6. Yield-Limiting Plant Nutrients on Onion Productivity under Irrigation in North Shoa Zone, Ethiopia

*Shawl Assefa, Yalemgena Getie, Kenzemed Kassie, Beza Shewangizaw, Getachew Lema, Lisanu Getaneh, Genet Taye

Debre Berhan Agricultural Research Center, P. O. Box 112, Debre Berhan, Ethiopia

***Correspondence**: shawelasefa@gmail.com

Abstract

The field experiment was conducted during irrigation season in 2022 to study the yield limiting nutrients on yield and yield components of onion. The experiment consisted of 10 treatments, involving application PKSZnB (N-omitted), NKSZnB (P-omitted), NPSZnB (K-omitted), NPKZnB (S-omitted), NPKSB (Zn-omitted), NPKSZn (B-omitted), NPKSZnB, recommended NP, recommended NP+30Kgha^{-1} S and control (without nutrient input). Treatments were randomized and arranged in a randomized complete block design and replicated three times at a site. The soil analysis result of the experimental locations indicated neutral to moderately alkaline soil reaction, low to moderate organic matter and total Nitrogen, medium to high available P, high to very high exchangeable K and low to medium ranges of available S. The Marketable onion yield result of the experiment revealed that Nitrogen is the most yield limiting nutrient and there was a reduction in marketable onion yield 10.6% for the omission of N. respectively. P, K, Zn and B nutrients omission resulted in no significant difference in marketable onion yield. Compared to the total Therefore, N is yield limiting nutrient for the production of onion under irrigation for the study sites. Besides, maintenance Phosphorus application is important. Recommended NP alone gave better yield than S omitted. Application of RNP with 30 Kgha^{-1} S gave 19.05% marketable bulb yield advantage than recommended NP alone. This implies, there might be lower application S rate. The soil analysis result also supported that, the study sites had low soil N and S chemical properties, the soil N and S content is below the critical value for crop production.

Keywords: Nutrients omission, Yield limiting nutrients, Onion under Irrigation, North-shoa

Introduction

Onion *(Allium cepa* L.*) is an important vegetable crop grown worldwide next to tomato.* Vegetables production grew faster between grown-up 65 percent (446 million to 1128 million tons) in 2019 compared to its status in 2000. Of the five vegetables that account about 42–45 % of the vegetables, the share of onion is about 9 % (FAO, 2020). The productivity of onion in Ethiopia is 8.89tha^{-1} and it is far below the world average (19.13tha^{-1}) according to FAO (2020). *T*he soil fertility is one of the major constraints for low onion productivity in Ethiopia *(*Kumilachew *et al.,* 2014; Alemayehu and Jemberie, 2018).

Fertilizer application to onion is required to attain maximum bulb yield as onion plants have shallow, sparsely branched root system (*Khalid, 2019*) that could not extract nutrients in the lower surfaces. Among the various factors a*ff*ecting the yield of crops, adequate mineral nutrient management plays a major role to optimize the quality and quantity of harvested plant products (Lakshmi & Sekhar, 2018). Nutrient management involves using crop nutrients as efficiently as possible to improve productivity while protecting the environment. When applied in proper quantities and at the right times, added nutrients help to achieve optimum crop yields; applying too little limit yield, while applying too much does not make economic sense it rather harms the environment (Khokhar, 2019).

Crop nutrient requirement varies with cultivars, yield potential, season, and locations. The steady depletion of native soil fertility and the occurrence of multiple nutrient deficiencies in farmers' fields, identified nutrient management as a key factor limiting sustainable onion production (Thangasamy, 2016). Nutrient inadequacies can affect the crop's ability to utilize other nutrients supplied. This leads to the need for investigating yield-limiting factors in various regions of the country. Identification of the most yield-limiting nutrient is the most important in formulating nutrient management strategies to maximize the profitability of crop and forage production while protecting the environment.

