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Enhancement in Maize-Wheat productivity and N use efficiency through sulfur application in two diverse climatic conditions

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In Maize-Wheat rotation, nitrogen fertilization plays a critical role in increasing grain yield, and the high N usage efficiency is the key to achieve such increases. Sulphur fertilization has been shown in many trials to improve NUE. The importance of balanced nutrient supplementation for improved crop production is widely acknowledged. Thus, the current study is a trial to find out the proper N:S ratio needed to improve wheat-maize productivity. To attain this aim, a field study was conducted at two different locations (Peshawar, semi-arid, hot and Buner, sub-humid, comparatively cooler) while considering the following treatments (individually or in combinations): N inputs were supplied in the form of urea at three different rates (i.e. 90, 120 and 150 kg ha^{-1}) while S was applied as elemental sulphur in four different rates (i.e 0, 20, 40 and 60 kg ha^{-1}). Factorial arrangement in RCB Design was followed with three replications. The key results showed that nitrogen (N) and sulphur (S) significantly improved the productivity of maize and wheat at both locations, (i.e biological yield, grain yield and 1000 grain weight of maize and wheat). In Peshawar, maximum crop productivity was recorded with supplementation of 150 kg N ha^{-1} and 20 kg ha^{-1} S while in Buner maximum crop productivity was recorded with 150 kg N and 40 kg S ha^{-1} application. The availability of S was more pronounced at Peshawar as compared to district Buner. The highest uptake of N was recorded for the application of 150 kg N ha^{-1} while the highest S uptakes were noticed with the application of 60 kg ha^{-1} S. The interaction between N and S have significantly affected crop productivity and soil fertility where there best combination which were noticed with the supplementation of 150 kg N ha^{-1} in combination with 20 kg S ha^{-1} at Peshawar while, the combination needed at Buner was 150:40 (N:S).

Keywords: Key Words: Maize, Wheat, Nitrogen, Sulphur

INTRODUCTION

Increased food grain production has become a necessity to satisfy the growing needs of increasing population in Pakistan and around the world (Shahzad et al. 2019). In order to increase the productivity of crop yield like maize and wheat per unit area, integrated and sustainable approaches are guaranteed for nutrients management on sustainable basis without affecting the future generation requirements (Elahi et al. 2020). An integrated approach to nutrients is required for agriculture suitability and higher crop productivity. Soil is a storehouse of most of the plant essential nutrients for plant growth, but their management will have a significant impact on plant growth and development, fertility, environment and conservation, and agricultural sustainability.(Manirakiza and Şeker, 2020). Accordingly, integrated roles of all stockholders like Farmers, researchers, institutions, and government should be taken into account in order to sustain agricultural productivity and; hence, increases per capita income from agriculture side (Gruhn et al. 2000; Tang et al. 2020).

Nitrogen (N) is the probably the most important nutrient, limiting crop productivity and soil fertility (Chu et al. 2020; Mohanty et al. 2020). The aerial parts of the plant contain 3-4% nitrogen (Cafaro et al. 2020), comprizing the major part of chlorophyll as well as being an integral component of amino acids and ultimately produce proteins (Wang et al. 2021). It is then thought that further N applications are needed to enhance production of cereals (Souza et al. 2016; Wang et la., 2020) and oil crops all over the world (Kaefer et al. 2015; Talebbeigi et al. 2018). Moreover, fodders, grasses, orchards need N (Dogra et al. 2007; McCulloch et al. 2021).Nitrogen inputs may exist in either organic or inorganic forms. Irrespective of the source the N, either NH_4^+ or NO_3^- are the soluble forms for plant uptake. (Chalk, et al. 2020) N is important constituent of all proteins several metabolic processes as well as in the synthesis and energy transfer during metabolic process which are taken place in the cells, N is integral important component of chlorophyll, Balance supply of N enhanced the transformation of carbohydrates into proteins while the unbalance supply of N will induces their assimilates in the vegetative parts of the plants, higher application of N increases succulence in plants, in all plant N is considerably influence the utilization of other nutrients like P,K and S during growth period (Yang et al. 2020a, 2020b).

The chemical fertilizers are readily available sources of N whereas the organic forms become only available after their decomposition/mineralization and so they are slower forms of N than inorganic fertilizers (Miner et al. 2020, Karmakar et al. 2020). Similar to the N should be applied in proper ration with other nutrients to attain high yield productivity (Salim and Raza, 2020, Abdoli, 2020). Sulphur is among the important micro utrients which are usually applied to soil as carriers to commercial mineral fertilizers for enhancing the crop production (Kissel et al. 2020). It is the fourth major nutrient required just slightly less or equal to phosphorus and plays important role in synthesis of protein, vitamins, S-containing essential amino acids (methionine, Cysteine and cysteine (Brosnan et al. 2006; Blachier et al. 2020). Nasreen et al. (2007) and Seilsepour. (2021) concluded that the application of 120 kg ha^{-1} N in combination with 50 kg S ha^{-1} significantly increased the yield of onion and also enhanced N and S uptake. In this concern, fertilizers or amendments of higher nitrogen usage efficiency (NUE) are guaranteed to protect land and surface waters (Qingfeng et al.2016). This efficiency indicates how effectively plant crops transform available N into grain yield. In case of S,

, this nutrient participate in some enzymatic reactions and is therefore important for plants which produces odor like garlic, mustard and onion (Lal, et al. 2018).If S deficiency occurs, the NO_3 Levels in the plant tissues increases considerably and therefore these these plants become toxic to animals when animals feed on them (Dutta et al. 2013; Hemesh and Brar, 2020). This is why balanced inputs of N and S should be considered in crop production. On the other hand, S availability might be limited under the alkaline conditions (Sambo, et al. 2019) as well as in light textured where S is subjected to soil leaching(downward movement of water along nutrients). In case of paddy soils sulphate ions may undergo reduction producing H_2S which is toxic to plants?? Thus, the timing of application of S-fertilizers should be considered precisely especially for S sensitive and high yielding varieties (Mishra et al. 2020; Rakesh et al. 2020; Rai et al. 2020). It is worthy to mention that its application as a secondary nutrient with commercial fertilizer may also raise its level to interrupt its balance with other nutrients especially with N (Carciochi et al. 2020; Perveen et al. 2021). Thus, finding out the suitable N and S ration is very important and a lot of work has been done on establishing this ratio in diverse soils and fertility management (Liu et al. 2020).

The ratio of nitrogen and sulphur is estimated by 20:1 in plant (Cram, 1990; Allahham et al. 2020); yet this ratio may vary according to soil, crop and climatic conditions (Yoshimoto et al. 2002; Takahashi et al. 2011). Both N and S are required for the synthesis of protein and amino acids (Kumar et al. 2020), and their presence in the plant tissue as well as in the soil can affect the protein formation rate in plant body (Kaya et al. 2020; Khanna et al. 2021). It has been found that for every 15 parts N in protein, 1 component S is present.(Walia and Kumar, 2021). The application of nitrogen and sulphur fertilizers at rate 150:30 with N:S ratio 5:1 is beneficial to maize crop (Rashid et al. 2004; Channahasamma, 2013; Singh and Dutta, 2021). This study was also designed with the goal of determining the impact of various N and S levels on wheat-maize productivity and N and S uptake in two different climatic conditions. And also to know about about how sulphur increase nitrogen use efficiency in both climatic conditions.

MATERIALS AND METHODS

Experimental Site

A field experiment was conducted in two different locations (Peshawar, semi-arid, hot and Buner, sub-humid, comparatively cooler)to investigate enhancement in maize-wheat productivity and N use efficiency through sulphur application in two diverse locations (Peshawar, semi-arid, hot and Buner, sub-humid, comparatively cooler) soil of the experiment site was silt loam at both location ,no saline, not alkaline and nor acidic soil, low in organic matter at Peshawar while optimum in Buner, low in Nitrogen phosphorus, and Sulphur however S is higher in Peshawar as compared to Buner. The experiment design was RCBD with factorial arrangement with three replications at both locations. Where N was applied from single conventional source of urea and S levels were applied as elemental sulphur. n this experiment three levels of Nitrogen (90, 120 and 150 kg N ha^{-1}) in the form of urea and four levels of Sulphur i.e 0, 20, 40 and 60 kg S ha^{-1} (as elemental S) were tested in combinations on productivity of both wheat and maize. The experimental was randomized complete block design here fertilizer was applied into plots. All treatments were applied at the time of sowing along with the basal dose of 90 kg P_2O_5 ha^{-1} and 60 kg K_2O ha^{-1} in the form of diammonium sulphate DAP (and KCl (MOP) fertilizers. N was applied in split doses (sowing and knee height stage) while sulphur was applied before sowing Weeds were controlled chemically / mechanically according to experiment situation and field conditions. Irrigation was applied as per need were performed as per recommended practice for research experiments. There were total 12 treatments of with three replications. Plot size was kept as 3.5× 3 m^2 throughout the experiments at both sites. After seed bed preparation, all the treatments were thorough mixing and applied to soil and maize seeds were sown on the line in the treatment plots through hand drill. In next season wheat variety (Pirsabak 2013) was sown. Both Crops was harvested at maturity of maize and wheat and data was recorded on agronomic parameters both for wheat and maize at both locations. Soil data was determined at pre sowing as well as after crop harvest at both sites.

