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Full Length Research Paper

Response of wheat (*Triticum aestivum* L.) to sulfur impurity supplied as triple-super phosphate under gypsum and urea fertilizer backgrounds

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On-farm experiments (24) were conducted in two seasons to assess the influence of sulfur impurity in triple-super phosphate (TSP) on wheat. The experiments were laid-out in completely randomized block design in triplicate. Nutrients investigated include: Nitrogen (N), sulfur (S) and phosphorus (P). The TSP is tested to contain about 2 to 6% sulfur as impurity. However, wheat did not show response to sulfur from TSP. Though, it was not statistically significant, however, there were always yield increments by certain percent due to S-TSP in eight out of 10 sites with increasing trends of yield curves. Overall, the effects of such nutrients incidentally supplied from concentrated fertilizers like TSP should not be overlooked, as the benefits could be expressed in quality attributes of crops. Indeed, this is vital in varietal specific nutrient requirement studies. Overall, the benefits of such small-dose of nutrients could be many-folds to small-holders if integrated with organic resources, thereby encouraging organic agriculture. But, wheat showed response to sulfur from gypsum (in 67%) and N from urea (100%) of sites. As depicted, the sharply-rising yield curves with applied nitrogen elucidate that nitrogen was the most limiting nutrient followed by S. Always rising yield response curves also show strong positive synergies between the applied nutrients.

Key words: Nitrogen, micro-dosing, precision-farming, sulfur impurity, triple-super phosphate (TSP), wheat yield response.

INTRODUCTION

Soil fertility decline in Ethiopia has been well documented with most attention that has been given to nitrogen (N), phosphorus (P) and potassium (K). Sulfur (S) is a macro-nutrient that is taken-up by grain crops in amounts similar to those of P, 10 to 30 kg/ha (Scherer, 2001; Jamal et al., 2010; Mengel and Kirkby, 1987). According to Weil (2011) adequate level of sulfur in soils is very important both for the satisfactory growth of plants; and also for ensuring optimum levels of S-containing essential amino-acids, oils, vitamins and flavored compounds in plants. The essential amino-acids methionine (21% S), cysteine (26% S) and cystine (27% S), which are the building blocks of proteins in food and feed contain S (Chattopaddhyay and Ghosh, 2012). It is also known to

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Table 1. Locations of the selected study sites in the central highlands of Ethiopia.

Location/zone	Farmer field/site	Latitude (N)		Longitude (E)		Altitude (m)	Soil type
		Degree	mm.mm	Degree	mm.mm		
Arsi (Ar)	Abosara Alko1 (AA1)	7	49.454	39	1.661	2297.02	CV
Arsi (Ar)	Dosha1 (Do1)	7	53.813	39	6.176	2418.32	Nit.
Arsi (Ar)	Boro Lencha1 (BL1)	8	7.476	39	17.722	2186.37	And.
East Shewa (ES)	Kilinto (Ki)	8	54.099	38	49.133	2204.00	PV
West Shewa (WS)	Nano Kersa1 (NK1)	8	55.605	38	31.062	2123.74	CV
West Shewa (WS)	Dawa Lafto1 (DL1)	8	59.147	38	26.92	2173.60	Nit.

PV = Heavy black clays or Pellic Vertisols; CV = Light black clays or chromic vertisols; Nit. = red clay soils (Nitosols); And. = are Andosols.
Source: Author Survey

enhance other nutrients use efficiency; and ranks second only to N in importance for optimum crop yield and quality produce (Brown et al., 2005). For example, wheat protein is rich in non-essential glutamic-acid and proline, whereas deficient in most essential-amino acids such as lysine, tryptophan, threonine, methionine and histidine (Khan et al., 2014). These amino-acids contain sulfur, and therefore, without modest or significant supply of sulfur, crop-plants can neither express their full genetic potential yield/quality nor can complete their life cycle (Khan et al., 2014).

But, when planning the nutritional requirement it is well recognized that oil crops and legumes have high sulfur demand. Whereas, cereals have lower sulfur demand, and are reported to remove about 10 to 20 kg S/ha for producing the grain yields of 8 Mg/ha (Walker and Booth, 1992; McGrath et al., 1996; Oates and Kamprath, 1985). Similarly, Zörb et al. (2013) reported a modest amount of S, 15 to 35 kg S/ha for better quality and optimum wheat yields.

With respect to its response, crops like wheat can respond to sulfur rating between 5 and 10 kg S/ha (Weil, 2011). A study by Menna et al. (2015, 2016) reported 5 to over 20 kg S/ha or even less for wheat, depending on soils. Indeed, this is an amount of sulfur that can be supplied to plants from accidental applications of concentrated fertilizers like TSP and DAP. These high-analysis fertilizers, however, contain significant amount of S, 2 to 6% by weight (Weil, 2011; Weil and Mughogho, 2000). This is a micro-dose amount that can significantly increase small-holding farmers' yields in precision-farming. In the view of the aforementioned, therefore, this paper sought to (1) evaluate wheat response to the incidental application of S impurity from TSP; (2) to infer the most yield limiting nutrient from yield response curve(s); and (3), to see the interaction effect of S, N and P following wheat yield trends.

MATERIALS AND METHODS

Site selection

On-farm field experiments were conducted in three representative locations, namely Arsi (Ar), East Shewa (ES) and West Shewa (WS) zones in central Ethiopian agricultural lands. The three representative locations and salient features are presented in Table 1.

Experimental materials, treatments and design

Gypsum samples were collected from six curie sites and analyzed for the SO_4-S contents and/or for its purity. The materials were tested to contain the SO_4-S contents of 13.5 to 18.0%. Then the samples with 18.0% SO_4-S were taken as experimental material. In order to investigate the response of wheat to S from TSP, 24 on-farm experiments were conducted in two seasons. The sites were geo-referenced using Global Positioning System (GPS) GARMIN-model # GPS-60 assisted by Google Earth (2011) as presented in Table 1. In season-I (2013/2014), 18 experiments were conducted, that is, 6 per zone (location) covering different agro-ecological zones (AEZs). In this season, four treatments: absolute control (CK); N alone = N_1; nitrogen + sulfur or NS = N_1S_1; and nitrogen + phosphorus + sulfur or NPS = $N_1P_1S_1$ were tested. The nutrients evaluated were 2-levels of S (0 and 20 kg/ha), 2-levels of P (0 and 20 kg/ha), and 2-levels N (0 and 69 kg/ha).

In season-II (2015/2016), another 6 experiments were conducted (2 per zone). In this season, three study sites, namely Gora Silingo$_2$ (GS_2), Keteba$_2$ (Ke_2), and Nano Suba$_2$ (NS_2) were selected because of the wheat response to S from gypsum in season-I. Whereas, Wonji Gora1 (Do_2), Bekejo$_2$ (Bk_2) and Berfeta Tokofa$_2$ (BT_2) were selected randomly without pre-soil testing, but on areas some 0.5 to 1.5 miles away from last season S responsive sites, namely Do_1, Bk_1 and (BT_1), respectively. In this set, 9 treatments were tested: CK; nitrogen alone or N = N_1; nitrogen + sulfur or NS_1; nitrogen + sulfur or NS_2; nitrogen + sulfur or NS_3; nitrogen + phosphorus or NP = N_1P_1; nitrogen + phosphorus + sulfur or NPS_1; nitrogen + phosphorus + sulfur or NPS_2; and nitrogen + phosphorus + sulfur or NPS_3. Nutrient evaluated were 4-levels of sulfur (S) (S_0 = CK, S_1 = 5, S_2 = 10 and S_3 = 20 kg S/ha); 2-levels of nitrogen (N) (N_0 = CK, N = 69 kg N/ha); and 2-levels of phosphorus (P) (P_0 = CK and P_1 = 20 kg P/ha). In both seasons, randomized complete block design (RCBD) was used in triplicate. In both season, each replicate had 12 plots, with an area of 3 m × 5 m = 15 m^2. Agronomic spacing for wheat (25 × 5 cm between rows and plants, respectively) was used. Each plot had 12-rows of plants with 2 borders in each side and another one-row for plant sampling. The central rows with an area of 4 m × 1.5 m = 6 m^2) were used for agronomic data collection. Nitrogen was split applied; where 1/3 was incorporated into soils before seeding and the remaining 2/3 was top-dressed at the stage of tillering. Whereas, the entire sources of S and P were incorporated into soils just before seeding. A wheat cultivar known as "Kekeba" was used as a test-crop.

