ORIGINAL ARTICLES

Effect of Blended Fertilizers on Potato (*Solanum tubersum* L.) Agronomic Performance and Tuber Yield at Kokate Sodo Zuria District, Southern Ethiopia

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ABSTRACT

Potato (*Solanum tubersum*L.) is one of the most important cash and food security crop in Ethiopia. Its production is limited by low soil fertility, lack of quality seeds and diseases. To this effect, field experiment was conducted to evaluate the effect of different blended fertilizer formulas on potato agronomic performance and tuber yield at Kokate Research Station (KRS) and on farmer's field (OnF) in SodoZuria district of southern Ethiopia. The experiment consists of seven treatments: control (no fertilizers), N-P (110-40), N-P-K (110-40-100), N-P-S (110-40-17), N-P-S-B (110-40-17-1), N-P-S-B-Cu (110-40-17-1-1), and N-P-K-S-B-Cu (110-40-100-17-1-1) in kg ha^{-1}. The experiment was set in randomized complete block design with three replications. Potato growth parameter (main stem number and plant height), tuber yield components and tuber yield were superior on OnF to KRS. Tuber number, average tuber weight and tuber size categories significantly ($p<0.05$) influenced by fertilizer application. The NPK fertilizer application improved marketable tuber yield by 50.5% at KRS and by 82% at OnF, as compared to the control. However, the K content of the study soils was high to very high. Thus, balanced NPK fertilizer application resulted in higher nutrient use efficiency, higher marginal rate of return (MRR) and higher net benefit as compared to other blended fertilizers and the control. Therefore, based on the results N-P-K (110 N – 92 P_2O_5 - 100 K_2O) fertilizer application could be recommended for potato production in KokateSodoZuria district, southern Ethiopia.

Keywords: Balanced NPK, food security crop, MRR, marketable tuber yield, nutrient use efficiency

declining of soil fertility and low use of improved technologies (Wakene et al., 2012). Soil degradation in the form of nutrient depletion is an important cause for the decline of agricultural production in the country (Bekele and Holden, 1998). It is important to note that fertilizer use is the core strategy to overcome soil fertility depletion through nutrient mining and the crop productivity decline (Rahman et al., 2014).

Assessment of the nutrient requirement of different crops for desired yield levels in cropping systems is the first step in developing sound fertilizer management practices (Mollah and Sarkar, 2011). Up-to-date and spatially explicit information about the soil condition and status of soil fertility in many parts of Ethiopia showed that N and P were not the only yield determining factors, but K, S, Zn, B, Fe and Cu deficiency are also common in many soils of the country (ATA, 2016).

Therefore, there is a need for a comprehensive and critical study of the fertilizer types and rates required for profitable crop production in different agro-ecologies of Ethiopia (Tamene et al., 2017).

Potato (*Solanum tubersum L.*) is the 4th most important crop among the staple food crops and more than 320 million tons of potatoes are being cultivated annually on 20 million hectares worldwide (FAO, 2009). It is one of the most common crops grown once or twice within a year during *Belg* and/or *Mehare* seasons in Ethiopia. In Ethiopia, a *Meher*season potato production estimated to be 66,923.33 ha, producing 921, 403tones tube yield with an average yield of 13.8-ton ha^{-1} (CSA, 2016/17). Even though potatoes more tolerant to low pH than most other crops and grow well on a wide variety of soils ideal soil for potato growing is deep, well-drained and friable soils (DAFF, 2013). Wolaita Zone contributes 1,277.21 ha in land coverage, and 24,190.7tons of tuber yield, crop that has great contribution to food security and cash income for farm households in Ethiopia. Potato bulks higher tuber yield in shorter time. It requires higher nutrients since it has shallow root systems and shorter growing season (Mihovilovich et al., 2014). Balanced application of mineral fertilizer reported to maximize potato yields and reduce N and P losses to the environment (Melkamu, 2010). In contrast, chemical fertilizers specifically DAP and Urea has been used for major crops production including potato over several decades in Ethiopia. Taking into account this gap, the Ethiopia Soil Information System (EthioSIS) suggested the general improvement of fertility management system by considering inclusion of more secondary macro and micro nutrients in the fertilizer program (ATA, 2016). For instance, the EthioSIS suggested some blended fertilizers such as NPS, NPSB, NPSBCu, NPSCu, NPSZnBCu and K fertilizers for crop production in Wolaita Zone (ATA, 2016). However, specific blended fertilizers type and rate for potato production in SodoZuria district of Kokate area of Wolaita Zone was not well identified and recommended. Therefore, the present experiment was conducted to assess and evaluate the effects of blended fertilizers for sustainable and profitable potato production in Kokate area of SodoZuria, southern Ethiopia.

