3. Identifying Major Yield-Limiting Nutrients for Potato (*Solanum tuberosum* L.) **Yield in Major Potato Growing Areas of North Western Amhara, Ethiopia**

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Abstract

In Ethiopia, fertilizer consumption has shown a linear increment. One year on-farm research was conducted in Western Amhara, Ethiopia with the objective of identifying major yield-limiting nutrients for potato yield (Solanum tuberosum L.) productivity. The experiment was conducted in 2021 under rain feed cropping season

Quarit-Yilmana Densa,

Debecha and Baja-Sekela). A total of ten treatments [NPSZnBK, NPSZnK-B, NPSBK-Zn, NPZnBK-S, NPSZnB-K, NSZnBK-P, PSZnBK-N, NPS, NP and control (no input)] were evaluated in the experiment. The treatments were arranged in randomized complete block design (RCBD) with three replications. Improved

(*CIP-386423-13****)***

KCl (muriate of potash), $MgSO_4$ (magnesium sulphate), EDTA and Borax was used for the sources of N, P, K, S, Zn and B nutrients, respectively. Except urea, all fertilizer types were applied at planting using basal application. While, Urea fertilizer was applied in three equal splits at different crop stages (planting, flowering and tuber initiation). Before plating, one composite soil sample from each experimental site was taken at 0-20 cm depth and subjected to analysis for some selected soil physic-chemical properties. Both potato yield components and biological yield (tuber yield) were taken using standard procedure. Marketable and total tuber yields of potato showed highly significant differences (pr< 0.0001) among treatment means at each individual experimental site as well as from combined analysis in the domains. The main driving force for the occurrence of significant difference among treatment means in the ANOVA was due to omitting of N and P nutrients. In the ANOVA result, both marketable and total potato tuber yields showed quick and

show any significant differences either due to adding or omitting of sulphur (S), Zinc (Zn), Boron (B) and Potassium (K) nutrients. This showed that, Nitrogen (N) and Phosphorus (P) nutrients are still the major potato yield-limiting nutrients, respectively at major potato growing areas in North West Amhara.

Keywords: Potato, nutrient, omission, marketable yield

Introduction

Agriculture in Ethiopia contributes over 35%, 80% and 75% to the annual GDP, export income and job opportunity, respectively (CSA, 2018). Of the agricultural GDP, crop production contributed about 70% and over. Due to increased use of agricultural inputs (improved seeds, fertilizers and pesticides), agriculture showed a dramatic progress with the annual growth rate of 8% and over (CSA, 2018).

In Ethiopia, potato (*Solanum tuberosum* L.*)* is an excellent smallholder farmers' crop in the highlands with a short cropping cycle (3-4 months) which serves as cash and food security crop. It is an important crop to fill food supply gap during 'serious food shortage months' (October to December) which is before small grain crops are being harvested. Potato has high potential for improving food security, increasing household income and provides important nutrients such as carbohydrates, proteins and vitamins (vitamin C) (FAOSTAT, 2008). Ethiopia is among the top potato producers in Africa, with 70% of area coverage at and above 1500 m a.s.l altitude (Yilma, 1991).

The annual production of this crop in 2013 was 1.62 million tons from 0.18 million ha (CSA, 2014). The national average yield was 9 tha^{-1} (CSA, 2014) which was very low compared to the world average yield (16.4 tha^{-1}) (Husna and Eliakira, 2014). As Yazie *et al.,* (2017) mentioned by referring (ANRS, 2007 and 2008) report, potato is the widely grown crop for food and income generating sources in Amhara National Regional State (ANRS). ANRS takes the largest area (71,000 ha) for potato production which accounted 43.25% of arable land and produce 338,781 tons of potato (CACC, 2003a). Both nationally and regionally potato production is constrained due to poor soil fertility, fluctuated climatic condition, inadequate seed supply, poor post-harvest management and storage, high input costs lack of disease tolerant varieties, appropriate cultural practices and market access (Gebremedhin *et al.*, 2001; Yazie *et al.*, 2017).