Table 2. Analytical method used for the studied soils.

Variable considered	Unit(s) of measurement	Analytical method by	References
pH	na	Potentiometrically,1:2.5 soil:water solution	McLean (1986)
Total Exch. Acidity (H^+ & Al^{3+})	cmol$_c$/kg	1.0M KCl & titration by 0.01M NaOH (at pH:7.0)	Pansu and Gautheyrou (2006)
Electrical Conductivity (EC)	mS/cm	1:5 soil:water suspension	Klute (1986)
Exch. Bases (Na^+ & K^+)	cmol$_c$/kg	1*M* NH4OAc solution, pH =7.00	Rowell (1994)
Exch. Bases (Ca^{2+} & Mg^{2+})	cmol$_c$/kg	1*M* NH4OAc solution, pH =7.00	Van Reeuwijk (2002)
Cation Exch. Capacity (CEC)	cmol$_c$/kg	1*M* NH4OAc solution, pH =7.00	Van Reeuwijk (2002)
Saturation percent (SP)	%	Calculation from exch. bases	Van Reeuwijk (2002)
Calcium Saturation % (Ca-SP)	%	Calculated from exch. Ca^{2+}	Van Reeuwijk (2002)
Cation exch. capacity (CEC)	cmol$_c$/kg	1 *M* NH_4OAc solution at pH =7.00	Van Reeuwijk (2002)
Exch. Al^{3+}	cmol$_c$/kg	The difference between exch. acidity and H^+	Bertsch and Bloom (1996)
Total nitrogen (TN)	%	Kjeldahl as described in	Okalebo et al. (2002)
Organic carbon (OC)	%	Walkley-Black as described in	Nelson and Sommers (1996)
Available P	mg/kg	Bray-I, (pH<7.00), for soils from Ar/WS.	Bray and Kurtz (1945)
Available P	mg/kg	Olsen (pH>7.00), for soils from ES.	Olsen et al. (1954)
Sulfate sulfur (SO_4-S)	mg/kg	Calcium phosphate, turbidimetric method	Rowell (1994)
Soil texture	na	Hydrometer method	Bouyoucos (1962)

Saturation percent (SP); total nitrogen (TN); organic carbon (OC); available phosphorus (P); sulfate sulfur (SO_4-S); electrical conductivity (EC); exchangeable (Exch.); and cation exchange capacity (CEC); na = not applicable.

Soil sampling, preparation and analysis

Soil samples (24) were collected in two seasons or sets. The first set, 18 samples were collected in season-I before planting each of the 18 gypsum (S + Ca) response experiments. The second set, 6 samples were collected in season-II before planting each of the 6 S rate experiments. In doing so, soil samples representing each block were taken from 10-spots (0-20 cm soil depth) and bulked together. Then the samples were further composted to make one sample per farmer field and air dried in dust free rooms. The dried samples were ground and made to pass through < 2 mm sieve and analyzed for the variables as per the methods shown in Table 2.

Agronomic data analysis

Yield data were analyzed using SAS Version-9 (SAS Inst. Inc. 2012). The ANOVA was done using PROC-MIXED in SAS protocols to evaluate treatment differences. When the differences between treatments were significant, the least significant difference (LSD) was used to separate means at 5%, 1% or 0.1% probability levels. More specifically, pair-wise orthogonal comparisons among treatments using SAS contrast statements were made to determine the significance of treatments at each level or to determine the effect of S as an impurity from TSP (S-TSP) together with N-urea and P-TSP on wheat yield.

RESULTS AND DISCUSSION

Physico-chemical properties of soils

Table 3 presents the properties of initial soils sampled before planning in the two seasons. As shown, in WS zone the pH ranged from strongly to moderately acidic, whilst it was strongly acidic to near neutral in Arsi zone. In ES zone it ranged from neutral to moderately alkaline (calcareous). The nitrogen (N) content is very low or low based on the ratings by Landon (1991). Available P at the ES and Arsi zones was either very low or low as per the ratings by (Horneck et al., 2011). In such low P soils, fertilizer responses are most likely expected, but in the calcareous soils of ES and in strongly acidic soils of WS its availability can be limited due to the precipitation reactions with Ca and aluminium (Al). With respect to sulfate sulfur (SO_4-S), based on the ratings by Tandon (1991) over 50% of soils were found to be S limiting. Organic carbon (OC) content of the soils in the first season was also either very low or low. In only about 30% of soils the OC were either marginal of above the threshold values.

Table 3. Selected physico-chemical variables of soils of the study sites before planting.

Study area/zone	Farmer field/site	pH Soil:H_2O	EC (mS/cm)	Exchangeable Base Cations (cmol$_c$/kg)				CEC (cmol$_c$/kg)	SP (%)	TN (%)	OC (%)	Av.P (mg/kg)	SO_4-S (mg/kg)	Texture
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}							
Season-I														
Ar	Abosara Alko (AA_1)	6.00	0.10	10.74	2.70	0.04	1.56	23.8	63.20	0.13	1.11	5.12	6.94	SC
Ar	Dosha (Do_1)	5.30	0.10	7.55	1.44	0.23	1.10	24.3	42.48	0.25	2.04	1.84	10.44	C
Ar	Boru Lencha (BL_1)	7.00	0.07	13.94	4.62	0.27	1.78	29.8	69.19	0.11	1.07	3.29	4.32	SC
ES	Ude (Ud_1)	7.10	0.06	26.10	6.06	0.29	3.32	39.4	90.80	0.10	1.23	9.53	12.37	C
ES	Kilinto (Ki_1)	8.00	0.24	32.48	8.53	0.32	4.18	47.8	95.23	0.06	1.39	8.17	8.27	C
OL	Nano Kersa (NK_1)	6.70	0.07	11.45	3.85	0.29	2.09	26.4	66.98	0.07	1.41	0.22	11.89	C
OL	Dawa Lafto (DL_1)	5.9	0.05	5.96	1.39	0.30	2.19	18.6	52.91	0.14	1.71	0.28	10.83	CL
Season-II														
Ar	Gora Silingo (GS_2)	6.24	0.11	8.79	4.20	0.34	4.14	26.8	65.24	0.17	2.18	3.01	12.11	CL
ES	Bekejo (Bk_2)	7.15	0.10	9.72	5.22	0.34	2.50	33.4	83.19	0.08	1.17	12.01	4.03	SC
WS	Nano Suba (NS_2)	5.85	0.07	4.01	1.27	0.24	2.09	13.8	55.16	0.14	0.96	0.89	4.58	C
WS	Berfeta Tokofa (BT_2)	4.85	0.21	7.73	2.89	0.44	2.50	36.2	37.45	0.15	2.03	0.50	35.83	C