MATERIALS AND METHODS

Description of the Study Area

The current study was conducted at Kokate kebele, SodoZuria district, WolaitaZoneof southern Ethiopia during *Belg* potato growing season under rain fed in 2017. The experimental field is located at 2138 *m.a.s.l.*, 06°83′ N and 37°60′ E for the farmer field, and at 2150 *m.a.s.l.*, 06°52′ N and 37°48′E for Kokate Sub-research Station of Areka Research Center. SodoZuria district has topography of the area. Most of the district's land coverage (95%) is midland and the remaining 5% is highland, excluding the area of mountain *Damota* that experience colder climate. Soils of Wolaita zone area are mainly *EutricNitisols* associated with *HumicNitisols* (Beshah, 2003). The annual rainfall ranges between 1200-1300 mm and the daily mean temperature ranges between 18°C - 28°C. The rainfall is bi-modal type: the main rainy season '*Kremt*' rain occurs in the months of June, July and August and the short rainy season the '*Belg*' rain occurs from mid-February to mid-May (Tona, 2014). The study area categorized under moist midland agro-ecological zone; which is within the preferable ecological range for potato production.

Soil sampling and preparation

Before planting 15 surface soil samples (0-20 cm) collected randomly per site by traversing in a zigzag pattern to obtain homogenous samples. Then the soil samples bulked into composite for each site. Core sampler was used for sampling soils for soil bulk density determination.At harvest, random soil samples collected on treatment (plot) base and a composite made per treatment. The collected soil samples were air-dried on wooden trays and then ground with a pestle and mortar, passed through 2-mm sieve (George et al., 2013). For determinations of OC and total N, 0.5 mm sieve used and the analysis carried following the standard laboratory procedures.

Laboratory analysis of soil samples

The pre-planting soil samples analyzed to determine soil bulk density, texture, pH (H_2O), OCpercentage, total Npercentage, CEC, available P, K, S, B, and Cu nutrients (Table 1). After harvesting soil pH, CEC, OC, total N, available P, and K, were also determined following their respective

Experimental Treatments and Design

The experiment consisted of seven treatments: control (no fertilizers), recommended N-P (110-40), N-P-K (110-40-100), N-P-S (110-40-17), N-P-S-B (110-40-17-1), N-P-S-B-Cu (110-40-17-1-1), and N-P-K-S-B-Cu (110-40-100-17-1-1) all are applied in kg ha^{-1}. The fertilizers sources used were TSP (Triple super phosphate) for P; NPS for N, P and S; KCl (Potassium chloride) for K (potassium); $CuSO_4.5H_2O$ (copper sulfate pent hydrate) for Cu and borax for B fertilizer and urea for the remaining N source. A test crop used was potato variety '*Gudane*' that was released by Holeta Agricultural Research Center (HARC) in 2006 for areas between 1600-2800 *m.a.s.l*(Habtamu and Mohamed, 2016). Potato seed tubers of 45-85g healthy, and well sprouted were used for the study. The treatments laid out in randomized complete block design (RCBD) with three replications at both testing sites (Kokate Research Station and On Farm). An experimental plot area was 10.5 squaremeters (3 m length x 3.5 m width) with a total of five rows and 10 potato plants per plot. The planting space was 30 and 75 cm between plants and rows respectively.