In Ethiopia, fertilizer consumption has shown a linear increment Endale (2010). Following Plan for Accelerated and Sustained Development to End Poverty (PASDEP) for consecutive five-years, from 1995-2009, fertilizer consumption was increased by 10 tons every year for 16 years. After the development of soil fertility map by Ethiopian Soil Information System (EthioSIS, 2015) and the second growth and transformation plan (GTP II, 2016-2020), the country has increased the fertilizer types used from two to five and more. Due to this, annual import and consumption of fertilizers raised to >100,000 $tyear^{-1}$. Currently, the country imports about 1.4 million tons of multi nutrient fertilizers and projected to use over 2 million tons by the end of 2025.

In targeting the right fertilizers to the right places, EthioSIS project team has mapped the soil nutrient status of agricultural lands in Ethiopia (EthioSIS, 2016). Based on the developed map by the project, N, P, K, S, B, Zn, Fe and Cu are the deficient nutrients identified and recommended for enhancing crop productivity in most of Ethiopian agricultural soils. Even though the newly formulated fertilizer types needed a validation work, Agricultural Transformation Agency (ATA) and Ministry of agriculture (MoA) in collaboration conducted a direct demonstration trial on over 60,000 trial sites within the country. However, the developed soil fertility map was not validated by the response of crops under field experiment and had a major limitation from different aspects. With those limitations, the Ethiopian government is already customized the use of the above mentioned nutrients and made available as fertilizer form on the fertilizer market. Although the new formulated fertilizers were available on the fertilizer market, still there is no national/regional conscience on the importance of those newly formulated fertilizer types. Therefore, this activity was conducted with the objective of identifying the major yield-limiting nutrients for potato productivity in North West Amhara Region, Ethiopia.

Materials and Methods

Study Area Description: The experiment was conducted at three major potato growing domains (belts) (Quarit-Yilmana Densa, Debecha and Baja-Sekela) which are found in Amhara regional state and located in North West direction from the capital city of Ethiopia (Fig 1). All the testing domains or districts grouped under optimum potato producer agro-ecology range.

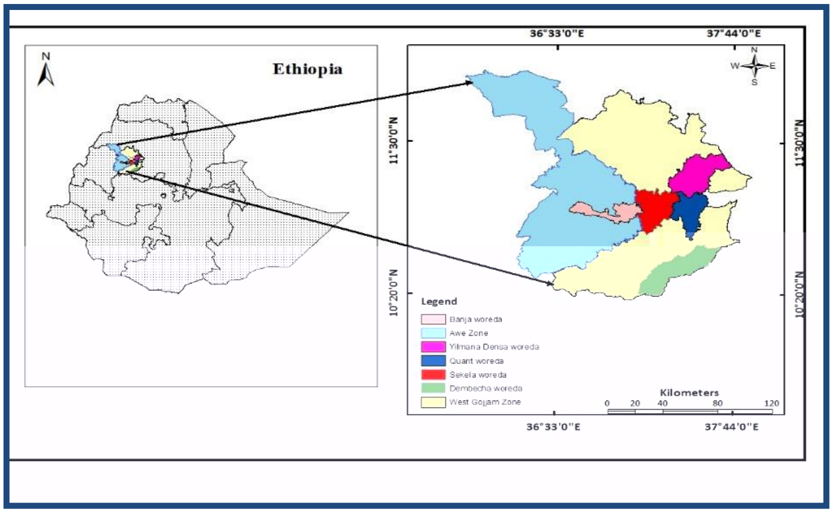

Fig 3 Map of the study districts

Soil sampling, Preparation and Analysis: From each experimental site, one composite soil sample was taken from five points following X- pattern sampling technique at the depth of 0-20 cm before planting. The sampled soils were air dried and sieved by (≤2 mm) sieve for the analysis of the required parameters. Soil pH, organic carbon (OC), cation exchange capacity (CEC), available Phosphorus (AP) and total Nitrogen (TN) were analysed using standard laboratory procedure. All the mentioned parameters were analysed at Adet agricultural research centre's (AARC) soil laboratory. Soil pH was determined using 1:2.5 soil-water suspensions according to (Taye *et al.*, 2002). Olsen (1954) was used for AP analysis. While, TN was analysed following Kjeldahl method (Bremner and Mulvaney, 1982). Soil OC was determined using wet oxidation. The CEC was determined using ammonium acetate method.