Study areas/zones/locations: Arsi (Ar), East Shewa (ES), West Shewa (WS). Soil texture: Sandy clay loam (SCL), Clay (C), Sandy clay (SC), and Clay loam (CL). Subscripts 1 & 2 in the tables indicate the two cropping seasons-I & II.
Source: Author Survey

Response of wheat to S impurity in TSP

Ethiopia needs to increase agricultural production in order to feed an ever increasing population estimated at 102 million in 2017 (EEA/EEPRI, 2017). However, to ensure cost-effective and quality produce, healthy soils are needed. Sulfur even in its micro-dose level is essential not only for plant growth and quality produce, but also enhances other nutrients' use efficiency and ranks second only to N in importance for optimum crop performance (Brown et al., 2005; Zörb et al., 2013). The following discuss wheat response specifically to S impurity from TSP (S + P) in relation to gypsum (S + Ca) and urea (N). For this purpose, sites/soils which did not show response to P from TSP or P-sufficient sites are considered. Responses and/or benefits of sulfur are easily overlooked where a basal dressing of P is applied as inorganic triple-super phosphate (TSP), a high-analysis fertilizer which is commonly assumed to be free of S (Shenkalwa, 1986). However, TSP typically contains agronomic-ally significant quantities of S, 2 to 6% by weight (Weil, 2011; Weil and Mughogho, 2000). According to the study, TSP is a soluble fertilizer primarily containing about 20% total P (44-48% P_2O_5) and 13-15% calcium (Ca). It is also estimated to contain a maximum amount of 4% residual phosphoric acid (H_3PO_4).

Sulfur is recognized to be associated with TSP during its manufacturing from rock phosphate and sulfuric acid (H_2SO_4). To see such effects on crop yields, pre-planned pair-wise orthogonal comparisons among treatments using SAS contrast statements were done on soils that showed response to applied S from gypsum (significantly or marginally), but not to P. The major target sites for such analysis were: AA_1, Do_1, BL_1, GS_2 (Ar zone); Ud_1, Ki_1, Ke_2 and Bk_2 (ES); and NK_1/(DL_1) (WS) in seasons-I and II (Tables 4 to 8). In this assessment, the effects of S-TSP can be seen from the yield gap between treatments NPS_3 and NS_3. It is well noted that wheat cultivar showed significant responses ($p \leq 0.001$) to S-gypsum on average, in 67% of sites. However, the responses of wheat to S-TSP were not statistically significant, or the ANOVA did not reveal such responses.

This might be due to the inherently low levels of available P in soils, which can be seen by looking

Table 4. Orthogonal comparisons among treatments in Arsi zone, at A/Alko, Dosha and G/Silingo sites (Season-I).

Treatment comparison	A/Alko site				Dosha site				B/Lencha site			
	DBM	95 % CL			DBM	95 % CL			DBM	95 % CL		
NPS-NS	0.09	-0.75	0.93	Ns	0.92	-0.01	1.84	ns	0.55	-0.07	1.14	ns
NPS-N	2.04	1.20	2.88	***	1.35	0.43	2.27	***	2.24	1.63	2.84	***
NPS-CK	4.73	3.89	5.57	***	3.63	2.71	4.56	***	3.83	3.23	4.44	***
NS-N	1.95	1.11	2.79	***	0.43	-0.49	1.36	ns	1.70	1.10	2.30	***
NS-CK	4.65	3.81	5.49	***	2.72	1.79	3.64	***	3.30	2.69	3.90	***
N-CK	2.69	1.85	3.53	***	2.28	1.36	3.21	***	1.60	0.99	2.20	***

DBM = Difference between means; CL = confidence limits; N = nitrogen; P = phosphorus; S = sulfur and; CK = Check (no any fertilize); ns = not significant at 95% CL. ***Comparisons significant at 0.001 levels. Percentage grain yield increase due to S from TSP at: AA_1 = 1.5%; Do_1 = 20.0%; BL_1 = 12.0%.
Source: Author Survey

Table 5. Orthogonal comparisons among treatments in E/Shewa zone, C/Donsa, Keteba and Ude sites (Season-I).

Treatment comparison	Ude site				Kilinto site				N/Kersa site			
	DBM	95 % CL			DBM	95 % CL			DBM	95 % CL		
NPS-NS	0.44	-0.15	1.04	Ns	0.32	-0.02	0.67	ns	0.59	-0.06	1.25	ns
NPS-N	0.84	0.25	1.44	***	1.80	1.46	2.15	***	1.13	0.48	1.79	***
NPS-CK	3.15	2.56	3.75	***	4.21	3.87	4.56	***	3.30	2.65	3.96	***
NS-N	0.40	-0.19	0.99	Ns	1.48	1.13	1.83	***	0.54	-0.11	1.19	ns
NS-CK	2.71	2.12	3.30	***	3.89	3.54	4.24	***	2.71	2.06	3.36	***
N-CK	2.31	1.72	2.90	***	2.41	2.06	2.76	***	2.17	1.52	2.82	***

DBM = Difference between means; CL = confidence limits; N = nitrogen; P = phosphorus; S = sulfur and; CK = Check (no any fertilize); ns = not significant at 95% CL. ***Comparisons significant at 0.001 levels. Percentage grain yield increase due to S from TSP at: Ud_1 = 12.2% and Ki_1 = 6.5%; NK_1 = 13.8%; and/or similar DL_1 = 13.9%.
Source: Author Survey

at yield responses due to P, that is, the yield gaps due to the treatment effects between NP and N. But, the comparisons showed non-significant negative limits at 95.0% (Tables 4 to 8 and Figures 1 to 10), indicating that there were no wheat grain yield responses to S from TSP (that is, beyond 20 kg S/ha, the amount of S supplied as mineral gypsum). If a site is responsive to S-gypsum, but not to P-TSP, then any yield increase beyond 20 kg S/ha can be regarded as the response coming due to S-TSP when keeping other factors constant. The major reason could be that the response of wheat to S that is expected from TSP might have been obscured due to the inherently low levels of P in soils (Table 3). This can easily been seen by looking at the yield gaps between NS_2 and NS_3 (responsive = r); NS_3 and NP (non-responsive = ns); and NP and NPS (responsive = r) in the x-axis of Figures 1 to 10 and Tables 4 to 8. Then, the observed difference in the first two and last two, and the lack of response between the second two treatments may suggest that the amount of S from TSP (that is, 2 to 6 kg S/ha) also might not be sufficient enough to bring the intended statistically significant yield. This can also be affirmed by looking at the lower treatments, for example (at 5 kg S/ha). This is to mean that there was yield increase due to S from gypsum, but which was not statistically significant. Though, the responses of wheat to S from TSP were not statistically significant, there are always yield increments between NS_3 and NP (nr) treatments by certain percentages. So, such yield progressions should not be overlooked, because it can be expressed in the quality attributes of crops like wheat. For example, at GS_2 site there was grain yield response due to N and S at all levels, except for S that is expected from TSP (that is, the yield gap between NPS_3-NS_3). But, the yield increments at this point can also be due to P as there was P response in this site, which is obtained as a yield difference between treatments, N and NP.

As the initial soils tested low in P, the suggested amount of S-TSP (2-6%) may also not be adequate enough to bring statically significant yield. This reason can be noticeable from yield differences between the lower treatments (N and NS_1) as there was no yield response due to S-gypsum at 5 kg S/ha. However, at GS_2 site, S treatments above 5 kg/ha had significant yield increases throughout, suggesting the existence of positive synergy between S and N or P. In general, it

Table 6. Orthogonal comparisons among treatments for wheat gain yield, at the Gora Silingo site in the Arsi zone (Season-II).

