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Research Article

# Nitrogen and Sulfur Rates and Timing Effects on Phenology, Biomass Yield and Economics of Wheat

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**Abstract** | Management of nutrients has a great impact over the yield and quality of crops as well as soil health. An experiment was performed to investigate the impact of nutrients management and application time over the yield and yielding attributes of wheat at the Agronomy Research Farm in the University of Agriculture, Peshawar, Pakistan during winter 2014-15. The experiment was designed in RCBD with split plots arrangement, replicated four times. Three levels of nitrogen (N) (90, 120, 150 kg ha$^{-1}$) were allotted to main plots, while combination of sulfur (S) levels (15, 30, 45 kg ha$^{-1}$) and application timings (100% at sowing, 100% at tillering and 50% at sowing + 50% at tillering) along with a control were allotted to the sub plots. Data regarding number of productive and unproductive tillers m$^{-2}$, thousand grain weight, grains spike$^{-1}$, biomass yield and value cost ratio (VCR) of wheat were significantly affected by N and S. Sulfur and its application time prominently influenced the productive tillers m$^{-2}$ and biomass yield. Nitrogen at 150 kg ha$^{-1}$ resulted in more number of productive tillers m$^{-2}$, less un-productive tillers m$^{-2}$ and higher thousand grain weight, biological yield and higher value cost ratio. Sulfur at 45 kg produced higher productive tillers m$^{-2}$, thousand grain weight, grains spike$^{-1}$ and biomass yield. Sulfur applied 50% at sowing and 50% at tillering significantly influenced number of productive tillers m$^{-2}$ and biological yield (9704 kg ha$^{-1}$). It was concluded from the analysis of data that nitrogen at the rate of 150 kg ha$^{-1}$ with sulfur at the rate of 45 kg ha$^{-1}$ applied 50% at sowing + 50% at tillering significantly contributed towards the economics and reproductive traits of wheat.

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## Introduction

Population pressure demands the increase in crop productivity particularly staple food crops including wheat. In Pakistan, its production and quality are low due to lack of proper agronomic practices and non-availability of different macro plants nutrients like nitrogen, phosphorus and potash as well as secondary plants nutrients including sulfur to the crop. Besides these facts the provision of these nutrients at specified time is also a best solution to withstand against the yield reducing phenomena (Ali et al., 2008).

Soils of Pakistan have lowest percentage of macro nutrients like nitrogen. Therefore, higher yield of a crop can be achieved through both of proper amount and supplementation of nutrients at right time to the crop. Provision of nutrients at right time maximizes the


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production (Raun and Johnson, 1990). Nitrogen has a predominant role in yield improvement. Several experiments showed that poor nitrogen management leads to its 50% loss (Bajwa, 1992). Uses of fertilizers in split application can minimize the leaching, volatilization and de-nitrification (Garrido-Lestache et al., 2005).

Secondary nutrients like sulfur have an important role in plant nourishment. Besides yield improvement, it also affects the quality and chemical composition of wheat grain. Sulfur with nitrogen play an active role in the protein building blocks and synthesis. Sulfur is getting importance as it upsurge the availability of other nutrients in tropical and subtropical areas around the world (McCune, 1982).

Sulfur is necessary for wheat crop during its different growth stages to accelerate the availability of other nutrients for its proper growth. Wheat requires sulfur along with other macro nutrients for its optimum growth and producing grain of better size because non-availability of sulfur greatly affects the grain size as compare to enough supplementation (Zhao, 1999). Sulfur has key role like other essential nutrients in growth and development of plants. On the basis of dry matter production in plant tissue sulfur is about 0.5% which shows significant effects over biomass (De kok, 2002; Ali, 2008). A crop can't reach to its peak growth and development without the adequate amount of sulfur fertilization (Zhao, 1999). Sulfur and nitrogen show their combine effects in different pathways especially during milk and seed filling duration stages; sulfur makes it easy for nitrogen to assimilate in seed (Tea et al., 2003; Tea et al., 2007). Nitrogen and sulfur interaction greatly influence reproductive phase of wheat during seed filling hence, their performance contributesto improved production and quality of grains (Luo, 2000). Balance provision of fertilizers and optimum agronomic practices greatly influence the yield and quality of crops as well as soil health. Balanced application of primary and secondary nutrients considerably increases the yield of crop if provided at critical growth stage (Randhawa et al., 2000).