As indicated in Table 2, soil pH values of the experimental sites found from strongly (4.5-5.2) to moderately acidic (5.3-5.9) ranges Tekalign (1991) which is optimum for potato production (4.5-5.5). Available Phosphorus (AP) values were rated from medium (5-10) to high ranges (>10) based on Olsen (1954) nutrient rating scale. Except at one trial site in Banja-Sekela domain (site 2), OC and TN were in medium to high (1.5-3%) to >3% and (0.12-0.25%) to >0.25% range according to Tekalign (1991). According to Hazelton and Murphy (2007), CEC readings of the experimental sites were medium (12-25) to high (25-40) $Cmol_cKg^{-1}$ range in nutrient rating scale.

Table 1. Before planting selected soil properties of the experimental sites

Parameter	Denbecha		Banja-sekela			Quarit-Yilmana				References
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	Rating level	
pH(H2O)	5.4	5.2	5.8	4.8	Na*	5.0	4.9	5.3	Strong-moderate	Tekalign (1991)
SOC (%)	1.798	2.176	1.065	3.631	Na	3.549	1.619	1.665	Low-High	Tekalign (1991)
AP (Ppm)	8.56	5.80	12.04	11.71	Na	5.74	8.67	5.8	Medium-High	Olsen (1954)
CEC	23.7	28.5	33.2	37.7	Na	32.8	33.7	33.0	Medium-High	Murphy (2007)
N (%)	0.182	0.162	0.083	0.273	Na	0.144	0.150	0.132	Low-High	Tekalign (1991)

**Na=Not available*

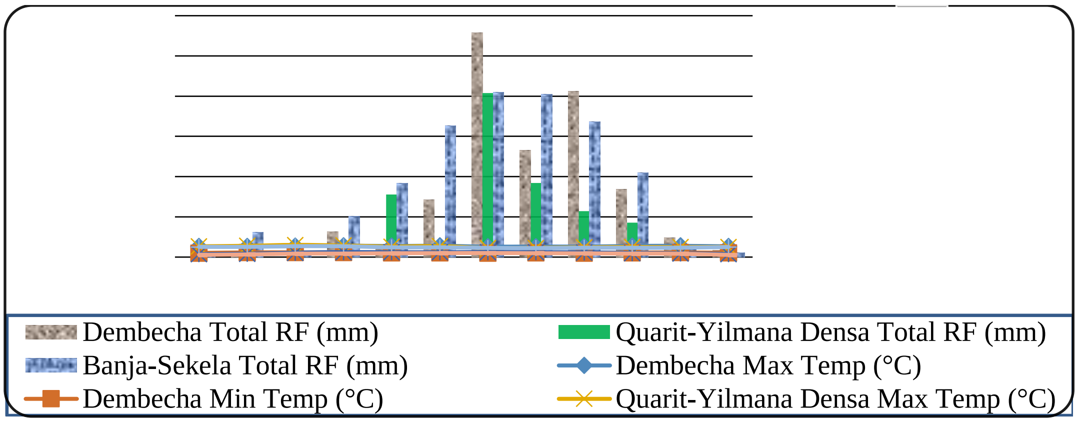

Fig 4. Climate data at study domains during the cropping season (2021) based on Ethiopian Meteorological Service Agency (EMSA), North West branch, Bahir Dar

Experimental Materials: Improved potato variety [Gudenie (CIP-386423-13)] was used as seed source. Urea, TSP, KCl, MgSO4, EDTA and Borax was used as a source of N, P, K, S, Zn and B nutrients, respectively. Soil auger and core-sampler was used to collect soil samples. Ridomil fungicide chemical was also used for controlling late blight diseases.