Treatment comparison	**G/Silingo site**			
	DBM	**95% CL**		
NPS_3-NPS_2	1.0933	0.5639	1.6228	***
NPS_3-NPS_1	1.3933	0.8639	1.9228	***
NPS_3-NP	1.7433	1.2139	2.2728	***
NPS_3-NS_3	1.8100	1.2806	2.3394	***
NPS_3-NS_2	2.6267	2.0972	3.1561	***
NPS_3-NS_1	3.2200	2.6906	3.7494	***
NPS_3-N	3.7233	3.1939	4.2528	***
NPS_3-CK	5.3033	4.7739	5.8328	***
NPS_2-NPS_1	0.3000	-0.2294	0.8294	ns
NPS_2-NP	0.6500	0.1206	1.1794	***
NPS_2-NS_3	0.7167	0.1872	1.2461	***
NPS_2-NS_2	1.5333	1.0039	2.0628	***
NPS_2-NS_1	2.1267	1.5972	2.6561	***
NPS_2-N	2.6300	2.1006	3.1594	***
NPS_2-CK	4.2100	3.6806	4.7394	***
NPS_1-NP	0.3500	-0.1794	0.8794	ns
NPS_1-NS_3	0.4167	-0.1128	0.9461	ns
NPS_1-NS_2	1.2333	0.7039	1.7628	***
NPS_1-NS_1	1.8267	1.2972	2.3561	***
NPS_1-N	2.3300	1.8006	2.8594	***
NPS_1-CK	3.9100	3.3806	4.4394	***
NP-NS_3	0.0667	-0.4628	0.5961	ns
NP-NS_2	0.8833	0.3539	1.4128	***
NP-NS_1	1.4767	0.9472	2.0061	***
NP-N	1.9800	1.4506	2.5094	***
NP-CK	3.5600	3.0306	4.0894	***
NS_3-NP	-0.0667	-0.5961	0.4628	ns
NS_3-NS_2	0.8167	0.2872	1.3461	***
NS_3-NS_1	1.4100	0.8806	1.9394	***
NS_3-N	1.9133	1.3839	2.4428	***
NS_3-CK	3.4933	2.9639	4.0228	***
NS_2-NS_1	0.5933	0.0639	1.1228	***
NS_2-N	1.0967	0.5672	1.6261	***
NS_2-CK	2.6767	2.1472	3.2061	***
NS_1-N	0.5033	-0.0261	1.0328	ns
NS_1-CK	2.0833	1.5539	2.6128	***
N-CK	1.5800	1.0506	2.1094	***

Trt = Treatment; DBM = difference between means; CL = confidence Limits; N = nitrogen; P = phosphorus; S = sulfur; CK = Check/control; ns = not significant. ***Comparisons significant at the 0.001 level. r = Response, nr = no response.
Source: Author Survey

should be noted that though not statistically significant, this can be expressed in quality attributes of harvested produces. Therefore, accounting for such nutrient contents existing as impurities in concentered fertilizers like TSP and DAP will be very important in precision-farming. This is also helpful in avoiding unnecessary fertilizer blending, if used in integration with locally available materials like gypsum. This at the same time will encourage organic farming practices.

Response of wheat to N, S from gypsum and phosphorus from TSP

As graphically presented, wheat showed significant responses to S from gypsum (S + Ca) (Figures 1 to 10).

Table 7. Orthogonal comparisons among treatments for wheat gain yield, at the Bekejo site in the E/Shewa zone (Season-II).

Treatment comparison	Bekejo site			
	DBM	95% CL		
NPS_3-NPS_2	1.25000	1.04998	1.45002	***
NPS_3-NPS_1	2.29333	2.09331	2.49336	***
NPS_3-NS_3	2.61667	2.41664	2.81669	***
NPS_3-NP	2.73667	2.53664	2.93669	***
NPS_3-NS_2	3.53667	3.33664	3.73669	***
NPS_3-NS_1	4.05667	3.85664	4.25669	***
NPS_3-N	4.43333	4.23331	4.63336	***
NPS_3-CK	5.40667	5.20664	5.60669	***
NPS_2-NPS_1	1.04333	0.84331	1.24336	***
NPS_2-NS_3	1.36667	1.16664	1.56669	***
NPS_2-NP	1.48667	1.28664	1.68669	***
NPS_2-NS_2	2.28667	2.08664	2.48669	***
NPS_2-NS_1	2.80667	2.60664	3.00669	***
NPS_2-N	3.18333	2.98331	3.38336	***
NPS_2-CK	4.15667	3.95664	4.35669	***
NPS_1-NS_3	0.32333	0.12331	0.52336	***
NPS_1-NP	0.44333	0.24331	0.64336	***
NPS_1-NS_2	1.24333	1.04331	1.44336	***
NPS_1-NS_1	1.76333	1.56331	1.96336	***
NPS_1-N	2.14000	1.93998	2.34002	***
NPS_1-CK	3.11333	2.91331	3.31336	***
NS_3-NP	0.12000	-0.08002	0.32002	ns
NS_3-NS_2	0.92000	0.71998	1.12002	***
NS_3-NS_1	1.44000	1.23998	1.64002	***
NS_3-N	1.81667	1.61664	2.01669	***
NS_3-CK	2.79000	2.58998	2.99002	***
NP-NS_3	-0.12000	-0.32002	0.08002	ns
NP-NS_2	0.80000	0.59998	1.00002	***
NP-NS_1	1.32000	1.11998	1.52002	***
NP-N	1.69667	1.49664	1.89669	***
NP-CK	2.67000	2.46998	2.87002	***
NS_2-NS_1	0.52000	0.31998	0.72002	***
NS_2-N	0.89667	0.69664	1.09669	***
NS_2-CK	1.87000	1.66998	2.07002	***
NS_1-N	0.37667	0.17664	0.57669	***
NS_1-CK	1.35000	1.14998	1.55002	***
N-CK	0.97333	0.77331	1.17336	***

Trt = Treatment; DBM = difference between means; CL = confidence Limits; N = nitrogen; P = phosphorus; S = sulfur; CK = Check/control; ns = not significant. ***Comparisons significant at the 0.001 level.
Source: Author Survey

Wheat specifically showed highly significant response ($p \leq 0.001$) to N-urea in all sites, but with less response to P when compared with S and N. Sites which did not show response to P in relation to next lower level treatment (that is, NS) are AA_1, Do_1, and BL_1 (Ar zone) making 16.7%; and Ud_1 and Ki_1 (ES zone), which make up 5.6% of the sites. Sites with marginal response to P were Do_1, Ud_1, DL_1, and NK_1 which make up 22% of the sites.

With respect to S, about 50% sites showed highly significant response ($p \leq 0.001$) to S-gypsum as related to soil-test levels; and 22% of the sites had marginal response ($p \leq 0.05$). Figures 7 to 10 depict wheat response to S-gypsum, N and/or P at GS_2, Ke_2, Bk_2, and N/S_2 sites in season-II. These are sites which showed

Table 8. Orthogonal comparisons among treatments for wheat gain yield, at the Nano Suba site in the O/Liyuu zone (Season-II).

