Table 6).

Nutrient uptake

Highly significant differences (P<0.01) between the two potato varieties with respect of haulm and tuber nutrient uptake were noted (Tables 4 and 5). Menagesha was superior to Tolcha by 80, 20 and 14% in haulm uptake of N, P and K, respectively (Table 5). Tuber uptake of N, P and K in Menagsha was also superior to Tolcha by 70, 71 and 70%, respectively (Table 5). The high nutrient uptake by Menagesha could be attributed to its higher dry matter production contributed by higher nutrient uptake by the plant tissue leading to increased metabolic activities.

Table 4. Variance ratio of haulm and tuber dry matter, nutrient uptake as influenced by variety, nitrogen and phosphorus and their interactions in potato varieties, Menagesha and Tolcha

	Sources of variation						
Characters	V (1)	N (2)	P (3)	VxN (2)	VxP (3)	NxP (6)	VxNxP (44)
HDM	518.14^{**}	38.96^{**}	2.04^{ns}	6.13^{**}	1.33^{ns}	0.61^{ns}	1.04^{ns}
TDM	79.99^{**}	21.59^{**}	0.06^{ns}	8.30^{**}	0.84^{ns}	0.19^{ns}	1.41^{ns}
HNUP	391.32^{**}	29.80^{**}	1.34^{ns}	5.21^{**}	1.20^{ns}	0.61^{ns}	0.98^{ns}
HPUP	42.31^{*}	7.47^{**}	1.75^{ns}	4.33^{*}	3.56^{**}	1.76^{ns}	1.29^{ns}
HKUP	0.44^{ns}	10.43^{***}	3.09^{*}	1.99^{ns}	4.36^{**}	3.29^{**}	4.34^{***}
TNUP	78.65^{**}	18.66^{***}	0.15^{ns}	2.05^{ns}	0.83^{ns}	0.20^{ns}	1.37^{ns}
TPUP	101.59^{**}	1257^{***}	052^{ns}	2.16^{ns}	0.91^{ns}	0.19^{ns}	1.33^{ns}
TKUP	76.77^{*}	18.69^{***}	0.35^{ns}	2.32^{ns}	0.783^{ns}	0.23^{ns}	1.36^{ns}

*, **, *** = Statistically significant at 5%, 1% and 0.1%, respectively, ns = non-significant at all levels.V = variety; N = nitrogen, P = phosphorus; HDM = haulm dry matter; TDM = tuber dry matter; HNUP= haulm nitrogen uptake; HPUP=haulm phosphorus uptake; HKUP=haulm potassium uptake; TNUP=tuber nitrogen uptake; TPUP=tuber phosphorus uptake and TKUP=tuber potassium uptake. Numbers in the parenthesis represented degrees of freedom

Total P uptake was low (12.3 kg ha^{-1}); perhaps this is attributable to the acidic nature of the soils (Table 5). However, despite this aspect and low P availability, Menagesha turned out to be efficient in P uptake and utilisation as compared to Tolcha. A phosphorus efficient plant is reported to have high P uptake and transport into the leaves (Föhse et al., 1988), and a total high yield in spite of low content of plant available P in the soil (Abdou, 1986). This could be the reason for vigorous vegetative growth and high dry matter production in Menagesha as compared to Tolcha (Tables 2 and 3). Nutrient uptake in plant is the function of nutrient concentration and dry matter weight (Guoping et al., 1999).

Table 5. Haulm and tuber N, P and K uptake (kg ha^{-1}) as influenced by the main effects of nitrogen, phosphorus and variety

	Haulm			Tuber		
Variety	N	P	K	N	P	K
Tolcha	14.61	1.58	9.81	34.69	5.12	60.50
Menagesha	26.25	1.90	11.21	58.96	10.36	107.04
LSD (0.05)	2.53	0.60	ns	11.77	1.59	20.74
N (kg ha^{-1})						
0	15.68	1.51	7.16	31.35	5.55	54.38
69	18.95	1.78	7.99	50.75	8.06	88.68
138	26.67	2.12	16.34	58.39	7.70	101.84
LSD (0.05)	2.95	0.32	4.49	9.20	1.38	15.84
P (kg ha^{-1})						
0	18.81	1.70	15.29	47.13	7.34	93.22
69	20.21	1.84	8.45	47.91	8.10	83.83
138	20.52	1.64	9.19	47.95	7.33	81.97
207	22.18	2.23	9.10	44.33	7.17	86.99
LSD (0.05)	ns	ns	5.19	ns	ns	ns

Nutrient uptake of haulm and tuber was significantly ($P<0.01$) enhanced due to N applications (Tables 4 and 5). Tuber N uptake increased from 31.4 kg ha^{-1} to 58.4 kg ha^{1} (86.3%) with an increase in N levels from 0 to 138 kg ha^{-1} (Table 5). This indicated a possibility for improving the soil N status and thereby potato yield through inorganic N fertilizer applications as the organic carbon and total nitrogen levels of the experimental site were low (Table 1). In many soils of Ethiopia, a significant fraction (98%) of the nutrient store, particularly nitrogen, is contained in the soil organic matter (Yeshanew Ashagarie et al., 1999).