Agronomical observations for Maize-Wheat

The following parameter was recorded by the end of the experimental period i.e. biological, grain yield and 1000 grain weight of maize-wheat, nutrient concentrations and uptake of nitrogen (N) and sulphur (S).

Grain yield (kg ha^{-1})

At physiological maturity growth stage, cobs (maize) and spikes (wheat) from the four harvested central rows of wheat and maize each treatment were separated, sun dried and threshed. The grain yield (kg ha^{-1}) was calculated by the following formula:

$$\text{Grain yield(kg ha}^{-1}) = \frac{\text{Grain yield in four central rows}}{\text{Row} - \text{row distance x Row length x No.of rows}} \text{x10000}$$

Biological yield (kg ha^{-1})

Biological yield of each experimental unit was reported by harvest of four central rows in every plot dried out, weighed and were changed into kg ha^{-1} by means of the following formula:

$$\text{Biologicalyield(kg ha}^{-1}) = \frac{\text{Biological yield in four central rows}}{\text{Row} - \text{row distance x Row length x No.of rows}} \text{x10000}$$

Uptake of nutrient (kg ha^{-1})

Based on the per cent nutrient content after determination of nutrient concentration such as N and S and weight of the plants, the uptake of nutrient were worked out and expressed in kg ha^{-1}.

Nutrient uptake = [% of nutrient concentration x biomass (kg ha^{-1})]

Chemical analysis of soil and plant samples

Collection and preparation of soil sample

Before conducting the experiment composite soil samples (0-15 cm) were collected from two experimental sites to find out their physico-chemical properties. These samples were air dried, ground in a stainless steel soil grinder then pass through 2 mm sieve. Samples were then analysed for their chemical and physical characteristics as follows:

Collection and preparation of plant samples

Whole plant samples at harvest and leaf samples at maturity were collected and were transported to the laboratory in properly labelled paper bags that allow the exchanges of air which reduces the chances of rotting of plant samples. Cleaning the plant samples to remove the dust and other materials which are adhered to plant samples first washed with tap water and then were distilled water. After washing the samples was dried in an oven to stop the enzymatic activity within the plant samples usually at 65^{O}C for 24 hours, after this plant samples were grinded through mechanical grinder to produce a material which are suitable for further analysis. Final drying at 65^{O}C of ground samples to obtain a constant weight through which to base for the analysis. Dried plant samples were stored in polythene bags for further chemical analysis.

Soil pH and ECe

We take 10 gram of soil samples by the help of top loader weight balance and put it in plastic bottle. The added 50 ml of distilled water into it for making 1:5 soil water suspension. Then put this suspension in a horizontal shaker and shake for 30 minutes. The p H meter was standardized with buffer solution and room temperature was noted as well. The p H of suspension was determined by using p H meter and for EC, EC meter are used.

For determination of soil pH (Mclean, 1982) and for EC (Rhoads, 1982) method ere used.

Soil Organic Matter

Soil organic matter content was determined by using of these Walkley-Black method, (Nelson and Sommer 1996) calculated by using this formula:

$$\% \text{ OM} = \frac{(\text{B} - \text{S}) \text{ x N x } 0.69}{\text{Wt. of soil}}$$

Mineral nitrogen

For determination of mineral N in soil take 20 g fresh soil samples into 250 ml flask and then added 100 ml 1M KCL solution (1:5 soil: KCL solution ratio). And then shake for 1 hour on an orbital shakr at 200-300 rmp. And finally the suspension filter by using whatman No. 42 filter paper. The pipette 20 ml an aliquot of soil extract into a 100 ml distillation flask and added 5 ml distill water into a 50 ml pyrex wolf bottle which is placed undermeath the condenser tip, with the tip touching the solution surface. And added about 0.2 g heavy MgO and 0.2 g Dervarda alloy with a calibrated spoon to the distillation flask. And immediately attached the distillation flask to the distillation unit and the started distillation and continue till 75 ml of distillate is collected and these tirate against 0.005 N HCL. (Mulvaney.,1996) was used for mineral nitrogen determination.

Extractable Phosphorus and potassium

The AB-DTPA extractable P and K concentrations in soil samples were determined by the AB-DTPA extraction method as described by Soltanpour and Schwab (1977). After the calibration soil samples were analysed by the help of Spectrophotometer LI-722 at 880 nm wavelength for P concentration and through Flame photometer model 410, Sherwood, UK for K concentration.

Available sulphur

The available sulphur were determined by extracting the soil with 0.15 percent $CaCl_2.2H_2O$ (Dissolve 1.5 g calcium chloride in 1L DI Water) solution and extracted S was quantified by turbidimetric method using spectrophotometer at 420 nm wave length. Take 5 g soil sample into 150 ml flask and then added 25 ml $CaCl_2$ shake for 30 minutes on reciprocal shaker. Filter the suspension through whatman No. 42 filter paper completely the extract of this suspension was colourless. Take 5 ml extract into 50 ml test tube and then add 1 ml HCL 6 M (Dilute 496.8 ml in 1L DI Water) , 5 ml sorbital solution and finally add 1 g barium chloride crystals. Shake continuously on the vertical shaker to form a homogeneous suspension also make blank and series of standard solution for standard solution (Dissolve 0.5434g potassium sulphate in 1L DI Water).This solution contain 100 ppm SO_4-S. Standard solutions that is 5 ppm, 10 ppm , 20 ppm, 30 ppm, 40 ppm and 50 ppm. And also prepare a calibration curve for absorbance against the sulphur concentrations (Verma, 1977).

Table 1: The physico-chemical properties of the experimental sites

Properties	Unit	Peshawar	Buner
Sand	%	47.3	40.2
Silt	%	40	51.1
Clay	%	12.7	8.7
Textural Class		Silty loam	Silty loam
EC (1:5)	dSm^{-1}	0.27	0.24
pH		8.05	7.92
Organic matter	%	0.95	1.1
$CaCO_3$	%	16.5	10.2
Total N	%	0.06	0.07
Phosphorus	mg kg^{-1}	3.43	5.3
Potassium	mg kg^{-1}	124.6	130.4
Sulfur	mg kg^{-1}	12	10
Mineral Nitrogen	mg kg^{-1}	16	22

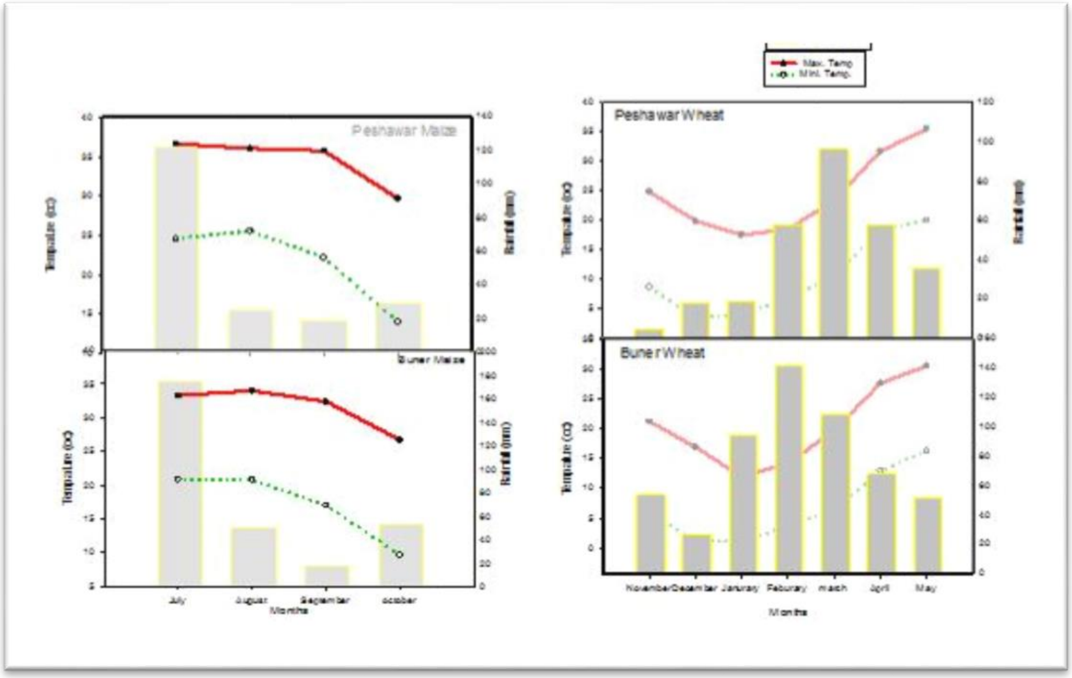

Figure 1: The means Maximum Temperature, Minimum Temperature and rainfall data of Peshawar and Buner on monthly basis