The productivity of vegetable crops significantly improves by application of nutrients. Onions are the most susceptible crop plants in extracting nutrients, especially the immobile types, because of their shallow and unbranched root system; hence they require and often respond well to addition of fertilizers (Brewster, 1994; Rizk *et al.,* 2012). In the target of the right fertilizers to the right places, EthioSIS (2014) revealed that in addition to N and P, identified a number of essential plant nutrients that are deficient and critically required by the agricultural soils of the country. Accordingly, the country customized the use of a number of soil nutrients and that were identified deficient in the agricultural soils appeared on the fertilizer market before the well-coordinated validation.

Thus, the evaluation/validation of the soil fertility map developed by EthioSiS can help to determine which nutrients are the most limiting to crop production and hence the nutrient omission nutrienttechnique is the simplest and straight forward technique that evaluates the nutritional requirements of crops and the most limiting nutrient (Laviola & Dias 2008; Miranda *et al.,* 2010). Therefore, this research was initiated nutrient(s) that are major yield-limiting in Kewot under irrigation conditions for onion production.

Materials and Methods

Description of the Study Area: The field experiment was conducted during in the irrigation season in Kewot district of North Shewa Zone at Aregay, and Merye sites. The trial was conducted on farmers' fields. Annual mean minimum and maximum temperatures were 10 and 25^{o}c, respectively. The study locations have a uni-modal rainfall pattern and receiving an average annual rainfall range from 900-2000 mm at Kewot. Major crops grown under irrigation are onion, cabbage, tobacco and pepper, in decreasing orders of area coverage. Fig 1 represents the location map of the study areas.

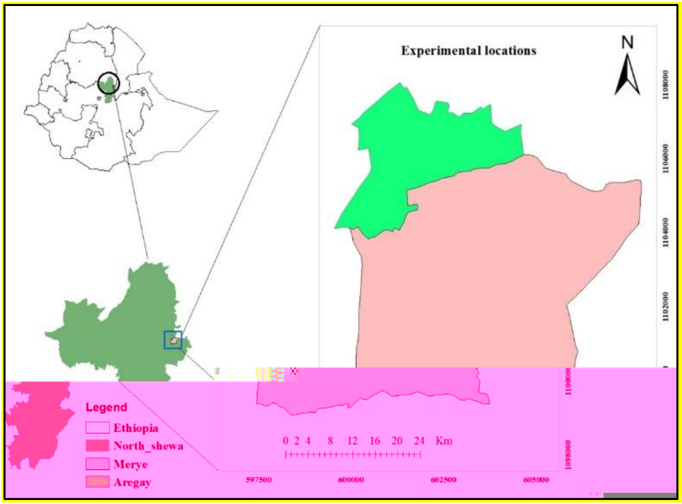

Table 1. Location map of the study area

Treatments and Experimental Design: The trials consisted of ten (10) treatments: Control (with no nutrient input), All-N, All-P, All-K, All-S1, All-B, All-Zn, RNP, RNP+S2 and All (NPKSZnB). The amount of each nutrient in the treatment (Kgha^{-1}) were N= 107, P_2O_5= 76, K_2O = 60, S1= 10.5, S2=30, Zn = 5, and B= 1. The experiment was laid out in randomized complete block design (RCBD) replicated three times across each individual farmers' fields.

Table 1. Treatment details

No	Treatments	Treatment Details
1	-N (PKSZnB)	The N-limited yield is measured in a zero-N omission plot. The plot receives sufficient fertilizer P, K, S, Zn, and B to achieve high yield, but no fertilizer sources of N are applied.
2	-P (NKSZnB)	The P-limited yield is measured in a zero-P omission plot. The plot receives sufficient fertilizer N, K, S, Zn, and B to achieve high yield, but no fertilizer sources of P are applied.
3	-K (NPSZnB)	The K-limited yield is measured in a zero-K omission plot. The plot receives sufficient fertilizer N, P, S, Zn, and B to achieve high yield, but no fertilizer sources of K are applied.
4	-S (NPKZnB)	The S-limited yield is measured in a zero-S omission plot. The plot receives sufficient fertilizer N, P, K, Zn, and B to achieve high yield, but no fertilizer sources of S are applied.
5	-Zn (NPKSB)	The Zn-limited yield is measured in a zero-Zn omission plot. The plot receives sufficient fertilizer N, P, K, S, and B to achieve high yield, but no fertilizer sources of Zn are applied.
6	-B (NPKSZn)	The B-limited yield is measured in a zero-B omission plot. The plot receives sufficient fertilizer N, P, K, S, and Zn to achieve a high yield, but no fertilizer sources of B are applied.
7	NPKSZnB	Full fertilization of nutrients applied, Fertilizers N, P, K, S, Zn, and B are applied sufficiently to ensure that yield is not limited by an insufficient supply of the added nutrients. Grain yield in the plot with full fertilization and crop management can be used to estimate an attainable yield target
8	RNP	Only recommended amount of N and P is applied. The yield without N, P limitation is measured in a plot receiving the same N rate used in the –N plot, the same P rate used in the –P plot
9	RNP+S2	Recommended amount of N and P plus S2 is applied. The yield without N, P, and S2 limitation is measured in a plot receiving the same N rate used in the –N plot, the same P rate used in the –P plot and the same S2 rate used in the –S2 plot
10	Control	The Nutrient-limited yield is measured in a no fertilizer that should not receive any fertilizer of N, P, K, S, Zn, and B.