Bulk density	Core sampling	Core sampler, Balance & Oven
Texture	Bouyoucos	Hydrometer
pH	1:2.5 (soil: water)	pH meter
CEC (cmol)	Ammonium acetate	Distillation & titration
OC (%)	Walkley& Black	Titration
TN (%)	Kedjelhal	Digestion, distillation and titration
P (mg kg^{-1})	Olsen et al.	Spectrophotometer
K (mg kg^{-1})	Morgan	Flam photometer
B (mg kg^{-1})	Hot water (HW)	Azometric
S (mg kg^{-1})	KH_2PO_3 (Turbimetric)	Spectrophotometer
Cu (mg kg^{-1})	DTPA Extr.	FAAS (Filtrate in Atomic Absorption Spectrophotometer)

Key: Bd=Bulk density, CEC= Cation Exchange Capacity, TN=Total Nitrogen, P=Phosphorous, K=Potassium, B=Boron, S= Sulfur and Cu =Copper.

Agronomic Practices

Fine seedbed was prepared using oxen plow for both study sites, Kokate Research Station and on farmer's field. Whole dose of P, K, S, and half of N fertilizerapplied during planting, while the remaining halfof N applied at 35days after planting.Boron and copper fertilizers were foliar applied at tuber initiation stageusing small hand spryer. All agronomic management practices carried out as per recommendation for potato production (Girma et al., 2005).

Plant data collection

Common potato growth and yield parameters considered in this experiment include plant height, number of stems per plant, number of tubers per hill, tuber weight per plant, tuber yield per treatment (plot) (<25, 25-50, 50-75 and >75g tuber size categories), marketable, un-marketable tuber yield per plot and total yield per hectare. Number of plants per hill and number of tubers per plant were recorded; by counting from the inner three rows. Tuber yields measured using portable digital measuring balance from each

defects considered as unmarketable (Fahmyet al., 2008.

Agronomic nutrient use efficiency in potato

The NUE is based on uptake efficiency (acquire from soil) and uptakeis related to the amounts of the nutrient applied or present in soil. Agronomic efficiency (AE) expressed as the additional amount of economic yield per unit nutrient applied (Fageria et al., 2001). Agronomic nutrient use efficiency is the basis for economic and environmental efficiency; as agronomic efficiency improves, economic and environmental efficiency will benefit (Roberts, 2008).

Agronomic efficiency (AE) =

$$= \frac{YF\ (kg) - YC\ (kg)}{\text{Quantity of nutrient applied (Fa) (kg/ha)}} \quad \text{------- (Equation-1)}$$

Where: YF = Yield obtained from fertilized plot (kg ha^{-1}), YC = Yield obtained from nonfertilized (kg ha^{-1}) .

Economic analysis

Partial budget analysis evaluates the

price per100 kg of potato tubers at harvesting in Ethiopian Birr considered for the analysis as suggested by Eicher et al. (1988). All costs and benefits calculated on hectare basis in Ethiopian birr (ETB) 600ETB Qt^{-1}). To make a rational choice of alternative blended fertilizers based on their economic benefit the partial budget and marginal rate of return (MRR) were analyzed for potato production (CIMMYT, 1988).

MRR (%) = (NB/ TVC) *100 ---(Equation-2)

where: NB= Net benefit and TVC =Total variable cost.

Statistical analysis

Growth, yield and yield component parameters subjected to analysis of variance (ANOVA) using SAS software (version 9.0). ANOVA was conducted at individual site and variances of the two locations computed independently. Generalized Liner Model (GLM) procedure employed to detect variation among treatments. Mean separation ofsignificant treatments performed using the leastsignificant difference (LSD) test at 5% probability level (SAS Institute Inc, 2002).