RESULTS AND DISCUSSION

Biological Yield (kg ha^{-1})

Data pertaining to biological yield of maize and wheat due to different nitrogen and sulphur levels are shown in Table 2. In general higher biological yield of maize and wheat are higher in Buner than in Peshawar. It seems that the biological yield of both plants varied significantly owing to the dos of N-inputs. In this concern, increase the level of nitrogen recorded significant increases vs 120 and 90 kg ha^{-1} N on the biological yield of both maize and wheat ($p<0.05$) Such increases were more pronounced with the application of the elemental sulfur. The Biological yield of maize increased from 9738 kg ha^{-1} to 10239 kg ha^{-1} due to the application of 20 kg S ha^{-1} in Peshawar and from 10346 kg ha^{-1} to 11652 kg ha^{-1} due to the application of 40 kg S ha^{-1} in Buner (data were calculated on average bases). In case of wheat, such increases were from 7993 kg ha^{-1} to 8088 kg ha^{-1} and 8437 kg ha^{-1} to 8936.1 kg ha^{-1} at the given 20 kg and 40 kg S ha^{-1} levels in both locations, respectively. Further increases in S levels did not promote further improvement in biological yield in both locations revealing that 20 kg S ha^{-1} in Peshawar and 40 kg S in Buner could be the optimum level of S at the ratio of N and S different at different climatic conditions for Peshawar 7.5:1 better while in Buner 3.75:1 is better for higher yield

When values were averaged across the locations, the maize biological yield significantly increased over control but all levels of S significantly at par with each other whereas such effects were statistically significant in the following wheat season due to higher variations in locations and responses to N levels. This variation of both maize and wheat productivity versus S and N levels are depicted in Fig. 2. In Buner soil, application of 40 kg of S ha^{-1} increased maize biological yield by 9 % at 150 kg N ha^{-1} and such increases were higher than the corresponding ones occurred at lower N levels. On the other hand, wheat grown on the same location exhibited higher grain yield due to S application by only 7 % observed due to the application of either 20 or 40 kg S and also noticed with the application of either 120 or 150 kg N ha^{-1}. Similarly in Peshawar, 8.5 % increase in maize biological yield was observed at higher N levels along with 20 kg S ha^{-1} such increases were only 3% with 120 kg ha^{-1} N application. Overall higher biological yield were recorded in Buner than in Peshawar. Interaction between S levels and the location of study indicate that the maximum maize yield were recorded at 40 kg ha^{-1} S at Buner while the minimal were recorded at the control treatment in Peshawar. Hernández et al. (2015) reported that higher application of N enhance chlorophyll, leaf area, leaf area index and ultimately produce higher auxin and this might have improved plant growth and development. When plants have good canopy which might have good interception, absorption and utilization of radiant energy leading to photosynthetic rate and finally more biological yield of maize and wheat by the plant were produced at both locations under different fertility. These results also agree with the findings of Duan et al. (2018), Sanchez-Bragado et al. (2016) and Li et al. (2019) on wheat and maize productivity. At Peshawar lower level of S perform better in the production of biological yield of maize and wheat while in Buner higher level of S were perform better for higher biological yield of maize and wheat. This might be due to the climatic condition as well as rainfall and relief of the locations. It is because S is important part of the synthesis of many amino acid which ultimately lead to higher production of biomass during growing season. In Buner, biological yield of maize and wheat was higher than the corresponding ones in Peshawar and this might take place because of the higher rainfall in Buner as compared to Peshawar. our result with accordance to the result was reported by Rossini et al. (2018).

1000 Grain (g) Weight Maize-Wheat

Data on 1000 grain weight pertaining to different nitrogen and sulphur levels are presented in Table 3. Highest 1000 grain weight was recorded at Buner as compared to Peshawar. There was significant improvement in 1000 grain weight of maize and wheat with increasing the level of nitrogen application. The highest 1000 grain weight of either of maize or wheat was recorded in the plot fertilized with 150 kg ha^{-1} N followed by 120 and 90 kg ha^{-1} N. Maize and wheat 1000 grain weight significantly ($p < 0.05$) enhanced with S application in both locations at all the three studied N levels. The 1000 grain weight of maize increased from 221.2 g to 235.8 g with the application of 20 kg S ha^{-1} in Peshawar and from 238 g to 258.5 g with the application of 40 kg S ha^{-1} in Buner (these data were calculated on average bases). In Wheat such increases were from 43.1 g to 43.9 g and maize 43 g to 44.7 g at the given 20 kg and 40 kg S ha^{-1} levels in both locations, respectively. Further increases in S levels did not execute further improvement in 1000 grain weight in both locations revealing that 20 kg S ha^{-1} in Peshawar and 40 kg S in Buner could be the optimum level regarding their mean values across the N levels.

Maize 1000 grain weight significantly increased over control but all levels of S remained at par with each other whereas such effects were statistically significant in wheat. Variation of maize and wheat to S and N levels is depicted in Fig. 3 In Buner, 40 kg of S ha^{-1} increased the maize 1000 grain weight by 9 % at 150 kg N ha^{-1} that was higher than the increased occurred at 120 and 90 kg N ha^{-1}levels. In case of wheat grown on the same location, the higher 1000 grain weight due to S was only 6 % attained for the application of either of 20 and 40 kg S. Similarly in Peshawar, 7 % increase in maize 1000 grain weight was observed at higher N levels at 20 kg S ha^{-1} such increases were only 3% recorded in following wheat crop with 120 kg ha^{-1} N application it is because of continue application of S and N into wheat crop. Higher 1000 grain weight of maize and wheat were recorded at higher levels of N at both locations. These findings highlight the importance

Nitrogen and sulphur as essential nutrients required for the plant growth and development during growth period of plants. Nitrogen in the presence of sufficient sulphur content in soil as well as in plants shows its optimal performance and enhanced higher photosynthetic activity leading to the production of enough uptake for subsequent translocation to various sinks and there by leading to the production of higher components such as 1000 grain weight, cobs $plant^{-1}$,cob length, cob weight, grain weight and ultimately increase yield of crops. Similar results were reported by Klikocka et al. (2016); Guerrini et al. (2020); Yu et al. (2018).

Grain Yield (kg ha^{-1})

Grain yield as affected by different levels of nitrogen and sulphur, solely or in combinations with each other, are presented in Table 4.The grain yield of Maize and wheat was higher in Buner than in Peshawar .probably because of the favourable climatic conditions for growth and yields in Buner as compared to Peshawar Grain yield significantly increase with progressive increase in nitrogen levels.

Table 2: Biological yield (kg ha^{-1}) of maize and wheat as influenced by the application of N and S fertilizers either solely or in different combinations.

Treatments		Maize			wheat			Average across N levels	
		Nitrogen (Kg ha^{-1})			Nitrogen (Kg ha^{-1})				
Location	S (Kg ha^{-1})	90	120	150	90	120	150	Maize	Wheat
Peshawar	0	9409	9750	10057	7371	8036	8573	9738d	7993d
	20	9604	10204	10908	7574	8260	8741	10239c	8192c
	40	9591	10034	10753	7428	8206	8631	10126cd	8088cd
	60	9666	9944	10515	7400	8193	8576	10042cd	8056cd
Buner	0	9867	10109	11063	8076	8383	8853	10346c	8437b
	20	10617	11212	11847	8343	8870	9431	11225ab	8881a
	40	10928	11447	12581	8362	8960	9486	11652a	8936a
	60	10684	11022	11377	8396	8816	9198	11028c	8803a
Peshawar		9567	9983	10558	7443	8174	8630	10036b	8082b
Buner		10524	10948	11717	8294	8757	9242	11063a	8764a
	0	9638	9929	10560	7723	8210	8713	10042c	8215b
	20	10110	10708	11377	7959	8565	9086	10732ab	8536a
	40	10259	10741	11667	7895	8583	9058	10889a	8512a
	60	10175	10483	10946	7898	8505	8887	10535b	8430a
	Means	10046c	10465b	11138a	7869c	8465b	8936.4a		

LSD values at $p < 0.05$ for location, N and S and location x S levels 235.79, 288.78 , 333.46 and 471.58 in maize and 47.43, 107.08, 123.65 and 174.86 in wheat, respectively. Means followed by same letters in the same block do not differ at $p < 0.05$.