Experimental Methods and Design: The experiment was conducted in 2021 at eight (8) farmers' field. Randomized complete block design (RCBD) with three replications was used as experimental design. Spacing between plants, rows, plots and blocks was 0.3m, 0.75m, 1m and 1.5m, respectively. The gross and netharvestable areas were (4.5x3=13.5), 7.2 m^2 areas, respectively. The experimenthad a total of ten treatments as indicated in Table 1. Except Urea, all fertilizers were applied at planting in basal application. While, Urea fertilizer was applied in three equal splits at different crop stages (planting, flowering and tuber initiation).

Table 2. Treatment setup for the on-farm experiment

			Nutrient application rates ($Kgha^{-1}$)					
No	Treatment	Description	N	P_2O_5	K_2O	S	Zn	B
1	NPSZnBK	All	138	69	60	10.5	5	1
2	NPSZnK-B	B-omitted	138	69	60	10.5	5	-
3	NPSBK-Zn	Zn-omitted	138	69	60	10.5	-	1
4	NPBZnK-S	S-omitted	138	69	60	-	5	1
5	NPSZnB-K	K-omitted	138	69	-	10.5	5	1
6	NSZnBK-P	P-omitted	138	-	60	10.5	5	1
7	PSZnBK-N	N-omitted	-	69	60	10.5	5	1
8	NPS	NPS alone	138	69	-	10.5	-	-
9	NP	NP alone	138	69	-	-	-	-
10	Control	No fertilizer	-	-	-	-	-	-

Data Collection and Analysis: Yield component data like plant height, steam number, tuber number, dry matter content, specific gravity, starch level and all biological yields (marketable and total yield weight) were collected using standard procedure. SAS software version 9.0 was used to analyze all collected agronomic data (SAS Institute, 2002). The least significant difference (LSD) was used for mean comparison at 5% probability.

Results and Discussion

Dry matter content, specific gravity and starch content: Dry matter content (DMC), specific gravity (SG) and starch content (SC) of potato showed significant difference (p-value) among treatment means at Dembecha district (domain) (Table 3). Even though the statistically significant differences observed at the district mentioned above, the response of the treatments on the parameters greatly vary from district to district without regular trend (Table 3). This inconsistence may be due to insignificant contribution of the nutrients on the parameters which is supported by Niguse *et al.*, (2016) finding. Even on the control treatment higher DMC, SG and SC values were recorded at some of the experimental domain. However, the result of this study was in contrary to the findings reported by Nebiyu *et al.*, (2019). As his report said, the highest DMC was obtained with no P application while the lowest was obtained from application of 60 Kgha^{-1} P. Unlike P, increased level of K application from 0 to 110 Kgha^{-1} increased the DMC from 21.1 to 24.4%. Similarly, increasing the application of P from 0 to 60 Kgha^{-1} significantly decreased SG of the tuber while increasing K levels from 0 to 110 Kgha^{-1} increased the tuber SG. Furthermore, higher levels of P and K increased the SC of potato tuber (Nebiyu *et al.*, 2019). But in our study, the application of all type of nutrients (N, P, K, S, Zn and B) showed insignificant on DMC, SG and SC of potato.