RESULTS AND DISCUSSION

Physicochemical properties of the experimental soils before planting and after harvesting

Pre-experimental soil analysis result indicated that soils in the study area dominated by clayey soil fraction with moderately compacted bulk density for agriculture use. The soils have properties of strong and medium acidity (pH-H_2O); low and medium CEC; high and very high K at Kokate Research Station and on farmer field, respectively. Both testing sites showed medium OC, TN, and available P, high B and Cu, and very low in S concentrations suggesting limitation of those nutrients for

After crop harvesting the experimental plots showed slight variations in soil chemical properties as expected. In both testing sites, the soil analysis results indicated a slight variationin soil pH, OC, CEC, TN, P and K concentration in all treatments (Table 2); implying that the application of balance fertilizers slightly affected properties of soil in the study area. Experimental plots which received NPK, NPS and NPSB showed higher CEC, and produced higher potato yields implying that nutrient availability was improved due to fertilizer application. NPS treated plot were higher in CEC and TN; but the available P level was lowerin both experimental soils. This might be due high P fixation at lower soil pH experimental soils (Jones, 2003).

Plant growth and yield components as affected by blended fertilizers

The analysis of variance revealed that there were significant ($P<0.05$) differences among the blended fertilizers tested in influencing potato growth parameters: main stem number (MSN) $hill^{-1}$, plant height (PH), tuber number (TN) $hill^{-1}$ and average tuber weight (ATW) in both study sites, KRS and OnF (Table 3).

Blended fertilizer application improved most of the growth parameters as compared to the control. Increased yields come from achieving the optimum tuber numbers, maintaining a green leaf canopy, and increasing tuber size and weight (https://www.yara.co.uk/crop-nutrition/potato/increasing-potato-yield/). In most of the cases the highest main stem number (MSN) $hill^{-1}$, plant height (PH), tuber number (TN) $hill^{-1}$ and average tuber weight (ATW) recorded in treatments receiving NPK fertilizers at both KRS and OnF sites. Average tuber number (TN) $hill^{-1}$ was increased by 49.8% and 74.5% in KRS and OnF, respectively while average tuber weight (ATW) was increased by 75.8% and ed soil physicochemical properties of the experimental sites before planting and after harvesting at Kokate Research Station and o

Physicochemical properties of experimental soils before potato planting									
Bulk density	Soil texture	pH 1:2.5 (soil: H_2O)	OC (%)	CEC (cmol kg^{-1})	TN (%)	Available nutrients (mg kg^{-1})			
						P	K	S	B
1.25	Clay	5.23	2.34	20	0.2	9.6	166.5	1.82	0.99
1.20	Clay	5.92	2.38	16	0.21	9.10	134.5	7.98	0.66
M	Clay	SA/MA	M	M	M	M	VH/H	VL/L	H

nical properties of experimental soils after harvesting as affected by blended fertilizer treatment

	ontrol	rNP		NPK		NPS		NPSB		NPSBCu		NPKSBCu		Ratin (categ
	OnF	KRS	OnF	KRS	OnF	KRS	OnF	KRS	OnF	KRS	OnF	KRS	OnF	KRS
	6.04	5.21	6.2	5.30	6.03	5.42	5.78	5.22	5.96	5.20	5.93	5.26	5.6	SA
	2.15	3.71	1.95	3.12	1.37	1.76	1.37	1.76	1.95	1.95	1.95	1.37	1.56	M
	10.6	11.2	16.4	23	14.4	23	16.8	15	22	11.2	13	17	8.2	M
	0.17	0.14	0.15	0.21	0.18	0.17	0.24	0.14	0.15	0.15	0.17	0.20	0.18	M
	8.41	9.10	8.47	12.3	8.68	6.41	5.89	12.7	6.89	9.46	10.15	13.7	9.31	M
5	168	210.5	209	192.5	190	254.5	179	214.75	239.25	181.5	173	215.5	199.75	VH

carbon, CEC =Cation exchange capacity, Av=Available, SA=Strongly acidic, MA=Medium in acidity, M=medium, H=high, VH=v
L=Low, P=phosphorous, TN=Total nitrogen, K=Potassium, S=sulfur, B=Boron and Cu= Copper and the measuring units of pH, O
AvK before and after harvesting were similar.