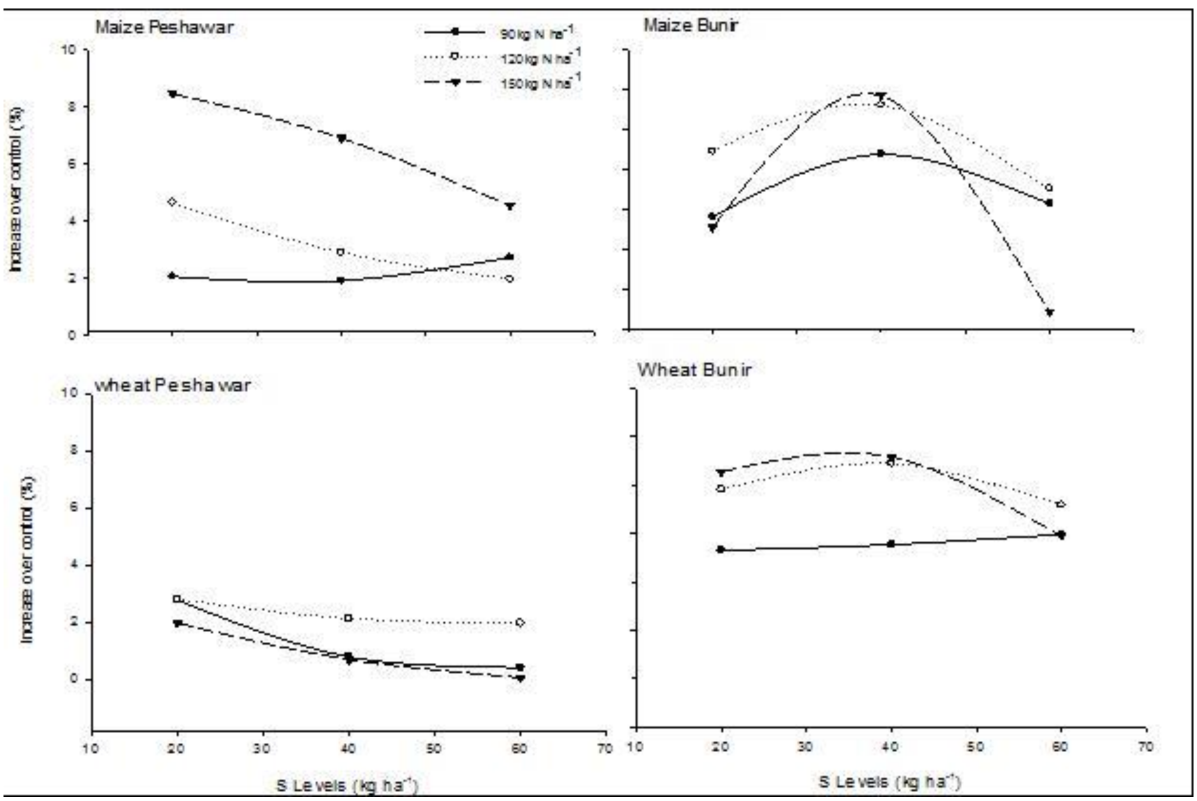

Figure 1:The increase in Biological Yield (%) of maize and wheat with S application over control at given N levels in both tested area.

Table 3: 1000 Grain weight (g) of maize and wheat as influenced by different levels of S application under various N levels at given two diverse locations

Treatments		Maize			wheat			Average across N levels	
			Nitrogen (Kg ha^{-1})		Nitrogen (Kg ha^{-1})				
Location	S (Kg ha^{-1})	90	120	150	90	120	150	Maize	wheat
Peshawar	0	209.9	220.7	232.9	42.0	43.1	44.2	221.2e	43.1cd
	20	223.8	234.9	248.7	43.2	43.4	45.1	235.8c	43.9bc
	40	220.4	227.4	237.2	42.4	43.6	44.4	228.3d	43.5cd
	60	217.2	222.0	234.1	42.9	43.4	44.3	224.4e	43.5cd
Buner	0	223.1	239.1	251.9	42.7	42.9	43.3	238.0c	43.0d
	20	231.9	248.0	270.5	43.4	43.5	45.1	250.1b	44.0b
	40	235.5	257.9	282.1	44.1	44.4	45.5	258.5a	44.7a
	60	224.0	251.1	278.8	43.4	43.0	44.3	251.3b	43.5bc
Peshawar		217.8	226.3	238.2	42.6	43.4	44.5	227.4b	43.5b
Buner		228.6	249.0	270.8	43.4	43.4	44.5	249.5a	43.8a
	0	216.5	229.9	242.4	42.3	43.0	43.8	229.6c	43.0b
	20	227.8	241.5	259.6	43.3	43.4	45.1	243.0a	44.0a
	40	227.9	242.7	259.6	43.3	44.0	45.0	243.4a	44.1a
	60	220.6	236.5	256.4	43.1	43.2	44.3	237.9b	43.5b
	Means	223.2c	237.6b	254.5a	43.0c	43.4b	44.5a		

LSD values at $p < 0.05$ for location, N and S and location, S levels 3.57, 4.38 , 5.05 and 7.15 in maize and 026, 0.31, 0.36 and 0.52 in wheat, respectively. Means followed by same letters in the same block do not differ at $p < 0.05$.

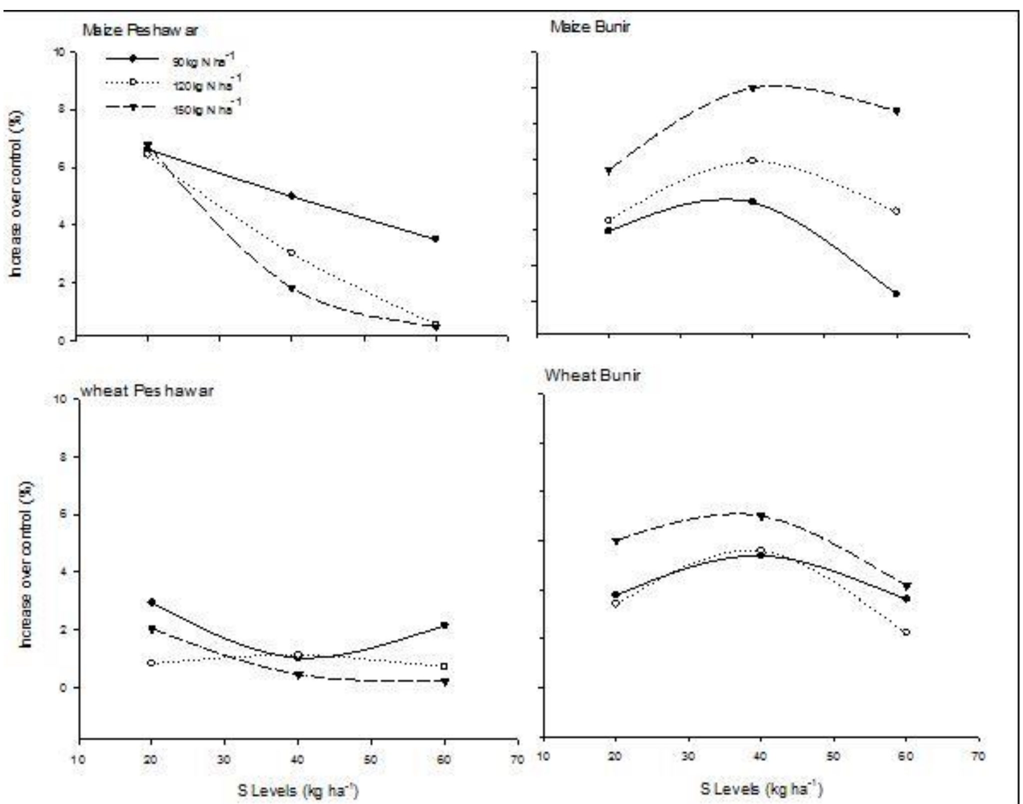

Figure 3:1000 Grain weight (g) % increases of maize and wheat with S application over control at given N levels in both tested areas.