Pakistani farmer's community is almost illiterate regarding the time and level of nutrients' application. They utilize larger quantities of expensive fertilizers at improper crop growth stages and hence expect to achieve higher and quality yield. Therefore, this research was planned to study the effect of N and S levels and application time of S in producing higher and qualitative yield of wheat.

## Materials and Methods

### *Experimental location*

A field study was carried out at Agronomy Research Farm of The University of Agriculture Peshawar, Pakistan during winter 2014-15. The experimental farm is situated at latitude of 34.01°N and longitude of 71.35°E, at 350 m of altitude above the sea level. Peshawar has continental type of climate and located about 1600 km to the north of Indian Ocean. Soil has clay loam texture, low in organic matter (0.87%), extractable phosphorus (6.57 mg P $kg^{-1}$), exchangeable potassium (121 mg K $kg^{-1}$) and calcareous in nature (pH 8.2) (Amanuallah et al., 2009).

### *Experimental details*

The current research was laid out in RCBD with split plot arrangements comprised of four replications. Nitrogen was assigned to main plots whereas sulfur levels and sulfur application timings were allocated to sub plots. The trial comprised of nitrogen levels ($N_1$: 90 kg $ha^{-1}$, $N_2$: 120 kg $ha^{-1}$ and $N_3$: 150 kg $ha^{-1}$), sulfur levels ($S_1$: 15 kg $ha^{-1}$, $S_2$: 30 kg $ha^{-1}$ and $S_3$: 45 kg $ha^{-1}$) and application timing of sulfur (AT1:100% at sowing, AT2: 100% at Tillering and AT3: 50% at sowing and 50% at tillering) with a control (no nitrogen and sulfur).

### *Crop management practices*

The plot size was 5 m × 3 m. Crop was sown in 5m long rows, apart 30 cm. Wheat cultivar 'Siran-2010' was sown at the rate of 120 kg $ha^{-1}$. Basal dose of phosphorus and potassium at the time of seeding were applied at the rate of 90 and 60 kg $ha^{-1}$, respectively. Half of the nitrogen was utilized at seeding time whereas half was applied at tillering stage. Nitrogen application was maintained from Urea and ammonium sulphate as a source for sulfur-cum-nitrogen while source of phosphorous and potash were triple super phosphate (TSP) and muriate of potash (MOP). The experimental units were weeded manually at various growth stages. Irrigation was maintained according to the crop requirement. The crop was sown on 20$^{th}$ November and harvested on May, 10$^{th}$ with help of hand sickle. The data were recorded on productive tiller $m^{-2}$, un-productive tillers $m^{-2}$, plant height, thousand grain weight, biomass yield, harvest index and economic analysis.

### *Procedures for recorded observations*

The data on productive tillers $m^{-2}$ was documented by calculating fertile tillers at three random positions in a meter long row and converted into $m^{-2}$ via formula:

$$\text{Productive tillers } m^{-2} = \frac{\text{total productive tillers counted}}{\text{row} - \text{row distance (m) x row length (m) x no. of rows}}$$

Unproductive tillers in each plot were totaled by subtracting productive tillers from total tillers $m^{-2}$. After threshing, thousand grains were calculated from each plot and weighed with electronic balance. Four central rows in each plot were harvested; sun dried, weighed and was converted into kg $ha^{-1}$ via the formula for biological yield;

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

The following formula was used for Harvest index.

$$\text{HI (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} \text{x100}$$

Economic yield was calculated using the following formula.

$$VCR = \frac{\textit{Economic yield in term of total benefit}}{\textit{Expendidure of total cost}}$$

### *Statistical analysis*

The documented data were analyzed by analysis of variance in accordance of RCBD with split plot arrangements. Means of the analyzed data were compared by applying LSD test at P≤0.05 (Steel and Torrie, 1997).