It is worth mentioning that in most of the cases the blended fertilizer application was superior in affecting most potato agronomic parameters than recommended N and P application (Table 3). This perhaps suggests that the study sites are deficient in K, S, B and Cu, in addition to N and P. Nevertheless, the contributions of S, B and Cu in influencing potato growth parameters appeared to be low as compared to K, suggesting potassium is very crucial nutrient for influencing sustainable potato production in Wolaita area. Similar potassium fertilizer experiment conducted in Northern Ethiopia showed significant influences of K on potato growth parameters stem number plant^{-1}, tuber diameter and average tuber weight (Niguse et al., 2016). The present finding is in line with many reports (Wassie, 2009; Wassie and Tekalign, 2013; Shiferaw, 2014). The current finding strongly agrees with the work of Singh and Lal (2012), which showed N and K application significantly, affected potato growth, and yield attributes. Similarly, Egataet al. (2017) reported similar finding that the application of potassium and nitrogen was highly significant in affecting the marketable tuber number and plant height.

Table 3. Effects of blended fertilizers on potato growth and yield components at Kokate Research station and on farmer field (KRS and OnF)

Treatments ($N-P_2O_5-K_2O-S-B-Cu$) (kg ha^{-1})	Main stem number hill^{-1}		Plant height (cm)		Tuber number hill^{-1}		Average tuber weight (kg hill^{-1})	
	KRS	OnF	KRS	OnF	KRS	OnF	KRS	OnF
Control (0)	6.2b	6.7ab	60.3c	63.67b	11.33c	8.67b	0.62c	0.70b
110-92-0-0-0-0	8.9ab	4.7b	76.2ab	73.45ab	13.40bc	11.20ab	0.83b	0.99ab
110-92-100-0-0-0	9.2ab	8.7ab	82.7a	80.670a	16.93a	15.13a	1.09a	1.23a
110-92-0-17-0-0	9.3ab	5.3ab	75.1ab	74.89ab	15.60ab	12.93ab	0.86b	0.91ab
110-92-0-17-1-0	8.4ab	10.0a	72.9ab	74.67ab	13.67bc	12.40ab	0.80b	1.02ab
110-92-0-17-1-1	7.2ab	6.0ab	68.3bc	70.56ab	12.40c	9.40b	0.82b	0.80b
110-92-100-17-1-1	10.5a	6.3ab	78.2ab	72.89ab	12.87bc	11.80ab	0.76bc	0.90b
Mean	8.5	6.8	73.4	72.97	13.74	11.65	0.83	0.93
CV (%)	27.8	38.9	8.2	10.85	11.89	22.85	10.81	19.70
LSD (5%)	4.23	4.71	10.77	14.01	2.91	4.73	0.16	0.34

Means with the same letter are not significantly different. KS= Kokate station, OnF= on farmer field, CV= coefficient of variance and LSD= list significant difference

Potato tuber yield size categories as affected by blended fertilizers

Analyses of variance revealed that potato tuber size categories were significantly ($p<0.05$) affected by fertilizer application (Table 4). The results showed that the application of NPK fertilizer showed significant difference on tuber yield category <25 g as compared with control and recommended NP fertilizer at KRS. The highest tuber yield category >75g was recorded by the application of NPK fertilizer in both testing sites. Generally, tuber size categories (<25 g and 25-50 g, ton ha^{-1}), were higher at KRS than OnF. On the other hand, tuber size category >75 g (ton ha^{-1}), and total tuber weight were higher at OnF than KRS; suggesting that farmer field was superior in terms of soil fertility than KRS (Table 4). From the results, it is evident that NPK largely affected potato tuber quality including marketable size through influencing tuber size categories.