Table 2. Each nutrient application rate (Kgha^{-1})

No	Treatment	Nutrients (Kgha^{-1})					
		N	P_2O_5	K_2O	S	Zn	B
1	- N (PKSZnB)	0	76	60	10.5	5	1
2	-P (NKSZnB)	107	0	60	10.5	5	1
3	-K (NPSZnB)	107	76	0	10.5	5	1
4	-S (NPKZnB)	107	76	60	0	5	1
5	-Zn (NPKSB)	107	76	60	10.5	0	1
6	-B (NPKSZn)	107	76	60	10.5	5	0
7	NPKSZnB	107	76	60	10.5	5	1
8	RNP	107	76	0	0	0	0
9	RNP+S2	107	76		30	0	0
10	Control	0	0	0	0	0	0

Management of the Experiment: All experimental fields were prepared with an oxen-drawn plough before planting and human power at planting time. The plot sizes of each treatment was 3m by 2.4 m (7.2 m^2). Bombay Red variety was used. The spacing of 5, 20 and 40 cm was between plants, row and ridge respectively while 2m between plots and 1,5m between replications used.

All nutrients were applied at planting while, N was applied in two equal splits: half at planting, and the resthalf after 45 days of planting. Urea, triple superphosphate (TSP), Muriate of potash (MOP), Zinc EDTA, $MgSO_4$, and borax were used as fertilizer sources for N, P, K, Zn, S, and B, respectively. Weeds, diseases, and pests managements were uniform for all plots.

Data Collection: Parameters like growth, yield and yield components (Plant height, bulb size, bulb weight, leaf number, marketable yield, unmarketable yield, total bulb yield for each site was collected with the procedures stated below.

Bulb Length (cm): The vertical average length of the matured bulb measured with a caliper.

Bulb Diameter (cm): The horizontal cross-sectional length of the matured bulbs of sampled plants measured with caliper at the widest point in the middle portion of bulbs

Mean Bulb Weight (gplant^{-1}): The average weight of matured bulbs, measured with balance atharvest.

Soil Sample Collection: After selecting the experimental sites, pre-planting soil samples were collected from each site for the analyses of selected physicochemical properties. Composite soil samples were taken from each site from a depth of 0-20 cm using an auger randomly from 10 spots by walking in a zigzag pattern. After thoroughly mixing, 1 Kg of the composite samples was taken and air dried and grounded to pass a 2 mm mesh-sized sieve.

The soil texture was analysed following Bouyoucous hydrometer method (Bouyoucous, 1962). The pH of the soil was measured using the pH-water method by making a soil-to-water suspension of a 1: 2.5 ratio and was measured using a pH meter. The soil OC content was determined by the wet digestion method (Walkley and Black, 1934). Total Nitrogen (TN) was determined by using the modified micro Kjeldahl method (Coterie, 1980), and available P (ava. P) was analyzed using Olsen's calorimetric method as described by Olsen *et al.,* (1954).