Treatment comparison	(N/Suba)$_2$ site			
	DBM	95 % CL		
NPS_3-NPS_2	1.7433	1.4751	2.0116	***
NPS_3-NPS_1	2.0533	1.7851	2.3216	***
NPS_3-NS_3	2.3500	2.0817	2.6183	***
NPS_3-NP	2.4667	2.1984	2.7349	***
NPS_3-NS_2	3.2033	2.9351	3.4716	***
NPS_3-NS_1	3.8133	3.5451	4.0816	***
NPS_3-N	4.1333	3.8651	4.4016	***
NPS_3-CK	5.4433	5.1751	5.7116	***
NPS_2-NPS_1	0.3100	0.0417	0.5783	***
NPS_2-NS_3	0.6067	0.3384	0.8749	***
NPS_2-NP	0.7233	0.4551	0.9916	***
NPS_2-NS_2	1.4600	1.1917	1.7283	***
NPS_2-NS_1	2.0700	1.8017	2.3383	***
NPS_2-N	2.3900	2.1217	2.6583	***
NPS_2-CK	3.7000	3.4317	3.9683	***
NPS_1-NS_3	0.2967	0.0284	0.5649	***
NPS_1-NP	0.4133	0.1451	0.6816	***
NPS_1-NS_2	1.1500	0.8817	1.4183	***
NPS_1-NS_1	1.7600	1.4917	2.0283	***
NPS_1-N	2.0800	1.8117	2.3483	***
NPS_1-CK	3.3900	3.1217	3.6583	***
NS_3-NP	0.1167	-0.1516	0.3849	ns
NS_3-NS_2	0.8533	0.5851	1.1216	***
NS_3-NS_1	1.4633	1.1951	1.7316	***
NS_3-N	1.7833	1.5151	2.0516	***
NS_3-CK	3.0933	2.8251	3.3616	***
NP-NS_3	-0.1167	-0.3849	0.1516	ns
NP-NS_2	0.7367	0.4684	1.0049	***
NP-NS_1	1.3467	1.0784	1.6149	***
NP-N	1.6667	1.3984	1.9349	***
NP-CK	2.9767	2.7084	3.2449	***
NS_2-NS_1	0.6100	0.3417	0.8783	***
NS_2-N	0.9300	0.6617	1.1983	***
NS_2-CK	2.2400	1.9717	2.5083	***
NS_1-N	0.3200	0.0517	0.5883	***
NS_1-CK	1.6300	1.3617	1.8983	***
N-CK	1.3100	1.0417	1.5783	***

Trt = Treatment; DBM = difference between means; CL = confidence Limits; N = nitrogen; P = phosphorus; S = sulfur; CK = Check/control; ns = not significant. ***Comparisons significant at the 0.001 level.
Source: Author Survey

response to S-gypsum but not to P from TSP. Particularly, wheat showed highly significant response *** to N and responses to S were either at ** or *. Most interestingly, in all investigated sites the responses to N, S and/or P are related to soil-test values.

From overall results it is observed that, ES had better consistency of wheat response to S at all treatment levels, correlating better with soil-test values compared with Ar and WS zones. Furthermore, in ES zone there was better synergy between S, N or P which is manifested by its always increasing yield advantage with the type and level of nutrients supplied. However, the interaction effect of S with N is more pronounced than that of S. Crista et al. (2013) made a similar observation.

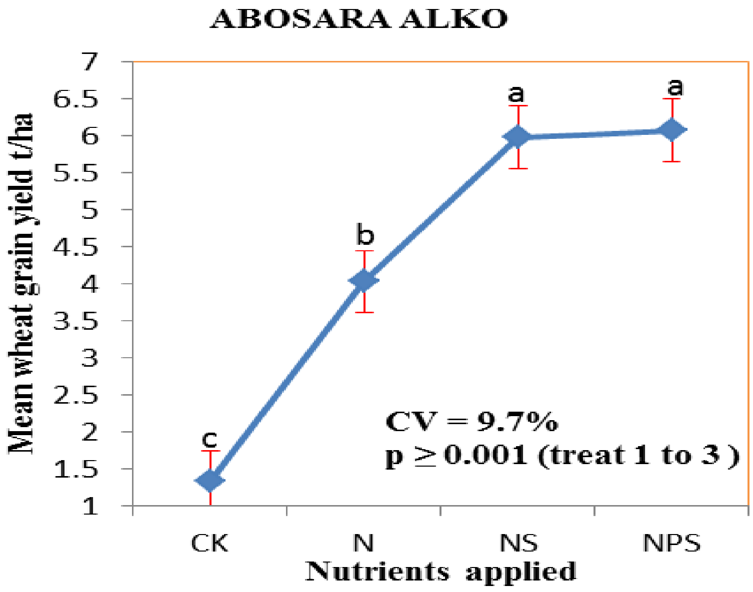

Figure 1. Wheat grain yield at AA1 in response to the applied S, N and P (season-I). Means bearing the same letter(s) on bars within a field-site are not significantly different at *p ≤ 0.05 prob. level; significant at **p ≤ 0.01; highly significant at ***p ≤ 0.001; and ns = not significant. % grain yield increase due to S-TSP at: AA_1 = 1.5%; Do_1 = 20.0%. Error bars show the standard error of the mean for each treatment.

Source: Author Survey

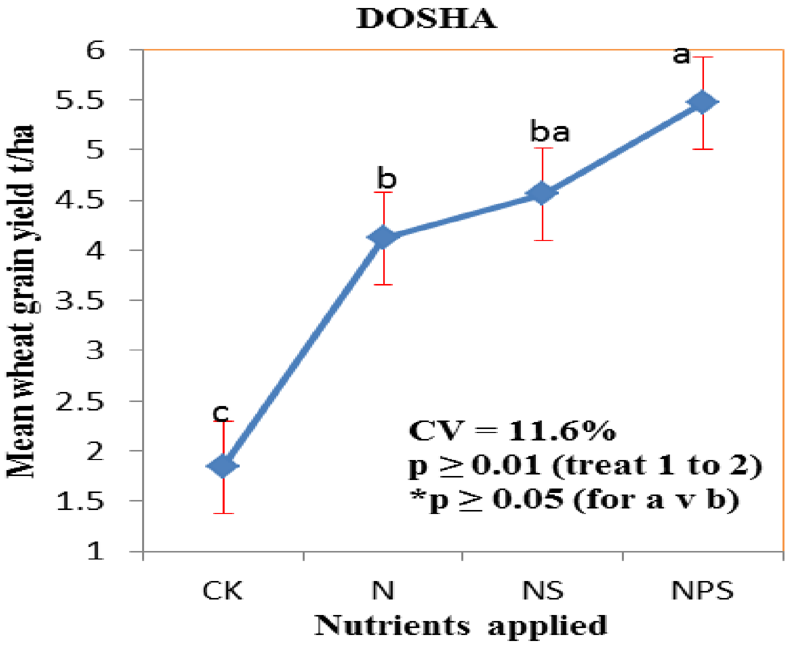

Figure 2. Wheat grain yield at Do1 (Arsi zone) in response to the applied S, N and P (season-I). Means bearing the same letter(s) on bars within a field-site are not significantly different at *p ≤ 0.05 prob. Level; significant at (**p ≤ 0.01); highly significant at ***p ≤ 0.001; and ns = not significant. % grain yield increase due to S-TSP at: AA_1 = 1.5%; Do_1 = 20.0%. Error bars show the standard error of the mean for each treatment.