Table 4. Tuber yield size categories of potato as affected by fertilizer in KRS and OnF

No	Treatments ($N-P_2O_5-K_2O-S-B-Cu$) (kg ha^{-1})	<25gm (ton ha^{-1})		25-50 gm (ton ha^{-1})		50-75gm (ton ha^{-1})		>75gm (ton ha^{-1})	
		KRS	OnF	KRS	OnF	KRS	OnF	KRS	OnF
1	Control (0)	1.5bc	1.4a	8.3b	5.2ab	12.1	7.9b	12.5b	23.7b
2	110-92-0-0-0-0	1.2c	1.1ab	10.2b	6.3ab	14.4	11.1ab	21.7a	33.9ab
3	110-92-100-0-0-0	3.1a	0.9b	11.9a	7.0a	13.5	11.1ab	24.20a	49.0a
4	110-92-0-17-0-0	1.9abc	1.2ab	13.4a	4.2b	12.8	8.4b	19.2ab	34.9ab
5	110-92-0-17-1-0	2.5ab	1.3ab	12.1a	5.9ab	12.2	12.9ab	19.8ab	39.3ab
6	110-92-0-17-1-1	2.6ab	1.1ab	10.2ab	5.6ab	11.9	15.5a	16.4ab	35.8ab
7	110-92-100-17-1-1	3.0a	1.4a	12.4a	6.0ab	16.4	13.5ab	18.1ab	29.8b
	Mean	2.3	1.2	11.2	5.7	13.3	11.3	18.8	35.2
	CV (%)	29.7	20.4	17.0	25.8	20.8	34.4	24.9	26.2
	LSD (P<0.05)	1.2	0.4	3.4	2.6	NS	6.9	8.4	16.4

Means with the same letter are not significantly different. KRS= Kokate research station, OnF= on farmer field, CV= coefficient of variance and LSD= List significant difference, NS= Non-significant

Total, marketable and un-marketable tuber yields as affected by blended fertilizers

The marketable, total and unmarketable tuber yield showed significant ($p<0.05$) differences among the fertilizer types and rates tested (Table 5).The highest marketable tuber yield of 49.6 and 67.1-tonha^{-1}, which were higher by 50.5% and 82% in NPK, applied plot than in control at KRS and OnF, respectively. The comparison of NPK with other blended fertilizers showed an improvement of 8.5% over NPKSBCu and 33% over NPSBCu at KRS. The comparison between different blended fertilizers with each other showed that the highest (53%) marketable tuber yield advantages over NPS with application of NPK fertilizer at OnF. The highest total tuber yield of 52.6 ton ha^{-1}and 68ton ha^{-1} were recorded by the application of NPK (110-92 P_2O_5-100 K_2O) at KRS and OnF respectively. Total potato tuber yield was higher by 56% and 78% yield advantage as compared with control (34 ton and 38ton ha^{-1}) at KRS and OnF respectively (Table 5). Similar to this , the highest biological and economic yield was obtained at K level of 100 kg ha^{-1} K_2O at Atsbi-Wenberta, Tigray Region of Ethiopia (Niguse et al., 2016). Application of S, B and Cu, with NP and NPK in the form of blended fertilizer did not show significant ($P<0.05$) effects on potato yield and yield components. This could be due to low applied S content into the soil and high B and Cu concentrations in soil pool for potato production and/or the toxicity of foliar applied B and Cu fertilizers. This finding is consistent with the work of Wassie and Shiferaw (2011), that the highest potato tuber yield (53-ton ha^{-1}) was recorded due to NPK application to acid soil of Chencha, southern Ethiopia. Higher marketable and total tuber yields were obtained at OnF than at KRS; suggesting that the OnF was superior in terms of soil fertility than KRS. Higher marketable and total tuber yield recorded on farmer field than research station, but higher un-marketable tuber yield obtained on station which is attributable due to low pH (strong soil acidity) and more soil compaction on Kokate station than OnF (Table 2 and 5).