Statistical Analysis: The collected data were subjected for the analysis of variance (ANOVA) using R software program using R version 4.2.1 (R Core Team, 2022). Normality and homogeneity of variance tests were checked and combined analysis for the 6 sites and the 2 years was done. The Least Significant Difference (LSD) at 5% level was used to separate the treatment means for those parameters that were statistically significant.

Results and Discussion

Soil Physicochemical Properties

The initial physicochemical characteristics of the experimental soil were determined (Table) using standard laboratory procedures as mentioned earlier. The soils of the experimental locations were belonging to clay textural class the average the soil pH of the two sites is 8.22 with moderately alkaline soil reaction (Murphy, 1968), it is above the ideal soil pH value of crop needs, therefore it needs closely monitored to amend with gypsum. Based on the analysis result the average TC and TN is 1.34 and 0.12 % respectively which is low categories according to soil chemical characteristics (Tekalign, 1991), the test crop was significantly responded to N application in the testing location. Medium range available P (Olsen *et al.,* 1954), the available P of the study sites was within the critical P content which is optimal for crop production. The average exchangeable K is 1.7 ($cmolKg^{-1}$) it is very high exchangeable (FAO, 2006) and found to be above the critical level of soil chemical properties. The test crop was not responded to the application of K fertilizer, this implies there was sufficient inherent soil K content. The soil analysis result showed low to medium ranges of available S (Hariram and Dwivedi, 1994). Based on this the soil analysis result indicated the average value of available soil S content is 8.86 ppm which was found to be below the critical value for crop production.

Table 3. Soil Physical and chemical properties

Location	PH (1:2.5)	Ex. K ($cmolKg^{-1}$)	OC (%)	AV. P (ppm)	T.N (%)	AV. S (ppm)	Texture (%)			Textural class
							Sand	Clay	Silt	
Merye	8.24	2.67	1.24	12.56	0.119	4.12	22	52	26	Clay
Aregay	8.2	0.72	1.43	13.20	0.114	13.60	10	60	30	Clay

Effects of Nutrient Omission on Yield and Yield Components of Onion: The yield components of onion showed no significantly response to nutrients omitted at all sites. However, it significantly ($p<0.01$) affected the marketable and total bulb yields (Table 4)

Table 4. ANOVA table for each parameter

Effects	PH	LL	LN	BL	BD	MBY	TBY
Rep	ns	ns	ns	ns	ns	ns	ns
Location	ns	ns	ns	ns	ns	*	*
Treatment	ns	ns	ns	ns	ns	**	**
Treatment*Location	ns	ns	ns	ns	ns	ns	ns
CV (%)	6.27	7.59	5.94	7.16	7.56	14.03	13.16

PH=plant height, Leaf Length, Leaf Number, Bulb Length, Bulb Diameter, Marketable Bulb Yield, Total Bulb Yield

Effects on Bulb Yeld: There was a significantly ($p<0.01$) effect of treatments on the marketable and total bulb yields at Merye site but non-significant at Aregay (Figure A and B). At Merye the highest marketable bulb yield (33.03 tha^{-1}) was recorded from the application of recommended NP fertilizer combined with 30 $Kgha^{-1}$ S followed by K omitted (28.10 tha^{-1}) treatments. The lowest marketable bulb yield (18.01 tha^{-1}) was obtained from control treatment followed by N omitted (20 tha^{-1}). A similar trend was observed on total bulb yield the highest total bulb (33.55 tha^{-1})

being from recommended NP combined with 30 $Kgha^{-1}$ S. In both marketable and total bulb yields omission of K and B resulted in a non-significant difference with treatments that resulted in the highest yield.