Source: Author Survey

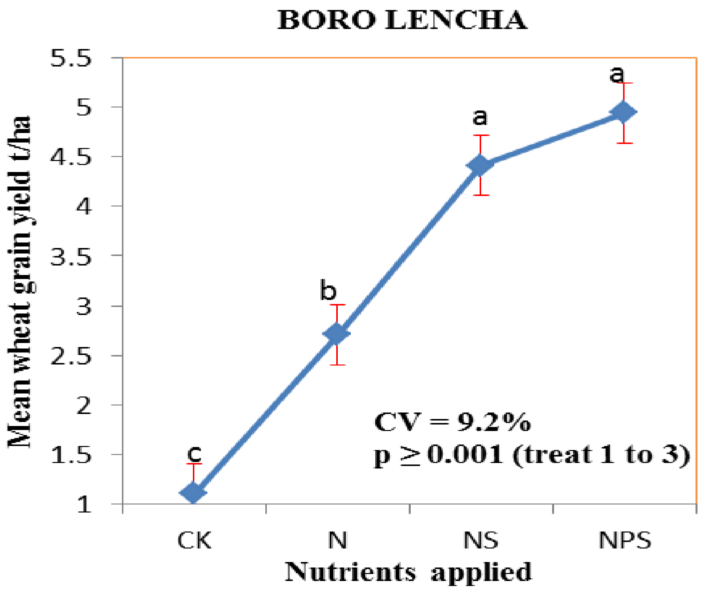

Figure 3. Wheat grain yield response at BL_1 to applied S, N, and P (season-I). Means bearing the same letter(s) on bars within a field/site are not significantly different at $p \le 0.05$ prob. Level.
Source: Author Survey

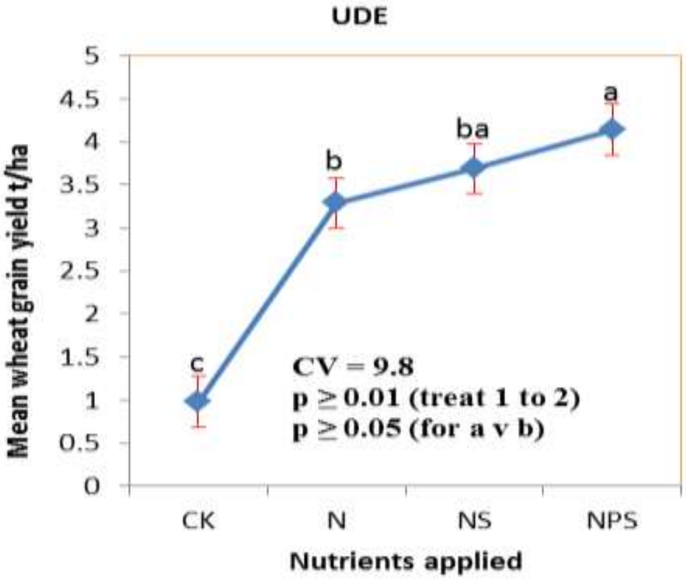

Figure 4. Wheat grain yield response at Ud_1 to applied S, N, and P (season-I). Means bearing the same letter(s) on bars within a field/site are not significantly different at $p \le 0.05$ prob. level.
Source: Author Survey

According to the authors, N and S have a highly significant influence and contribution to protein contents of crop produces than P. Conversely, P has no such greater influence on protein content other than supporting the assimilation and metabolism of absorbed N forms (Crist, et al., 2013).

As depicted in the figures, in all sites with the applied N there were sharp-rises in yield curves even including the P and S non-responsive sites like Boneya Edo (BE_1) indicating that N was the most yield limiting element

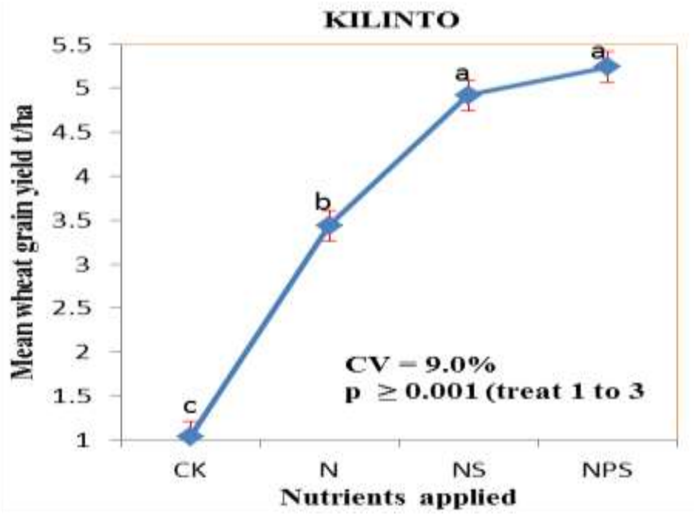

Figure 5. Wheat grain yield response at Ki to S, N, and P (season-I). Means bearing the same letter(s) on bars within a site are not significantly different at p ≤ 0.05 prob. level. Percentage grain yield increase due to S from TSP at: BL_1 = 12.0%, Ud_1 = 12.2% and Ki_1 = 6.5%; NK_1 = 13.8%, and/or similar DL_1 = 13.9%.
Source: Author Survey

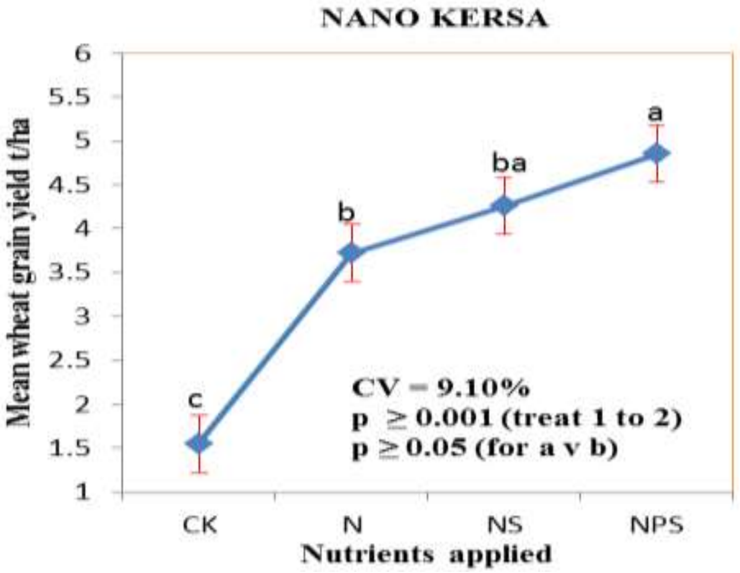

Figure 6. Wheat grain yield response at NK/DL to S, N, and P (season-I). Means bearing the same letter(s) on bars within a site are not significantly different at p ≤ 0.05 prob. level. Percentage grain yield increase due to S from TSP at: BL_1 = 12.0%, Ud_1 = 12.2% and Ki_1 = 6.5%; NK_1 = 13.8%, and/or similar DL_1 = 13.9%.
Source: Author Survey

followed by S and/or P.

With applied N in in terms of yield gains, for example, 72.2 to 148.7% grain yield advantages over control in season-II alone were obtained. This further affirms that N was the most limiting element in the studied soils. So, supplying soils first with adequate amounts of N is of paramount importance to get responses or benefits from any other kind of added essential element(s). Indeed, this is strongly linked with the low contents of OM vis-à-vis the dynamics of N in tropical soils.