Table 5. Total, marketable and un-marketable tuber yields (t ha^{-1}) in both testing sites

No	$N-P_2O_5-K_2O$-S-B-Cu (Kg ha^{-1})	Marketable (t ha^{-1})		Un-marketable (t ha^{-1})		Total (t ha^{-1})	
		KRS	OnF	KRS	OnF	KRS	OnF
1	Control (0)	32.94c	36.89c	1.52bc	1.37a	33.76c	38.20c
2	110-92-0-0-0-0	46.23ab	50.15abc	1.21c	1.09ab	47.39ab	51.18abc
3	110-92-100-0-0-0	49.57a	67.10a	3.15a	0.87b	52.57a	67.93a
4	110-92-0-17-0-0	45.46ab	47.57bc	1.94abc	1.16ab	47.31ab	48.69bc
5	110-92-0-17-1-0	44.06ab	58.13ab	2.52ab	1.26ab	46.52ab	59.31ab
6	110-92-0-17-1-1	38.56bc	56.87ab	2.61ab	1.08ab	41.04bc	57.90ab
7	110-92-100-17-1-1	46.92ab	49.29bc	3.03a	1.40a	49.81a	50.61abc
	Mean	43.39	52.29	2.28	1.17	45.48	53.40
	CV (%)	10.84	18.89	29.71	20.45	10.07	18.35
	LSD (P<0.05)	8.37	17.57	1.21	0.43	8.15	17.44

Means with the same letter are not significantly different. KRS= Kokate Research station, OnF= on farmer field, CV= coefficient of variance and LSD= list significant difference

Agronomic nutrient use efficiency in potato

The agronomic nutrient use efficiency (AE) of potato showed variation among the fertilizers tested (Table 6). However, the AE of the fertilizers were not consistent in both study locations.For KRS, the highest AE (9.51 kg kg^{-1}) recorded with NP application, whereas for OnF, the highest AE (14.49 kg kg^{-1}) recorded with NPSBCu application. Overall, higher AE recorded at OnF than KRS, suggesting that the OnF soil was more responsive to the fertilizer applied. It is important to note that relatively the highest AE observed in NPSBCu, but yield and yield components response was inversely lower in both testing sites with this treatment. According to Mengel et al. (2006), AE value for a nutrient should not be less than five (5 kg kg^{-1}). In the present study, all AE values were higher than the minimum limit (5 kg kg^{-1}), and that ranges from 6.3 to 9.51 at KRS and 5.83 to 14.5 on farmer field (Table 6). It is essential to note that AE is the basis for economic and environmental efficiency; as agronomic efficiency improves both economic and environmental efficiency (Roberts, 2008). The NPKSBCu and NPK applied treatment showed the highest AE than those non-K consisting treatments at KRS (Table 6). This suggests that the application of K fertilizer improved nutrient use efficiency of potato and tuber yield. This finding is in line with the findings of different authors (Melkamu, 2010; Singh and Lal, 2012).

Economic analysis for potato marketable tuber yield

The net benefit advantage of NPK over rNP, NPS, NPSB, NPSBCu and NPKSBCu was 20, 23, 33, 75, and 22%, respectively at KRS (Table 7). Similarly, the net benefit return by NPK was higher by 59, 67, 29, 41 and 71% over rNP, NPS, NPSB, NPSBCu and NPKSBCu respectively on the farmer field (Table 8). Nevertheless, the highest MRR was 5478 with NPS blended fertilizers applications as compared with other treatments at KRS (Table 7).The current finding agrees with the reports of Wassie and Shiferaw (2011),who reported the highest net benefit attained by K fertilizer applications on acid soils at Chencha, southern Ethiopia.

The net benefit obtained on farmer's field showed consistency with the results obtained at KRS suggesting that the application of NPK fertilizer showed superior net benefit over all other blended fertilizers. The highest MRR 6805 obtained with NPSB blended fertilizers, as compared with other treatments (Table 8). Hence the results of this finding for marginal rate of returns (MRR %) were consistently greater than 100% in both testing sites and thus was in acceptable range for the minimum rate of return (CIMMYT, 1988). Based on net benefit, MRR, tuber yield and AE, we recommend NPK fertilizer for high and good quality potato production for Kokate area and similar agro-ecology.