Table 3. Dry matter content, specific gravity and starch content

Treatments	Dray matter content (%)			Specific gravity			Starch content (%)		
	Denbecha	Banja-sekela	Quarit-Yilmana	Dembecha	Banja-sekela	Quarit-Yilmana	Dembecha	Banja-sekela	Quarit-Yilmana
NPSZnBK	20.86	22.18	21.89	1.081	1.087	1.085	14.59	15.76	15.51
NPZnBK-B	20.88	21.93	21.85	1.081	1.086	1.085	14.61	15.54	15.48
NPSBK-Zn	21.36	22.26	22.08	1.083	1.087	1.086	15.04	15.84	15.68
NPSZnK-S	20.11	22.17	22.07	1.077	1.087	1.086	13.92	15.75	15.67
NPSZnB-K	22.23	21.81	22.44	1.087	1.085	1.088	15.81	15.44	16.00
NSZnBK-P	21.40	22.27	21.67	1.083	1.087	1.084	15.07	15.84	15.31
PSZnBK-N	21.35	22.55	21.51	1.083	1.088	1.084	15.02	16.10	15.17
NPS	21.86	22.24	21.92	1.085	1.087	1.086	15.48	15.82	15.54
NP	21.23	22.93	22.15	1.082	1.090	1.087	14.92	16.44	15.74
Control	21.97	22.67	21.75	1.086	1.089	1.085	15.58	16.21	15.38
LSD (0.05)	0.99	0.95	1.54	0.005	0.005	0.008	0.88	0.85	1.37
Sign	**	NS	NS	**	NS	NS	**	NS	NS
CV	4.0	4.53	7.48	0.36	0.53	0.77	5.06	5.68	9.41

***=Highly significant, *= Significant, NS= Non significant*

Potato Tuber Yields: At each experimental site in study domains, marketable tuber yield of potato showed a highly significant difference among treatment means (Table 4). Most of the observed significant differences among treatment means of the tuber yield in the study domains were derived due to control and N omitting treatments, respectively. The minimum marketable yield values were recorded either on the control treatment or N omitting treatment interchangeably. This showed that, the contribution of N was highest on potato yield across the study sites. However, the maximum values observed at any one of the treatments at least it contains N and P nutrients together. In all testing sites, high and significant responses on potato marketable yields were observed when both N and P nutrients were added. This confirmed that, N and P nutrients were still yield-limiting nutrients which is in line with the finding of (Tadele *et al.,* 2022). Tadele *et al*., (2022) stated that the yield-limiting nutrients to produce maize and wheat in major growing areas in Amhara region were N and P nutrients, respectively. However, no significant difference were observed among potato marketable tuber yield means due to adding or omitting of S, Zn, B and K in the study domains which is in line with the report of Tadele *et al.,(* 2018).

Table 4. Total marketable tuber yield weight (tha^{-1}) values at the study domains

Treatments	Denbecha		Banja-sekela			Quarit-Yilmana Densa		
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
NPSZnBK	26.0	30.5	29.1	23.7	24.3	17.2	14.0	18.9
NPSZnK-B	28.3	30.1	28.5	22.0	23.4	16.9	15.7	22.0
NPSBK-Zn	23.1	31.4	25.7	26.4	24.9	16.3	16.9	21.5
NPBZnK-S	26.4	26.1	26.1	25.6	23.3	17.6	14.7	19.1
NPSZnB-K	26.0	32.0	27.8	19.6	22.8	12.6	11.7	19.8
NSZnBK-P	21.7	26.1	18.9	16.4	18.1	10.6	8.3	19.4
PSZnBK-N	16.6	10.4	7.6	9.1	9.4	10.1	5.3	5.4
NPS	23.0	29.1	28.6	21.8	20.2	13.1	12.5	23.2
NP	25.5	27.3	27.2	22.9	19.0	11.9	13.1	23.9
Control	13.8	15.2	8.9	7.4	8.7	6.8	4.9	5.4
LSD (0.05)	6.0	6.9	5.1	4.7	6.5	3.7	3.2	4.5
Sign	**	**	**	**	**	**	**	**
CV (%)	15.3	15.8	13.2	14.0	19.8	16.5	15.9	14.6

At all experimental sites, unmarketable potato tuber yield didn't show any statistical significant difference among treatment means (Table 5). This may not tell us, the treatments had no significant difference on potato total yield production. But it indicated that, the parameter we took (unmarketable tuber yield) could not determine significantly by the treatments we used. For this reason, all the observed trends on marketable potato tuber yield also replicated on total potato tuber yield weight at all experimental sites of the study domains (see Table 4 and 6).