## Results and Discussion

### Productive tillers $m^{-2}$

Analysis of variance exhibited that nitrogen (N) and sulfur(S) as well as application timing (AT) of sulfur had significantly influenced productive tillers $m^{-2}$. Interactions were not significant. Minimum number (163 tillers $m^{-2}$) was recorded in control plot. Among the N treated plots, more productive tillers were obtained from 150 kg N $ha^{-1}$compared to lower N rates. Higher sulfur fertilization (45 kg $ha^{-1}$) resulted in significantly higher productive tillers. Regarding sulfur application timing, more productive tillers were obtained when sulfur fertilizer was appliedin two splits, 50% at sowing and 50% at tillering compared to whole S applied either at sowing or at tillering (Table 1).

### *Unproductive tillers $m^{-2}$*

Analysis of data pertained that unproductive tillers $m^{-2}$ had positively responded to N. Sulfur (S) application timing (AT) and all the interactions were not significant. The highest unproductive tillers $m^{-2}$ (14) wasobserved in control plots. The plots treated with 150 kg N $ha^{-1}$reduced the number of tillers $m^{-2}$(09) (Table 1).

### *Plant height (cm)*

Nutrients contribute tocrops vegetative growth and phenology. Plant height of wheat significantly responded to N and S as well as S application timing (Table 1). Interactions were not significant. Short statured plants (82.4 cm) were observed in control plots. Among the N treated plots, taller plants (94.4 cm) were noted at 150 kg N $ha^{-1}$ as compare to lower N rates. Higher sulfur level (45 kg $ha^{-1}$) resulted in significantly taller plants. Regarding S application timing, taller plants were recorded when S applied in two splits, 50% at sowing and 50% at tilleringcompared to sole application either at sowing or at tillering.

### *Thousand grains weight (g)*

The role of seed weight in cereal crops has great importance. Analysis of variance exhibited that N and S had significantly influenced thousand grains weight, whereas AT and all interactions except N x S were not significant (Table 1). Lowest grains weight (38.6 g) was recorded in control plots. Among the N fertilized plots higher grains weight was obtained from 150 kg N $ha^{-1}$compared to lower N rates. Higher S fertilization (45 kg $ha^{-1}$) resulted in heavier grains (45.6 g). Regarding N and S interaction, heaviergrains (46.2 g) wereobserved at 150 kg N $ha^{-1}$ and 45 kg S $ha^{-1}$(Figure 1). Lighter grains (38.6 g) were recorded in control plots.

### *Biological yield (kg $ha^{-1}$)*

Biological yield was significantly influenced by nitrogen and sulfur as well as sulfur application time. Interactions were not significant. Lower biological yield (7725 kg $ha^{-1}$) was recorded in control plots. Among the N fertilized plots, higher biological yield (10005 kg $ha^{-1}$) was obtained from 150 kg N $ha^{-1}$ in comparison to low N rates (Table 1). It was also noted that higher sulfur fertilization (45 kg $ha^{-1}$) resulted in significantly higher biological yield (9996 kg $ha^{-1}$). Regarding sulfur application timings greater biological yield (97047 kg $ha^{-1}$) was obtained when sulfur was applied 50% at sowing + 50% at tillering compared to its sole application either at sowing or at tillering.

**Table 1:** *Productive tillers (PT, m$^{-2}$), unproductive tillers (UP, m$^{-2}$), plant height (PH, cm), thousand grain weight (TGW, g), biomass yield (BY, kg ha$^{-1}$) and harvest index (HI, %) of wheat as affected by management of nitrogen, sulfur and application timing of sulfur.*