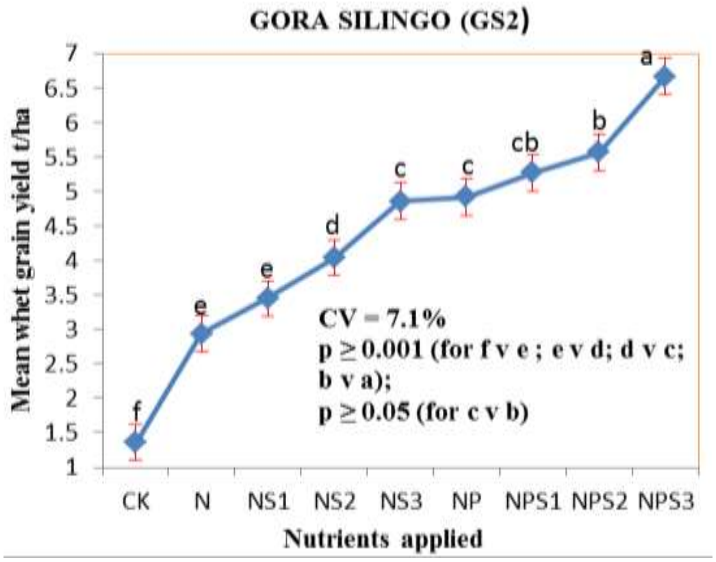

Figure 7. Wheat grain yield at GS_2 site in response to N, S and P nutrition (season-II). Means bearing the same letter(s) within a group are not significantly different statistically at the probability level analyzed by t-test. Percentage grain yield increase due to S from TSP at: GS_2 = 1.23%; and Ke_2 = 4.64%.
Source: Author Survey

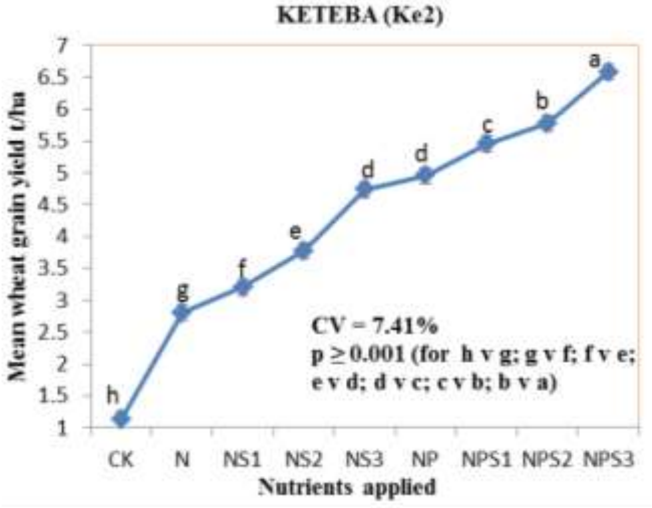

Figure 8. Wheat grain yield at Ke_2 site in response to N, S and P nutrition (season-II). Means bearing the same letter(s) within a group are not significantly different statistically at the probability level analyzed by t-test. Percentage grain yield increase due to S from TSP at: GS_2 = 1.23%; and Ke_2 = 4.64%.
Source: Author Survey

Overall, the maximum grain yield recorded in the present experiments was only about 6.6 t/ha. The average grain yield of wheat, however, can reach ≥ 8.5 t/ha under optimal conditions (Zhao et al., 1999). Indeed this indicates the significance of multitude of factors analysis that is expected to be affecting crop yields. Interestingly, all sites had positive yield gains by certain percentages, except, $Bekejo_2$ and Nano $Suba_2$ sites. These two sites had slightly negative yield disadvantage in the treatments between NP and NS_3. For example, at Bk_2 site the grain

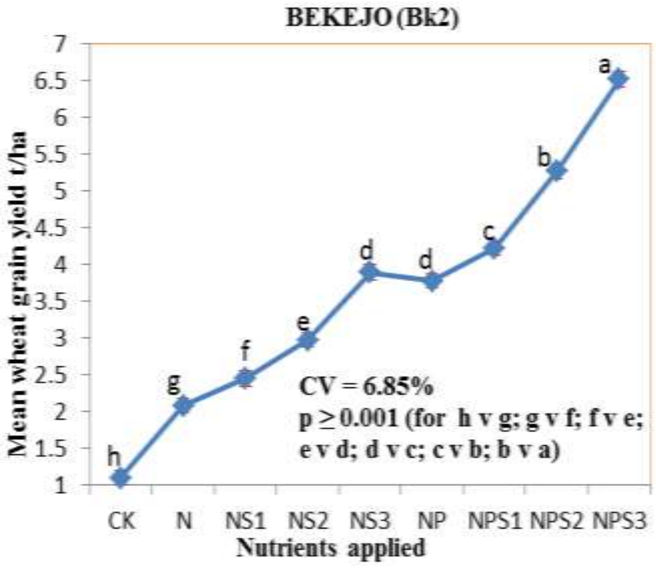

Figure 9. Wheat grain yield response to applied N, S and P nutrients at Bk_2 site (season-II). Means bearing the same letter(s) within a group are not significantly different statistically at the probability level analyzed by t-test. Percentage grain yield increase due to S from TSP at: Bk_2 = -3.08%; N/S_2 = -2.87%.
Source: Author Survey

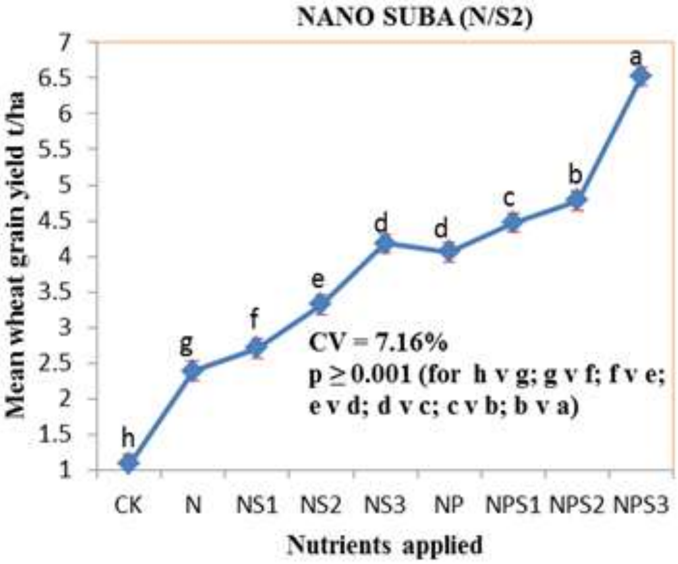

Figure 10. Wheat grain yield response to applied N, S and P nutrients at N/S_2 site (season-II). Means bearing the same letter(s) within a group are not significantly different statistically at the probability level analyzed by t-test. Percentage grain yield increase due to S from TSP at: Bk_2 = -3.08%; N/S_2 = -2.87%.
Source: Author Survey

yield obtained from NS_3 treatment was 3.9 t/ha, slightly greater than that from treatment NP (3.8 t/ha). At $N/Suba_2$ site also the yield obtained from treatment NS_3 (4.18 t/ha) was greater than that from treatment NP (4.06 t/ha). This may indicate that in highly S deficient soils, the test-crop's tendency in absorbing more S than P. Indeed, the soils from these sites were tested very low in SO_4-S compared with others, showing better interaction of N with S in impacting wheat yield under S limiting soils than with P. Such strong interaction effect of N with S on wheat yield and quality attributes was also reported by other workers (Habtegebrial and Singh, 2009; Reussi et al., 2012; Saeed et al., 2013).

CONCLUSIONS AND RECOMMENDATIONS

From the results it can be concluded that there is wheat yield incensements by certain percentages with applied S impurity from TSP in 8 out of 10 target sites, but not statistically significant. These percentages are indicated as captions under the figures. Such small percentage yield increments, however, can be big enough to be expressed in quality attributes of harvested produces. And, this small-dose shouldn't be overlooked as crop varieties differ in their nutrient requirements. This micro-dose amount of nutrient will be important not only in terms of cost-effective fertilizer managed farming practices, but also important in terms of environmental concerns. It should further be noted that such small amounts of S are important to sustain crop production, if integrated particularly with organic resources, because smallholding farmers can afford to buy, 5 to 10 kg bag of similar fertilizers, thereby encouraging organic agriculture. With respect to N, it is noted that in all studied sites, wheat showed highly significant response as depicted by sharply rising yield curves, indicating that N was the most yield limiting nutrient followed by S. Also, always increasing yield gains as observed in the graphs indicate a positive synergy that is occurring between the applied three nutrients, particularly N and S. But, as TSP contains mainly P and Ca as nutrients and others like S as impurity, its effect particularly on alkaline soils of ES zone may need further investigations.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests

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REFERENCES

Bertsch PM, Bloom PR (1996). Aluminum. *In*: Methods of Soil Analysis. Part-3, Chemical Methods, SSSA. Book Series-5, Edited by: Sparks DL, ASA and SSSA, Madison, Wi. USA.