Total P uptake, on the contrary, was observed to be low by 11% despite increase of P levels from 0 to 207 kg ha^{-1} (Table 5) probably arising from the fixation of freshly applied P fertilizer due to soil acidity. The higher dry matter production of Menagesha, under low available P could be explained in terms of its higher relative nutrient use efficiency over Tolcha. Genotypic variation for nitrogen (Sauerbeck and Helal, 1990) and phosphorus use efficiency (Yohannes

Uloro and Richter, 1999) have been well documented. Therefore, use of amendments like farmyard manure and compost (organic manure), and liming to improve the efficiency of P fertilizer use needs due consideration at the test site. Variety x N and variety x P interactions revealed significant ($P<0.01$) effect on haulm N and P uptake, respectively (Table 4). On the contrary, variety x N, variety x P, N x P and variety x N x P interaction effects were non-significant in respect of tuber N, P and K uptake (Table 4). This indicates that each variety has different haulm N and P uptake potential, whereas tuber N, P and K uptake of both varieties were similar.

Table 6. Simple correlation of haulm and tuber dry matter, some potato agronomic parameters, available phosphorus, and N and P uptake in potato varieties Menagesha and Tolcha.

Characters	PH	HDM	TDM	DF	DM	SG	SN	Av. P	NUP	PUP	AN
PH	1										
HDM	0.93^{**}	1									
TDM	0.75^{**}	0.79^{**}	1								
DF	0.65^{*}	0.65^{**}	0.62	1							
DM	-0.53	-0.40	-0.63	0.15	1						
SN	0.72^{**}	0.56	0.03	0.02	0.27		1				
Av. P	0.53^{*}	-0.46^{*}	0.21^{ns}	0.34^{ns}	0.25^{ns}	-0.22^{ns}	-0.06^{ns}	1			
NUP	0.77^{***}	0.99^{***}	0.99^{**}	0.33^{**}	0.45^{**}	0.41^{ns}	0.17^{ns}	0.15^{ns}	1		
PUP	0.79^{***}	0.98^{***}	0.11^{ns}	0.38^{***}	0.29^{ns}	0.43^{ns}	0.19^{ns}	0.67^{**}	0.45^{*}	1	
AN	0.33^{**}	0.55^{***}	0.71^{**}	0.22^{ns}	-0.25^{ns}	0.35^{ns}	0.19^{ns}	-0.19^{ns}	0.75^{**}	0.17^{ns}	1

PH =plant height; HDM =haulm dry matter; TDM=tuber dry matter; DF=days to flowering; DM=days to maturity; SN=stem number; Av.P=available phosphorus; NUP=nitrogen uptake; PUP=phosphorus up take and AN=applied nitrogen.

CONCLUSION

Fertilizer use improves establishment and early ground cover of potato, which consequently reduces the hazards of erosion. This study underlines that potato needs external supply of N fertilizers for high yield and good quality tuber production through its optimum uptake. Tangible differences were recognised in respect of dry matter and nutrient uptake between the two potato varieties. The variety Menagesha produced higher tuber dry matter, correspondingly its nutrient uptake was higher. Accordingly, application of 69 kg N $ha^{-1}$was critical for

Menagesha. This suggested the possibility of selecting high yielding and efficient nutrient utilizing genotypes for a profitable and viable potato production. On the contrary, potato was none responsive to the applied P, owing to the acid nature of the soils limiting P availability. Despite this, the use of P becomes imperative, as its concentration was very low at the test site. Hence, future research direction should articulate towards systematic investigation including use of amendments and liming in order to improve the efficiency of phosphate fertilizers. To summarise, in a strategy of maximizing potato yields by via fertilizers use, knowledge of the inherent nutrient status and nature of nutrient release by the soils, and the nutrient uptake potential of the crop should receive adequate consideration in view of the present escalating fertilizers cost especially in western Ethiopia.

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