Table 5. Total unmarketable tuber yield weight (tha^{-1}) values at the study domains

Treatments	Denbecha		Banja-sekela			Quarit-Yilmana Densa		
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
NPSZnBK	0.15	0.31	0.35	0.21	0.28	0.48	0.23	0.55
NPSZnK-B	0.44	0.57	0.33	0.28	0.36	0.46	0.17	0.34
NPSBK-Zn	0.21	0.25	0.40	0.23	0.31	0.66	0.14	0.46
NPBZnK-S	0.38	0.27	0.31	0.25	0.86	0.59	0.12	0.60
NPSZnB-K	0.40	0.55	0.29	0.19	0.34	0.54	0.34	0.62
NSZnBK-P	0.34	0.51	0.30	0.37	0.44	0.42	0.17	0.30
PSZnBK-N	0.22	0.37	0.26	0.24	0.98	0.28	0.19	0.32
NPS	0.28	0.81	0.22	0.27	0.51	0.36	0.29	0.70
NP	0.23	0.28	0.26	0.26	0.86	0.32	0.18	0.56
Control	0.24	0.18	0.26	0.33	0.31	0.56	0.13	0.27
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Sign	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	53.3	93.2	61.2	41.5	73.5	35.5	61.4	48.4

Table6.Total tuber yield weight (tha^{-1}) values at the study domains

Treatments	Denbecha		Banja-sekela			Quarit-Yilmana Densa		
	Site 1	Site 2	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
NPSZnBK	26.2	30.8	29.5	23.9	24.6	17.7	14.2	19.5
NPSZnK-B	28.8	30.7	28.8	22.3	23.7	17.3	15.8	22.4
NPSBK-Zn	23.4	31.6	26.1	26.7	25.2	16.9	17.0	22.0
NPBZnK-S	26.7	26.4	26.4	25.8	24.2	18.1	14.8	19.7
NPSZnB-K	26.0	32.6	28.1	19.8	23.1	13.2	12.0	20.4
NSZnBK-P	22.1	26.6	19.2	16.8	18.6	11.0	8.5	19.7
PSZnBK-N	16.8	10.8	7.9	9.4	10.4	10.4	5.5	5.7
NPS	23.3	29.9	28.8	22.1	20.7	13.5	12.8	23.9
NP	25.7	27.6	27.5	23.2	19.8	12.2	13.3	24.5
Control	14.0	15.4	9.1	7.7	9.0	7.4	5.0	5.7
LSD (0.05)	6.1	7.2	5.2	4.6	6.6	3.8	3.2	4.5
Sign	**	**	**	**	**	**	**	**
CV (%)	15.3	16.1	13.2	13.8	19.5	16.4	15.5	14.5

Similar to the individual experimental sites, both marketable and total tuber yields of potato showed highly significant difference among treatment means in each study domain (Table 7). Next to the control treatment, highly significant responses (yield penalty) on potato marketable and total tuber yields occurred when N and P nutrients were omitted, respectively. This finding confirmed by Tadele *et al.*, (2022) finding who mentioned, N and P nutrients are the yield-limiting nutrients to produce maize in Amhara region, respectively. However, similar to the individual testing site results, any significant difference didn'thappen among potato marketable and total tuber yields due to S, Zn, B and K nutrients application in the study domains (Table 7).

Table7. Combined result of marketable and total tuber yield weight at each domain (tha[-1])

Treatments	Denbecha		Banja-sekela		Quarit-Yilmana Densa	
	MTY*	TTY	MTY	TTY	MTY	TTY
NPSZnBK	28.23	28.46	25.71	25.99	16.69	17.11
NPSZnK-B	29.22	29.72	24.63	24.95	18.18	18.50
NPSBK-Zn	27.26	27.49	25.66	25.97	18.20	18.62
NPBZnK-S	26.23	26.55	25.00	25.47	17.11	17.54
NPSZnB-K	28.80	29.27	23.39	23.67	14.69	15.19
NSZnBK-P	23.93	24.36	17.82	18.19	12.79	13.09
PSZnBK-N	13.51	13.81	8.729	9.22	6.914	7.18