Bouyoucos G (1962). Hydrometer method improved for making particle size analysis of soils. Agronomy Journal 54(5):464-465.

Bray HR, Kurtz LT (1945). Determination of total, organic and available forms of phosphorus in soils. Soil Science 59(1):39-46.

Brown BD, Westcott MJ, Christensen NW, Pan WL, Stark JC (2005). Nitrogen management for wheat protein enhancement. Available at: [http://extension. oregonstate.edu].

Chattopaddhyay S, Ghosh GH (2012). Response of rapeseed (*Brassica Juncea* L.) to various sources and levels of sulfur in red and lateritic soils of west Bengal. International Journal of Plant, Animal and Environmental Science 2(4):59-70.

Crista F, Radulov I, Crista L, Lato A, Sala F, Berbecea A, Nita L, Lato K (2013). Changing quality indicators of wheat crops following fertilizers application. Research Journal of Agricultural Sciences 45(1):1-12.

EEA/EEPRI (2017). Report on the Ethiopian Economy: Challenges of Sustaining Ethiopia's Foreign Exchange Earnings From Exports and Remittances. Ethiopian Economic Association (EEA)/Ethiopian Economic Policy Research Institute (EEPRI), Addis Ababa, Ethiopia.

Habtegebrial K, Singh BR (2009). Response of wheat cultivars to nitrogen and sulfur for crop yield, nitrogen use efficiency and protein quality in the Semiarid Region. Journal of Plant Nutrition 32(10):1768-1787.

Horneck DA, Sullivan DM, Owen JS, Hart JM (2011). Soil test Interpretation Guide. Extension Crevice No. 1478. Oregon State University, USA. 12 p.

Jamal A, Moon Y, Abdin MZ (2010). Sulfur – A general overview and interaction with nitrogen. Australian Journal of Crop Sciences 4(7):523-529.

Khan MS, Ali E, Ali S, Khan WM, Sajjad M A, Hussain F (2014). Assessment of essential amino acids in wheat proteins: a case study. Journal of Biodiversity and Environmental Sciences 4(6):185-189.

Klute A (1986). Methods of Soil Analysis, Part I-Physical and Mineralogical Methods, 2nd (ed.) Vol. 9. ASA and SSSA, Madison, Wi., USA.

Landon JR (1991). Booker Tropical Soil Manual. A handbook for soil survey and agricultural land evaluation in the tropics and sub-tropics. Longman Scientific and Technical Publishers. Essex, New York, USA pp. 113-475.

McGrath SP, Zhao FJ, Withers PJA (1996). Development of sulfur deficiency in crops and its treatments. Proceedings of the Fertilizer Society, No.379, The Fertilizer Society, Peterborough. P J A Withers, ADAS Bridgets, Winchester, UK.

McLean EO (1986). Soil pH and lime requirement. *In*: Methods of Soil Analysis, Chemical and Mineralogical Properties, Part-2, 2nd (ed.) by Page, AL, Miller RH, Keeney DR. ASA and SSSA, Madison, Wi, USA. Agronomy Monograph 9:99-223.

Mengel K, Kirkby EA (1987). Principles of Plant Nutrition. (4th ed.), International Potash Institute. Bern, Switzerland 685 p.

Menna A, Amuri N, Mamo T, Semoka JMR (2015). Wheat response to applied nitrogen, sulphur and phosphorus in three representative areas of the Central Highlands of Ethiopia. International Journal of Plant and Soil Science 8(5):1-11.

Menna A, Semoka JMR, Mamo T, Amuri N (2016). Estimation of Optimum Rate of Sulfur for Application in Soils for Wheat Production in Ethiopia–III. Journal of Agriculture and Ecology Research International 7(1):1-13.

Nelson DW, Sommers LE (1996). Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis, Part-3, Chemical Methods, Sparks DL (ed.) ASA-SSSA, Madison, Wi, USA pp. 961-1010.

Oates KM, Kamprath EJ (1985). Sulfur fertilization of winter wheat grown on deep sandy soils. Soil Science Society of America Journal 49(4):925-927.

Okalebo JR, Gathua KW, Woomer P (2002). Laboratory methods for soil and plant analysis. A work manual 2nd (ed.), (128pp), TSB- CIAT and SACRED Africa, Nairobi, Kenya.

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular-939, US. Government Printing Office, Washington DC, USA.

Pansu M, Gautheyrou J (2006). Handbook of soil analysis: Mineralogical, organic and inorganic methods. Springer, Berlin, Germany.

Reussi N, Echeverría HE, Rozas HS (2012). Stability of foliar N:S ratio in spring red wheat and S dilution curve. Journal of Plant Nutrition 35(7):990-1003.

Rowell DL (1994). Soil Science Methods and Applications. Department of Soil Science, Longman Group, University of Reading, UK 205 p.

Saeed B, Khan AZ, Khalil SK, Rahman HU, Ullah F, Gul H, Akbar H (2013). Response of soil and foliar applied nitrogen and sulfur towards yield and yield attributes of wheat cultivars. Pakistan Journal of Botany 45(2):435-442.

SAS Institute Inc. (2012). SAS Statistical Users Guide. Version-9 (ed.) SAS software, Cary, North Carolina, USA 5136 p.

Scherer HW (2001). Sulfur in crop production. Institute of Agricultural Chemistry, University of Bonn, Germany. European Journal of Agronomy 14(2):81-111.

Shenkalwa EM (1986). Importance of sulfur in balanced plant nutrition in Tanzania. National Soil Survey and Agricultural Research Institute of Mlingano Misc. Publ. M4. Agricultural Research Institute, Tanga, Tanzania.

Tandon HLS (1991). Sulfur Research and Agricultural Production in India, 3rd (ed.). The Sulfur Institute, Washington DC, USA.

Van Reeuwijk LP (2002). Procedure for Soil Analysis, 6th (Ed.), Technical paper-9. International Soil Reference and Information Center (ISRIC), Wageningen, The Netherlands pp. 24-37.

Walker KC, Booth EJ (1992). Sulfur research on oilseed rape in Scotland. Sulfur in Agriculture 16:15-19.

Weil RR (2011). Sulfur deficiency and ammonia volatilization from urea in Ethiopian agricultural soils. Dept. of Env'l Sci. and Tech., Univ. of Maryland, College Park, Umd, USA.

Weil RR, Mughogho SK (2000). Sulfur nutrition of maize in four regions of Malawi. Agronomy Journal 92(4):649-656.

Zhao FJ, Salmont SE, Withers PJA, Monaghan JM, Evans EJ, Shewry PR, McGrath SP (1999). Variation in the bread making quality and rheological properties of wheat in relation to sulfur nutrition under field conditions. Journal of Cereal Sciences 30(1):19-31.

Zörb C, Mühling KH, Hasler M, Gödde V, Niehaus K, Becker D, Geilfus CM (2013). Metabolic responses in grain, ear, and straw of winter wheat under increasing sulfur treatment. Journal of Plant Nutrition and Soil Science 176(6): 964-970.