The result presented on Figure showed the mean marketable and total bulb yield. The result showed that, omitting some of the nutrients significantly influenced both marketable and total bulb yield of onion. The highest marketable bulb yield (25.5 tha^{-1}) was recorded with RNP+30 $Kgha^{-1}$ S followed by RNP (22.05 tha^{-1}). The lowest marketable bulb yield (15tha^{-1}) was obtained from control treatment followed by N omitted (16.83 tha^{-1}). The highest total bulb yield (26 tha^{-1}) yield was obtained from RNP+30 $Kgha^{-1}$ S. Nitrogen is the most yield limiting plant nutrient from the current study. The summarized data from Fig 3 showed that the relative importance of nutrients on marketable yield of onion due to omission of different nutrients from treatment that received all nutrients. In comparing the yield penalty of by omitting each nutrient, N resulted in the highest marketable bulb yield reduction (10.6%) followed by S (7. 6%). While application omitting of nutrients including P, K, Zn and B did not significantly affect marketable bulb yield. In short, K, P, Zn and B nutrients are not yield limiting nutrients for the onion production of the study area. This implies that N is the most critical nutrient that affect bulb yield of onion in the study area under current soil situation. Lower bulb yield from omission of N indicated the soil N is very low to support the production of onion for the attainable yield with the applied Nitrogen fertilizer. This means the inherent N supplying capacity of the soil is not enough to supply for the optimum production onion. The soil analysis result of N was the lower ranges. Hence, N is the most onion yield limiting nutrient for the study areas.

The result clearly showed that RNP alone gave better yield than S omitted, this might be the antagonistic interaction effect exist between nutrients. The previous study report stated, antagonistic effect of P and S nutrient effect on the uptake and utilization of each other nutrient and changes in N: S ratio affected by S and P application (Aulakh and Pasricha, 1977). In addition, other study revealed that, the interaction of soil nutrients affects their availability to crops as on overabundance one may result in deficiency of another nutrients (Karimizarchi *et al.*, 2014). Application of RNP alone gave 55.6%, 24.8% and 20.8% marketable bulb yield advantage than control, N omitted and S omitted respectively. Application of RNP with 30 $Kgha^{-1}$ S gave 19.05.0% marketable bulb yield advantage than recommended NP alone. This implies, there might be lower application S rate. The soil analysis result supported that, the study sites had low to medium ranges, the one site soil S content is below the critical value for crop production (Hariram and Dwivedi, 1994). The K, P, B and Zn omission did not show bulb yield penalty, rather a slight yield increase was observed by omitting these nutrients. In Ethiopia, different Studies conducted on nutrient omission trials and on S showed different results leading to different conclusions. For instance, by Beamlaku *et al.*, 2023), revealed K, S, Zn and B were not yield limiting nutrients for tef production in Adet area. Similar result was also reported by Tadele *et al.*, 2022, stated that the most yield limiting plant nutrients for the production of maize for the majority of maize growing areas of Gojam was N followed by P while, K, S, Zn and B were not yield limiting. On the contrary, Kiros and Singh (2009) found that S application significantly increased grain yield, N-use efficiency and S uptake. Wondwosen and Sheleme (2011) also stated that S was identified as crop yield limiting nutrient in the Alfisols of southern Ethiopia. Based on Assefa's (2016) finding, S application on the *vertisols* and *nitisols* significantly affected the grain yield of bread wheat. He reported that soils of responding sites had S content below critical level S for optimum production of crop. Recently, research report by Assefa (2022) revealed, Nitrogen was the most yield limiting nutrient followed by S.