Table 4: Grain yield (Kg ha^{-1}) of Maize and Wheat as influenced by different levels of S application under various N levels at given two diverse locations.

Treatments		Maize			wheat			Average across N levels	
			Nitrogen (Kg ha^{-1})		Nitrogen (Kg ha^{-1})				
Location	S (Kg ha^{-1})	90	120	150	90	120	150	Maize	wheat
Peshawar	0	2905	3629	3775	2470	2617	2690	3436c	2592d
	20	3038	3851	4088	2539	2700	2783	3659abc	2674bc
	40	3029	3669	3956	2490	2626	2717	3551bc	2611cd
	60	2943	3655	3852	2475	2620	2707	3483bc	2601cd
Buner	0	3281	3522	3632	2538	2728	2824	3478bc	2694ab
	20	3402	3752	3898	2607	2777	2907	3684ab	2763a
	40	3557	3825	4054	2613	2796	2901	3812a	2770a
	60	3408	3690	4032	2540	2750	2840	3710ab	2710ab
Peshawar		2979	3701	3916	2494	2641	2724	3532b	2619b
Buner		3412	3698	3904	2574	2761	2868	3671a	2734a
	0	3093	3575	3704	2504	2669	2757	3457b	2643b
	20	3220	3808	3993	2573	2738	2845	3672a	2719a
	40	3294	3747	4005	2551	2711	2809	3682a	2690ab
	60	3175	3673	3942	2507	2685	2773	3597ab	2655b
	Means	3195c	3699b	3911a	2534c	2701b	2796a		

LSD values at $p < 0.05$ for location, N and S and location x S levels 119.12, 145.90, 168.47 and 238.25 in maize and 39.17, 47.97, 55.40 and 78.38 in wheat, respectively. Means followed by same letters in the same block do not differ at $p < 0.05$.

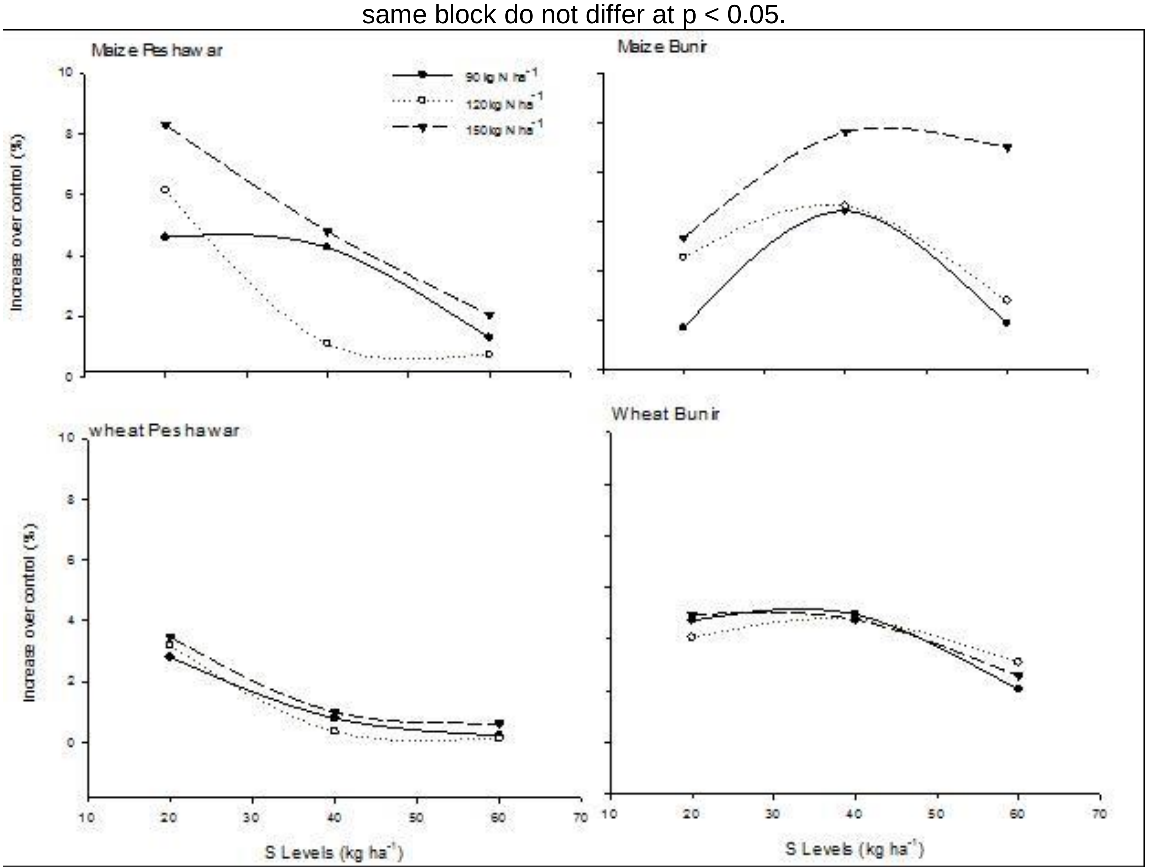

Figure 4: The (%) increase in Grain Yield of maize and wheat with S application at given N levels in both tested area

The highest grain yield was recorded for the application of 150 kg ha^{-1} N followed by 120 and 90 kg ha^{-1} N. Sulphur application also improved significantly grain yield production ($p<0.05$) and such increases were more detectable with increasing levels of sulphur application. in this concern, grain yield of maize increased from 3436 kg ha^{-1} to 3659 kg ha^{-1} in Peshawar due to application of 20 kg S ha^{-1} while the concurrent increases in Buner were from 3438.50 kg ha^{-1} to 3812 kg ha^{-1} at 40 kg S ha^{-1} (these values were calculated on average bases). Wheat increase from 2592 kg ha^{-1} to 2674 kg ha^{-1} and from 2694 kg ha^{-1} to 2770 kg ha^{-1} when increasing the dose of elemental sulphur from 20 to 40 kg S ha^{-1} in both locations, respectively. Further increases in S levels did not execute further improvement in grain yield in both locations revealing that 20 kg S ha^{-1} in Peshawar and 40 kg S in Buner could be the optimum levels of application. This variation of maize and wheat to S and N levels is depicted in Fig. 4. In Buner, literally low in soil S content, 40 kg of S ha^{-1} increased the maize grain yield by 8 % at 150 kg N ha^{-1} that was higher than the increases that occurred at lower N levels. In the same location, the higher wheat grain yield was increases due to S was only 5 % at both 20 and 40 kg S at 90 kg ha-^{1} N level that could be attributed to continuous application of S and N to consecutive maize and wheat crops. Similarly in Peshawar, the highest increase in maize grain yield (about 9%) was observed at higher N levels but at lower S dose i.e. 20 kg S ha^{-1} yet the increases were only 4% recorded in following wheat crop.

Higher application of nitrogen along with sulphur application had positive effect on plant physiological process, growth and plant metabolisms (Khan et al. 2016). They take part in protein synthesis and this consequently enhance grain yield production (Rossini et al. 2018).Similar finding were reported by Singh et al. (2017), Dong et al. (2018), Qahar et al. (2016) who reported that the combined application of N at a rate of 350 kg ha^{-1} along with 40 kg ha^{-1} S at Peshawar on hybrid of maize increased grain yield considerably. Increased grain yield of maize-wheat with sulphur application could also be owing to higher availability of nutrients to plants. Nitrogen and Sulphur have positive effect on one other .It was found that the highest maize yield was attained for the application of 40 kg S ha^{-1} while for wheat 20 kg S ha^{-1} was enough. This is because maize crop had higher S requirement than wheat (Sutradhar et al 2017) at Buner higher S levels perform better while in Peshawar lower level of S perform better for the production of higher grain yield of maize and wheat. Over all higher grain yield of maize and wheat was recorded at Buner as compared to Peshawar it may be due to higher rainfall and climatic condition as well as fertility status of the area of research (Duncan et al. 2018), xie et al. (2017). The improvement in grain yield due to application of sulphur and nitrogen is because of enhance crop growth rate, net assimilates rate and dry matter production per plant which ultimate increased grain yield of maize-wheat under different climatic conditions (Singh et al. 2018), Tao et al. (2018).