Table 6. Agronomic nutrient use efficiency of total potato tuber yield at Kokate research station (KRS) and on farmer field (OnF) as affected by blended fertilizers (yield dry weight kg ha^{-1})

Treatments	Fertilizer Amount (kg ha^{-1})	KRS Dry TPTY (kg ha^{-1})	KRS AE (kg kg^{-1})	OnF Dry TPTY (kg ha^{-1})	OnF AE (kg kg^{-1})	Average AE (kg kg^{-1})
Control	0	7779.08		8817.83		
rNP	440	11965.98	9.51	12922.95	9.32	9.51
NPK	607	12616.8	7.9	16303.2	12.33	10.115
NPS	385	10747.26	7.7	11060.75	5.83	6.765
NPSB	386	10660.83	7.47	13542.45	12.34	9.905
NPSBCu	387	10225.8	6.32	14426.75	14.49	10.405
NPKSBCu	554	12759.66	8.99	12669.37	6.95	7.97

TPTY=Total potato tuber yield, AE=Agronomic nutrient use efficiency

Table 7: Net benefit analysis of adjusted marketable tuber yield of potato at Kokate Research Station (yield on fresh weight base)

Treatment	AMTY (Kg ha^{-1})	10%ATY (Kg ha^{-1})	GFB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)
Control	32,940	29,646	177,876	0	177,876	
rNP	46,230	41,607	249,642	5,580	244,062	4373.87
NPK	49,570	44,613	267,678	7,250	260,428	3592.11
NPS	45,460	40,914	245,484	4,401	241,083	5477.91
NPSB	44,060	39,654	237,924	4,546	233,378	5133.70
NPSBCu	38,560	34,704	208,224	9,850	198,374	2013.95
NPKSBCu	46,920	42,228	253,368	11,520	241,848	2099.38

Table 8: Net benefit analysis of adjusted marketable tuber yield of potato on farmer field (yield in fresh weight base)

Treatment	AMTY (Kg ha^{-1})	ATY (Kg ha^{-1})	GFB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	MRR (%)	B:C Ratio
control	36,890	33,201	199,206	0	199,206	--	
rNP	50,150	45,135	270,810	5,580	265,230	4753.23	85.18
NPK	67,100	60,390	362,340	7,250	355,090	4897.79	67.56
NPS	47,570	42,813	256,878	4,401	252,477	5736.81	130.35
NPSB	58,130	52,317	313,902	4,546	309,356	6805.02	149.69
NPSBCu	56,870	51,183	307,098	9,850	297,248	3017.75	30.64
NPKSBCu	49,290	44,361	266,166	11,520	254,646	2210.47	19.19

*Note: AMTY = average marketable tuber yield, ATY = Adjusted Tuber yield, GFB =Gross field benefit, TVC= Total variable cost, MRR= Marginal rate of return, NB= Net benefit

CONCLUSION

Potato growth performance (main stem number and plant height, tuber yield components and tuber yield were significantly ($p<0.05$) influenced by blended fertilizer application over the two study sites (KRS and OnF). Tuber number, average tuber weight and tuber size categories also substantially influenced by fertilizer application. The results revealed that marketable tuber yield increased by 50.5% and 82%, while total tuber yield was increased by 56% and 78% with NPK application as compared to the control at KRS and on the farmer fields, respectively. Particularly, NPK fertilizer application resulted in higher agronomic nutrient use efficiency, higher MRR and higher net benefit as compared to other fertilizers and the control. Therefore, balanced N-P-K (110 N – 92 P_2O_5 - 100 K_2O) fertilizer can be recommended for high tuber yield and good quality potato production in Kokate kebele, SodoZuria district of Wolaita Zone, southern Ethiopia.

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