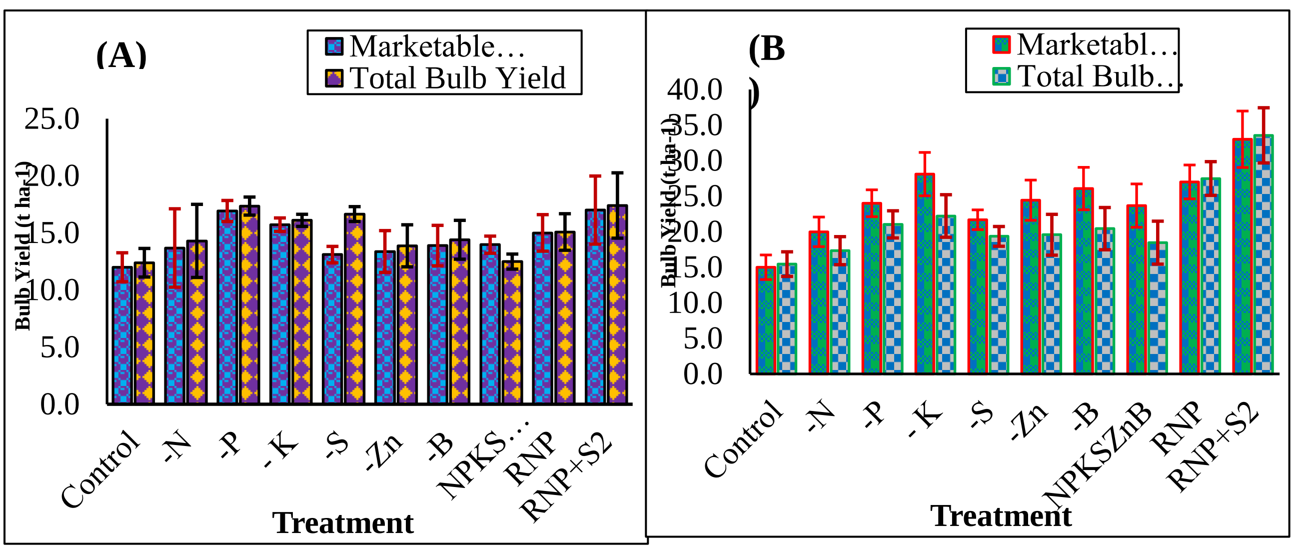

Figure 2. Effect of nutrient omission on Marketable and Total Bulb Yield at Aregay (A) and Merye (B)

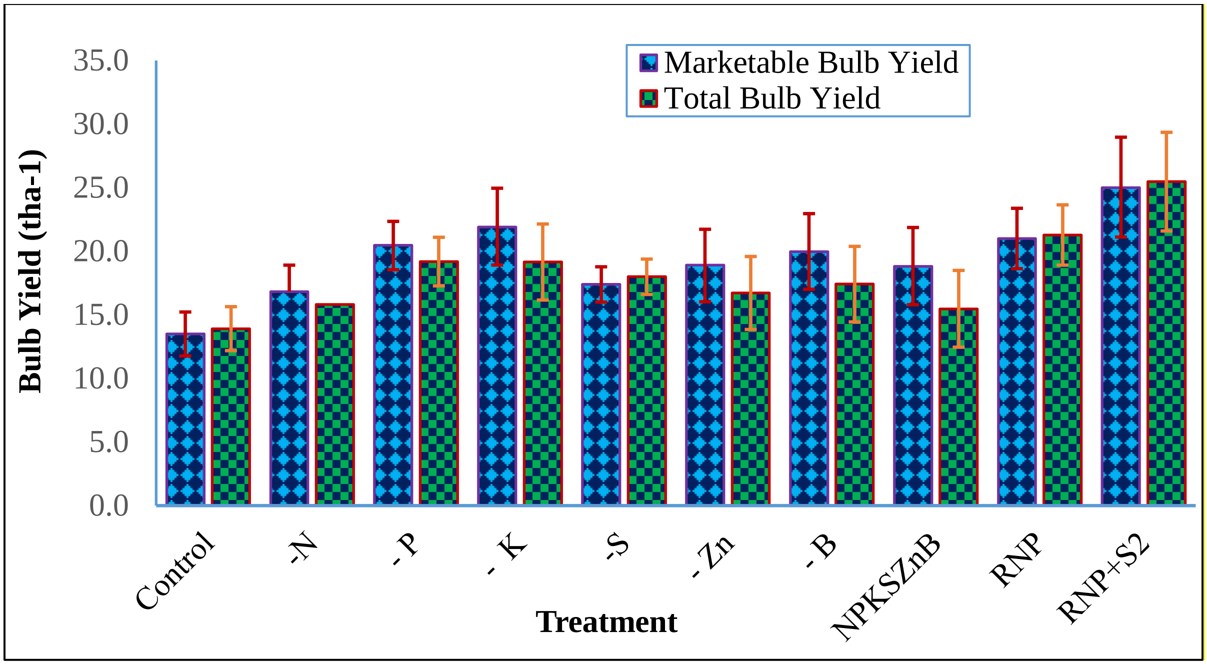

Figure 3. Effect of omitting of nutrients on mean marketable bulb yield and total bulb yield