Sulphur in Soil (mg kg^{-1})

Available S became low in soil after harvesting the two investigated crops at both locations of study when soils were amended with higher doses of N and vice versa (Table 6). Overall higher available sulphur was recorded at Peshawar as compared to Buner after harvest of both crops. Increasing the rate of sulphur application raised available sulphur in soil was recorded at both locations of study. The highest available sulphur content in soil was recorded due to the application of 60 kg S ha^{-1} followed by 40, 30 and 20 kg S ha^{-1} in both locations. The available sulphur increases from 12.7 to 18.0 mg kg^{-1} at Peshawar due to the application of 60 kg S ha^{-1} after the harvest of maize while in Buner such increases were from 10.85 to 15.26 mg kg^{-1} . Similar trend were recorded for wheat crop at the given location from 12 to 18.2 mg kg^{-1} at Peshawar and from 11.40 to 16.32 mg kg^{-1} due to the application of 60 kg S ha^{-1}. Sulphur nitrogen interactions were found also significant for sulphur content in soil after harvesting of maize and wheat crops at both investigated locations. The % increase of sulphur over control is in Fig 5. In Peshawar, sulphur application raised available sulphur in soil up to 50 % with 120 kg ha^{-1} N application while in the same location after wheat cropping the available sulphur increased up to 55 % with 60 kg S ha^{-1} along with 150 kg N ha^{-1}. In Buner after maize harvest the increases in available S were approximately 45 % higher than the non-amended control treatment due to the application of 60 kg S ha^{-1} along with 150 kg N ha^{-1}, while for wheat crop 55 % increase over control occurred due to the application of 60 kg ha^{-1} S along with 150 kg ha^{-1} N. the S concentration of soil increases with increases S application into soil. Overall maximum soil S was recorded at

Peshawar as compared to Buner it may be due to higher rainfall and ultimately may be leached S from the experimental area during experiment. The interaction of location and S level had significant effect on soil available S higher soil S was recorded at Peshawar as compared to Buner. Higher soil S was recorded in the treatment which is treated with 60 kg S ha^{-1} at both location after harvest of maize and wheat. While the interaction between N and S have significant effect of soil S concentration at both location, maximum Soil S was recorded at lower level of S at both location it may be due to positive effect of N and S and S perform better at higher level of N at both location. Our results with accordance of (Chen et al. 2020)

Nitrogen Uptake (kg ha^{-1})

Data on total nitrogen uptake are presented in Table 7. Analysis of data indicates that total N uptake increased significantly with increasing nitrogen levels for both crop at both locations. The highest total nitrogen uptake was recorded with the application of 150 kg N ha^{-1} as compared to either of 120 or 90 kg N ha^{-1}.

Perusal data shows significant improvement on the basis of statistical analysis of total nitrogen uptake influenced by locations. Total uptake of nitrogen was significantly higher in Buner as compared to Peshawar for both crops.

Application of sulphur raised significantly the total N uptake by maize and wheat. Overall 20 kg ha^{-1} S performs better for both locations and crops. But in Peshawar uptake of N increased in maize from 91.84 kg ha-1 to 100.13 kg ha^{-1} with the application of 20 kg ha-1 S while in same location for wheat crop such increases were only from 66.2 to 68.67 kg ha^{-1}. In Buner, N-uptake by maize crop increased from from 95.15 to 111.79 kg ha^{-1} with application of 40 kg ha^{-1} S while for wheat crop the increases were from 70.0 to 74.54 kg ha^{-1} at given S application. Overall, there was a positive relation between S inputs and N-uptake by plants with the application of Nitrogen applications from 90 to 150 kg ha^{-1} such increases as from 79.0 to 118.28 in maize while in wheat such increases are from 64.27 kg ha^{-1} to 75.43 kg ha^{-1}. The % of increase of total N uptake according to the application of N fertilizers over the control was depicted in Fig 6. In Peshawar, nitrogen uptake increased in maize crops 6 % with the application of 150 kg N ha^{-1} along with 60 kg S ha^{-1} while in same location for wheat crop, the concurrent increases were only 4 % recorded with the application of 40 kg S ha^{-1} + 120 kg N ha^{-1}. While in Buner, maize crop % increased by 7% with the application of 40 kg S ha^{-1}and for wheat crop such increases were only 4 % with 40 kg ha^{-1} S application along with 120 kg ha^{-1} N application. The interactive effect of different levels of N with S levels on N uptake was also detectable. Every increase in nitrogen level has led to concurrent increase in its uptake at all sulphur levels in both locations of experimentation. The highest N-uptake 118.75 kg ha^{-1} were recorded in Peshawar with the application of 150 kg N ha^{-1} along with 20 kg S ha-^{1} while in Buner wheat crop same trend were recorded which was 100.13 kg ha^{-1} while in Buner maximum 130.64 kg ha^{-1} N uptake were recorded with 40 kg S ha^{-1} along with 40 kg S ha^{-1} while in wheat same trend were recorded which was 111.79 kg ha^{-1} N uptake. Higher uptake of N was recorded at both location with the application of 150 kg N ha^{-1} while minimum N uptake of N was recorded in the treatment which is treated with 90 kg N ha^{-1} at both location, higher Nitrogen may be due to higher utilization of nutrients during growth period of crops. of the mutual effect of S application on N-uptake may be explained as follows: both nutrients play important role the synthesis of protein (Briat et al. 2020) . Sulphur is key component of the enzymes which are involved in the N metabolism in the plant body (Karthika et al. 2018) (Perveen et al. 2021). Sulfur is required for the synthesis of S containing amino acids such as cystine, cysteine and methionine. Accordingly, a synergistic effect exists between both nutrients (Jaiswal et al.2020). Abera et al. (2020)reported that S and N have positive effect on growth of plant because S improve photosynthates translocation from source to sinks. Our results show similarity with the study of (Sandhu et al. 2019). Also reported that with the increases of S level the N uptake also increases up to some extend.

Nitrogen Use Efficiency

Statistical analysis of the data showed that S application improve nitrogen use efficiency (NUE) ($P<0.05$) (Fig 7). In Peshawar, NUE increases up to 9.2 % in maize due to the application of 20 kg S ha^{-1} along with 150 kg N ha^{-1} while the corresponding increases were only 10 % in wheat and such an increase was attained due to the application of 20 kg S kg^{-1} + 120 kg N ha^{-1}. In Buner NUE increased up to 16 % in maize and 17% in wheat with the application of 40 kg S ha^{-1} along 120 kg N ha^{-1} for both crops at same location.

Table 5: Sulphur (mg kg^{-1}) of maize and wheat as influenced by different levels of S application under various N levels at given two diverse locations.

Treatments		Maize			wheat			Average across N levels	
		Nitrogen (Kg ha^{-1})			Nitrogen (Kg ha^{-1})				
Location	S (Kg ha^{-1})	90	120	150	90	120	150	Maize	wheat
Peshawar	0	13.57	11.83	12.80	12.503	11.533	11.973	12.733e	12.003f
	20	15.90	14.37	14.57	17.307	15.707	16.120	14.944c	16.378c
	40	17.07	16.03	16.10	18.510	17.147	17.687	16.400b	17.781b
	60	18.83	17.30	17.93	18.850	17.450	18.303	18.022a	18.201a
Buner	0	10.77	10.93	10.87	11.690	11.237	11.283	10.856f	11.403g
	20	13.10	12.37	12.57	14.440	13.523	13.880	12.678e	13.948e
	40	14.77	13.70	13.03	15.673	14.823	14.340	13.833d	14.946d
	60	14.87	15.00	15.93	16.773	16.153	16.047	15.267b	16.324c
Peshawar		16.34	14.88	15.35	17.293	15.709	16.271	15.525a	16.424a
Buner		13.88	12.75	13.10	14.394	13.434	13.888	13.242b	13.905b
	0	12.17	10.88	11.83	11.097	10.385	11.128	11.628d	10.870d
	20	14.50	13.37	13.57	15.873	14.615	15.000	13.811c	15.163c
	40	15.92	14.87	14.57	17.092	15.985	16.013	15.117b	16.363b
	60	17.85	16.15	16.93	19.312	17.302	18.175	16.978a	18.263a
	Means	15.11a	13.82b	14.23b	15.843a	14.572c	15.079b		

LSD values at $p < 0.05$ for location, N and S and location x S levels 0.3579, 0.4384, 0.5062 and 0.7158 in maize and 0.3676, 0.4502, 0.5199 and 0.7352 in wheat, respectively. Means followed by same letters in the same block do not differ at $p < 0.05$.