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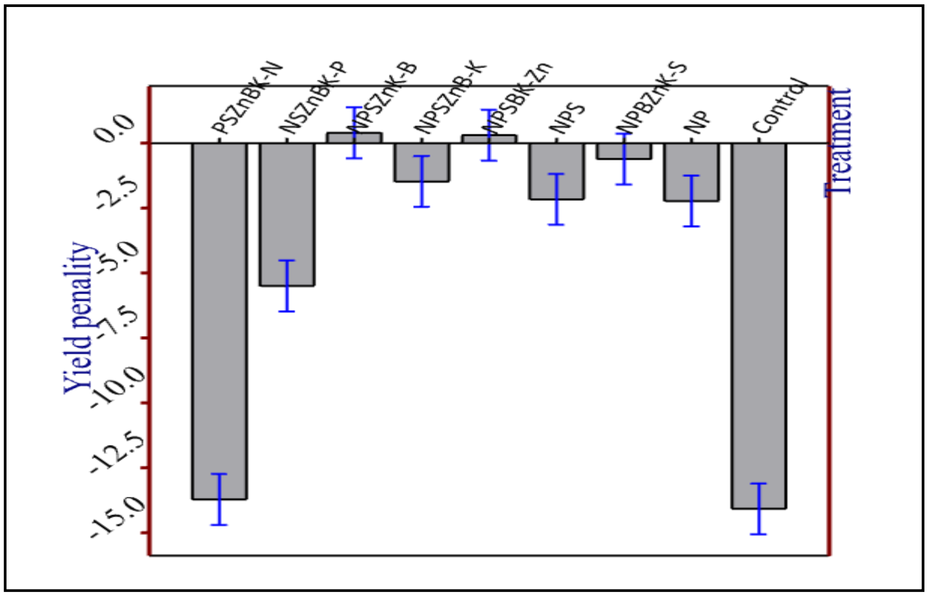

Figure 5. Yield penalty /advantage of potato tuber yield due to nutrient omitting

*__Note__: All stands for treatment containing nutrients.

In all study domains, total tuber yield of potato showed strong and positive significant correlation with yield components like plant height, total tuber number and total marketable yield except with steam number. Similarly, most potato yield components by themselves also showed highly and positive significant correlation with each other (Table 8).

Table8. Correlation of some yield components with of potato yield at each study domains

Parameters	Dembecha				Banja-Sekela			
	PH*	SN/hill	TN	TMY	PH	SN/hill	TN/plant	TMY
PH	-				-			
SN/hill	0.18	-			0.20	-		
TN/plant	0.29	0.26	-		0.50	0.38	-	
TMY	0.84	0.09	0.28	-	0.76	0.41	0.70	-
TYW	0.84	0.09	0.28	0.99	0.76	0.40	0.70	0.99

Quarit-Yilmana Densa		
	TN/plant	TMY
TN/plant	-	
TMY	0.37**	-
TYW	0.36**	0.99**

***PH=plant height, SN=steam number, TN=tuber number, TMTY=total marketable tuber yield, TTY=total tuber yield, **=Correlation is significant at p<0.01; *=Correlation is significant at p<0.05 & ns=Correlation is non-significant (p≥0.05).

Conclusion

Both marketable and total tuber yields of potato showed a highly statistically significant difference among treatment means at each site as well as at all study domains. The study confirmed that N is the primary potato yield-limiting nutrient followed by P nutrient. However, the remaining four nutrient types (S, Zn, B, and K) didn'thave any statistically significant role in the enhancement of potato tuber yield. Therefore, it is still possible to enhance potato productivity using sole N and P fertilizer sources including other improved potato production technologies. However, frequent revision of the soil fertility status is too important for updating nutrient type requirements for enhancing potato productivity and production in the Amhara region, Ethiopia

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