Table 5. Marketable bulb yield reduction due to omission of nutrients to all nutrients added at Merye site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb reduction (tha^{-1})	% Reduction
-N	19.98	-3.69	-20.71
-P	24.00	0.33	1.85
-K	28.10	4.43	24.86
-S	21.68	-1.99	-11.17
-Zn	24.43	0.76	4.26
-B	26.07	2.40	13.47
NPKSZnB	23.67		

Table 6. Marketable bulb advantage due to comparison of RNP from each treatment at Merye Site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb increment (tha^{-1})	% increment
Control	15.0	12.0	80.0
-N	19.98	7.0	35.1
-P	24	3.0	12.5
-K	28.1	-1.1	-3.9
-S	21.68	5.3	24.5
-Zn	24.43	2.6	10.5
-B	26.07	0.9	3.6
NPKSZnB	23.67	3.3	14.1
RNP+S2	33.0	-6.0	-18.2
RNP	27.0		

Table 7. Marketable bulb yield reduction due to omission of nutrients compared to all nutrients added at Aregay site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb reduction (tha^{-1})	% Reduction
-N	13.67	0.30	1.68
-P	16.91	-2.94	-16.50
-K	15.65	-1.68	-9.43
-S1	13.10	0.87	6.22
-Zn	13.34	0.63	3.54
-B	13.88	0.09	0.51
NPKSZnB	13.97		

Table 8. Marketable bulb yield comparison of RNP from each treatment at Aregawy site

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable yield increment (tha^{-1})	% increment
Control	12.0	3.0	25.1
-N	13.68	1.3	9.6
-P	16.92	-1.9	-11.3
- K	15.72	-0.7	-4.6
-S	13.1	1.9	14.5
-Zn	13.37	1.6	12.2
-B	13.89	1.1	8.0
NPKSZnB	13.97	1.0	7.4
RNP+S2	17.0	-2.0	-11.8
RNP	15.0		

Table 9. Overall mean marketable bulb yield reduction due to omission of nutrients compared to all nutrients added

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable Bulb reduction (tha^{-1})	% Reduction
-N	16.83	-1.99	-10.60
-P	20.46	1.64	8.71
-K	21.91	3.09	16.25
-S	17.39	-1.43	-7.61
-Zn	18.9	0.16	0.85
- B	19.98	1.16	6.16
NPKSZnB	18.82		

Table 10. Overall mean marketable bulb yield comparison of RNP from each treatment

Treatment	Marketable Bulb Yield (tha^{-1})	Marketable yield increment (tha^{-1})	% increment
Control	13.5	7.5	55.6
-N	16.8	4.2	24.8
-P	20.5	0.5	2.6
- K	21.9	-0.9	-4.2
-S	17.4	3.6	20.8
-Zn	18.9	2.1	11.1
-B	20.0	1.0	5.1
NPKSZnB	18.8	2.2	11.6
RNP+S2	25.0	-4.0	-16.0
RNP	21.0		

Conclusion and Recommendation

Based on the results over two testing locations it was revealed that the supplying capacity of the soils to N was low, medium available P, high to very high exchangeable K, low to medium soil S. The highest marketable bulb yield (25.5 tha^{-1}) was recorded with RNP+30 $Kgha^{-1}$ S followed by K omitted (28.10 tha^{-1}). While the lowest marketable bulb yield (18.01 tha^{-1}) was obtained from control treatment followed by N omitted (20tha^{-1}). The omission of N caused by 10.9% marketable bulb yield of onion. For that reason, the use of N nutrients increases onion productivity under irrigation condition. The effect of N, omission caused the highest bulb yield. N is the most considerably nutrient in the study area. Nutrients P, K, B, Zn omission have not significant impact on yield onion in contrary application of those nutrients have also yield penalty. In summary, based on the result, there was N nutrient response variability across locations and there needs rate determination on N with P nutrients. Application of RNP with 30 $Kgha^{-1}$ S gave 19.05% marketable bulb yield advantage than recommended NP alone. This implies, there might be lower application S rate. The soil analysis result supported that, the study sites had low to medium ranges, the one site soil S content is below the critical value for crop production. Based on this there need more investigation to claim the soil of the study district deficient in S in addition to N and P.

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