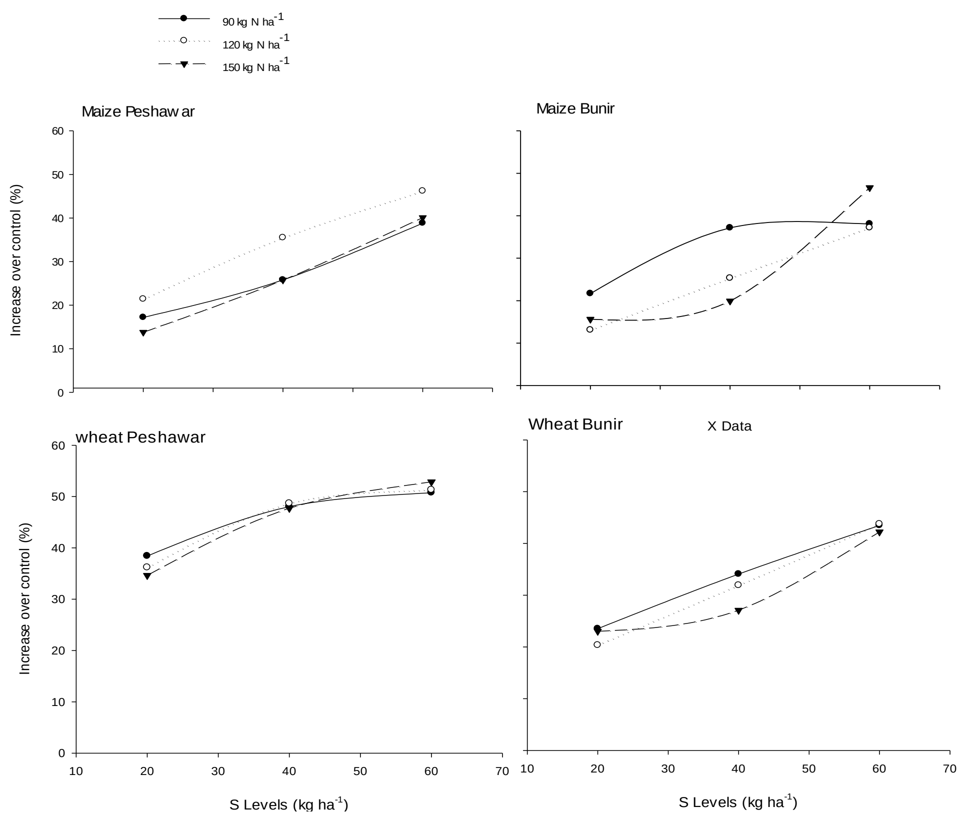

Figure 5: Soil Sulphur (mg kg^{-1}) % increases of maize and wheat with S application over control at given N levels in both tested areas.

Table 6: Nitrogen uptake (kg ha^{-1}) of maize and wheat as influenced by different levels of S application under various N levels at given two diverse locations.

Treatments		Maize			wheat			Average across N levels	
			Nitrogen (Kg ha^{-1})		Nitrogen (Kg ha^{-1})				
Location	S (Kg ha^{-1})	90	120	150	90	120	150	Maize	Wheat
Peshawar	0	70.39	96.09	109.06	60.385	66.624	71.637	91.845e	66.215e
	20	75.99	105.65	118.75	62.309	69.407	74.320	100.130cd	68.679cd
	40	74.18	100.43	117.36	61.217	68.752	72.866	97.325d	67.612de
	60	74.75	98.74	117.61	61.027	68.517	72.468	97.030d	67.337de
Buner	0	77.22	96.56	111.69	65.516	69.771	74.763	95.158de	70.017c
	20	84.68	108.49	120.31	67.799	73.387	79.582	104.490bc	73.589ab
	40	89.39	115.35	130.64	68.216	75.356	80.071	111.794a	74.548a
	60	85.47	112.43	120.80	67.719	73.159	77.745	106.231b	72.874b
Peshawar		73.83	100.23	115.70	61.235	68.325	72.823	96.583ba	67.461b
Buner		84.19	108.20	120.86	67.313	72.918	78.040	104.418a	72.757a
	0	73.81	96.32	110.38	62.951	68.197	73.200	93.501b	68.116c
	20	80.33	107.07	119.53	65.054	71.397	76.951	102.310a	71.134a
	40	81.78	107.89	124.00	64.717	72.054	76.468	104.560a	71.080ab
	60	80.11	105.58	119.21	64.373	70.838	75.106	101.631a	70.106b
	Means	79.01c	104.22b	118.28a	64.274c	70.621b	75.431a		

LSD values at $p < 0.05$ for location, N and S and location x S levels 2.4529, 3.0042, 3.4689 and 4.9058 in maize and 0.7178, 0.8791, 1.0151 and 1.4356 in wheat, respectively. Means followed by same letters in the same block do not differ at $p < 0.05$.

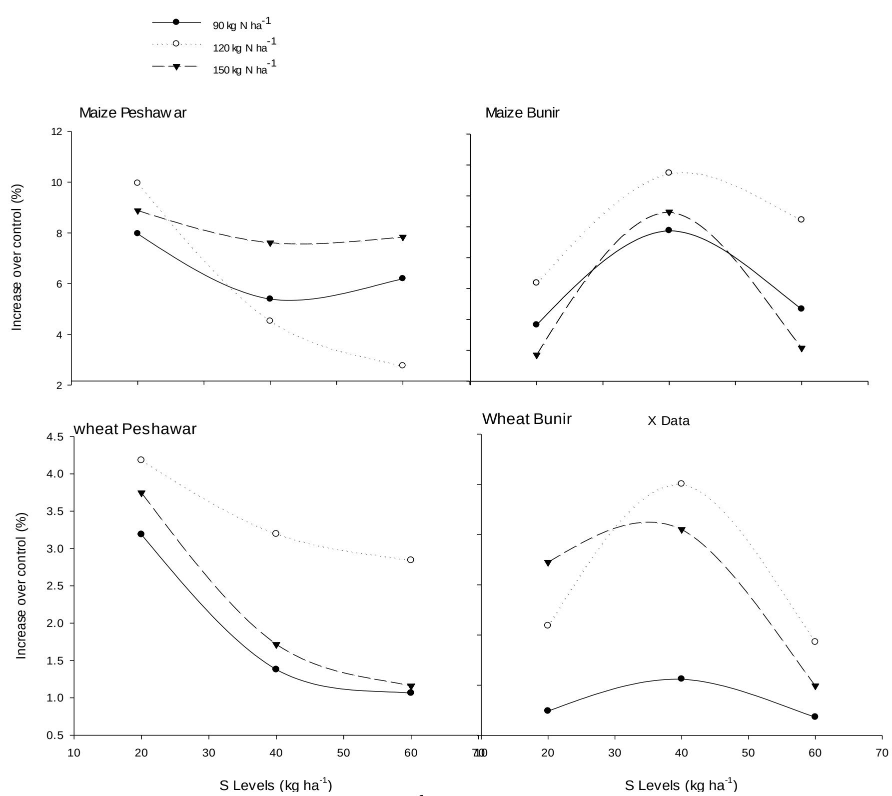

Figure 6: Nitrogen uptake % increases (kg ha^{-1}) of maize and wheat with S application over control at given N levels in both tested areas

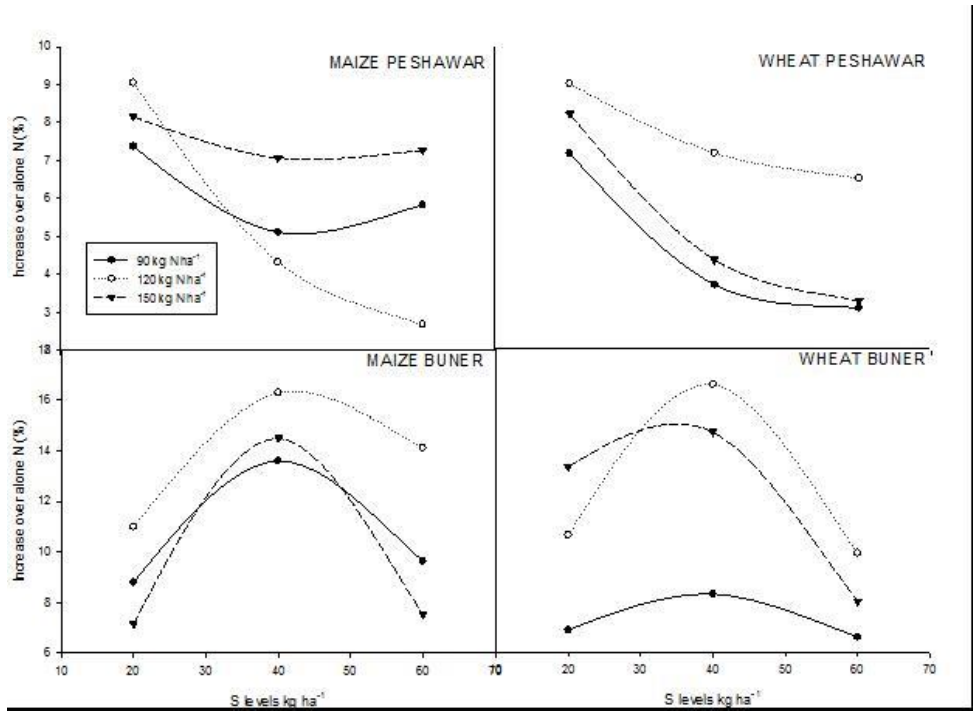

Figure 7: Enhancement in NUE of maize and wheat with S application at given N levels in both tested areas

Table 8: Sulphur uptake (kg ha^{-1}) of maize and wheat as influenced by different levels of S application under various N levels at given two diverse locations.

Treatments		**Maize**			**wheat**			**Average across N levels**	
			Nitrogen (Kg ha^{-1})		**Nitrogen (Kg ha^{-1})**				
Location	S (Kg ha^{-1})	90	120	150	90	120	150	Maize	wheat
Peshawar	0	8.90	9.37	10.77	7.730	8.414	8.665	9.676	8.270
	20	11.00	11.66	11.61	10.483	9.640	9.701	11.422c	9.942
	40	13.08	15.67	15.29	11.384	10.875	12.042	14.679b	11.433
	60	14.70	15.98	15.79	12.062	11.923	11.891	15.491b	11.959a
Buner	0	9.55	9.73	9.85	6.704	6.976	9.362	9.708	7.681
	20	11.56	12.76	13.34	8.969	10.553	12.652	12.555c	10.725
	40	14.38	14.97	17.64	10.197	11.238	13.199	15.663b	11.545
	60	14.82	15.59	21.49	11.924	11.734	14.196	17.303a	12.618a
Peshawar		11.92	13.17	13.36	10.415	10.213	10.575	12.817b	10.401a
Buner		12.58	13.26	15.58	9.448	10.125	12.352	13.807a	10.642a
	0	9.22	9.55	10.31	7.217	7.695	9.014	9.692d	7.975c
	20	11.28	12.21	12.48	9.726	10.097	11.176	11.989c	10.333b
	40	13.73	15.32	16.47	10.790	11.056	12.621	15.171b	11.489ab
	60	14.76	15.79	18.64	11.993	11.829	13.044	16.397a	12.289a
	Means	12.25c	13.22b	14.47a	9.932b	10.169b	11.464a		

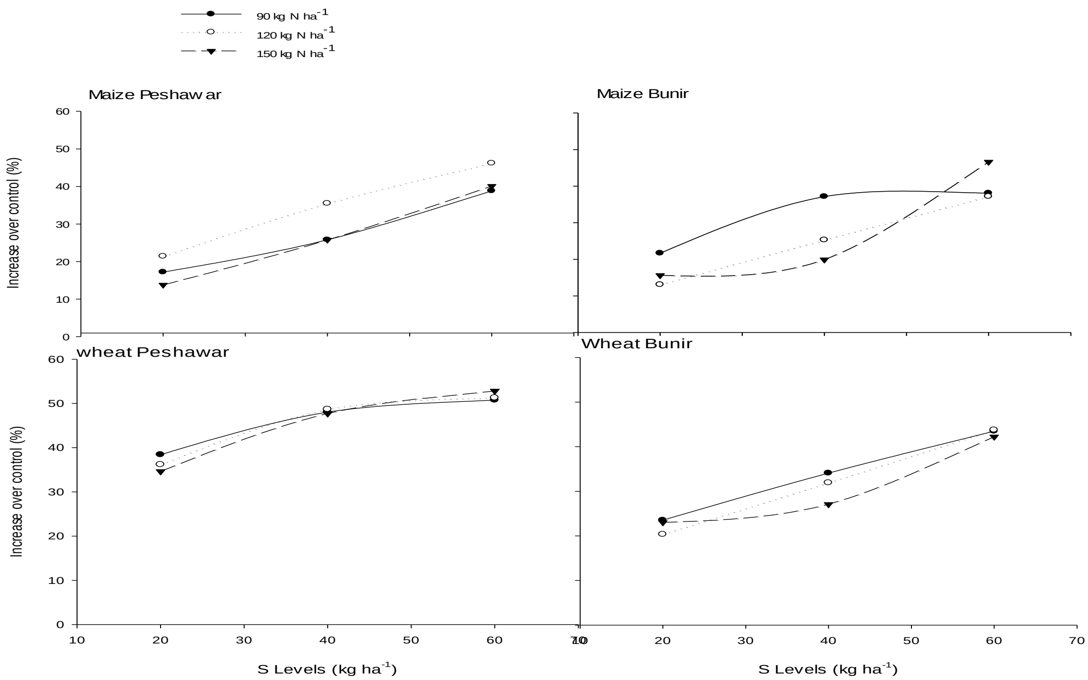

Figure 8: Sulphur uptake (kg ha^{-1}) of maize and wheat with S application at given N levels in both tested areas

As expected a greater N uptake was observed when N fertilizer rate increased. However the results obtained herein indicated that the positive synergism between N and S since the addition of S boosted N uptake as N fertilizer rate increased.

Nitrogen use efficiency varied between experimental sites as Peshawar 20 kg S ha-1 perform better to increases NUE while in Buner 40 kg S ha-1 perform better to increase NUE it is because of synergism between N and S and a suitable ratio of N and S is needed for higher yield of maize and wheat. That why in Peshawar at 20 kg of S ha^{-1} perform better it is because of sufficient amount are supply to crop from sink and have no S leaching while in Buner 40 kg ha^{-1} of S perform better for NUE it is because of lower level in soil due to leaching of S from soil at Buner. (Carciochi et al. 2020Our result confirm the finding of (Salvagiotti et al. 2009).

Sulphur uptake (kg ha^{-1})

Data related to total sulphur uptake by maize and wheat are presented in Table 9.Total sulphur uptake by maize and wheat was significantly increased with increasing nitrogen levels from 90 to 150 kg N ha^{-1}. The significant higher uptake of total S were recorded with the application of 150 kg N ha^{-1} followed by 120 kg N ha^{-1} and 90 kg N ha^{-1}. Sulphur application recorded significantly highest total sulphur uptake by maize and wheat at both locations. In this concern, application of 60 kg S ha^{-1} led to the significantly highest increases in total sulphur uptake by maize and wheat at both locations. Overall, higher sulphur uptake was recorded in Buner than Peshawar. The interaction between sulphur and nitrogen are given in Fig. 8. In Peshawar, S uptake increased by 75% over the control treatment when received 120 kg N ha^{-1} along with 60 kg S ha^{-1} while at the given location such increases were 60% for wheat grown on soil that received 90 kg N ha^{-1} along with 60 kg S ha^{-1}. In Buner for maize crop maximum sulphur uptake were recorded over control on 150 kg N ha^{-1} along with 40 and 60 kg ha^{-1} which was 70 % while for wheat crop such increases as 60 % at 120 and 90 kg N ha^{-1} along with 60 kg S ha^{-1}. Overall, S uptake was higher at Buner than at Peshawar because of higher biomass production of maize and wheat produced at Buner as compared to that obtained from Peshawar. Our results show similarity with the results of (Duncan et al. 2018).

CONCLUSION

From this experiment it was concluded that the agronomic parameters such as grain yield, biological and 1000 grain weight have shown positive response toward 150 kg N ha^{-1} as compared to 120 and 90 kg N ha^{-1}.while the response of S was different.In Peshawar, 20 kg S ha^{-1} showed best outcomes on plant growth and total grain yield while in Buner 40 kg S ha^{-1} were needed to attain the best result. The combine use of both N and S (150 kg N ha^{-1} along with 20 kg S ha^{-1}) at Peshawar and 40 kg S ha^{-1} at Buner is recommended for improving NUE and achieving higher yield of Maize-Wheat.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEGEMENT

IU and DDM designed the experiment. Draft written by IU, reviewed by DDM. IU collected data, soil and plant analysis and data analysis. All authors read and approved the final version.

AUTHOR CONTRIBUTIONS

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