| Nitrogen levels (kg ha$^{-1}$) | PT(m$^{-2}$) | UPT (m$^{-2}$) | PH (cm) | TGW(g) | BY (kg ha$^{-1}$) | HI (%) |
|---|---|---|---|---|---|---|
| 90 | 182 c | 12.0 a | 89.9 b | 42 c | 8893 b | 35.86 b |
| 120 | 192 b | 10 ab | 91.5 b | 43.5 b | 9102 b | 38.50 a |
| 150 | 200 a | 9 b | 95.4 a | 45.9 a | 10005 a | 36.47 b |
| LSD (0.05) | 2.45 | 0.86 | 1.4 | 1.28 | 332.53 | 1.62 |
| **Sulfur levels (kg ha$^{-1}$)** | | | | | | |
| 15 | 187 b | 11 | 90.3 c | 41.2 c | 8926 b | 35.36 b |
| 30 | 189 b | 11 | 92.6 b | 44.6 b | 9077 b | 39.32 a |
| 45 | 198 a | 10 | 94 a | 45.6 a | 9997 a | 36.16 b |
| LSD (0.05) | 2.28 | ns | 0.88 | 0.92 | 277.21 | 1.01 |
| **Sulfur application timing (AT)** | | | | | | |
| 100% at sowing | 189 b | 11 | 90.8 c | 43.7 ab | 8985 c | 36.99 |
| 100% at tillering | 190 b | 10 | 92.4 b | 43.4 b | 9310 b | 37.12 |
| 50% at sowing + 50% at tillering | 195 a | 11 | 93.7 a | 44.4 a | 9705 a | 36.73 |
| LSD (0.05) | 2.28 | ns | 0.88 | 0.92 | 277.21 | Ns |
| **Planned mean comparison** | | | | | | |
| Control | 163 | 14 | 82.41 | 38.6 | 2619 | 33.92 |
| Rest | 191 | 11 | 92.27 | 43.8 | 3426 | 36.95 |
| Interactions | | | | | | |
| N x S | ns | ns | Ns | * | ns | ** |
| N x AT | ns | ns | Ns | ns | ns | Ns |
| S x AT | ns | ns | Ns | ns | ns | Ns |
| N x S x AT | ns | ns | Ns | ns | ns | Ns |

**PT:** *Productive tillers;* **UPT:** *Unproductive tillers;* **PH:** *Plant height;* **TGW:** *Thousand grain weight;* **BY:** *Biomass yield;* **HI:** *Harvest index. Mean values of similar category pursued by different letters discloses significant differences (p≤ 0.05) using LSD test. *, ** significant at 5% level of probability.* **Ns:** *Non significant.*

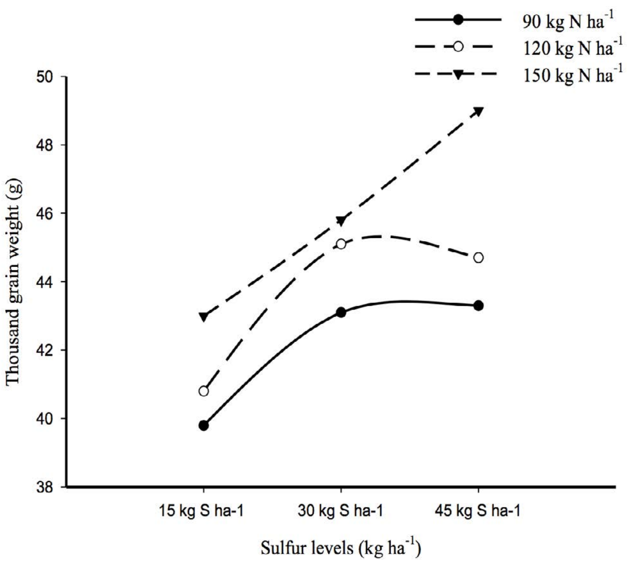


**Figure 1:** *Interaction of nitrogen (N) and sulfur (S) for thousand grains weight of wheat.*

*Harvest index (%)*

Analysis of variance indicated that nitrogen, sulfur and N x S had significantly influenced harvest index whereas application timings and all other interactions were not significant (Table 1). Among N treated plots, higher harvest index (38.50) was recorded at 120 kg N ha$^{-1}$compared to lower N rates. Sulfur fertilization (30 kg S ha$^{-1}$) resulted in significantly higher harvest index (39.32). In case of N and S interaction, maximum harvest index (41.75) was recorded at 120 kg N ha$^{-1}$ and 30 kg S ha$^{-1}$ (Figure 2). Minimum harvest index (33.92) was recorded in control plots.

*Economic analysis*

Analysis indicated that nitrogen and sulfur had significantly influenced value cost ratio (VCR). Among the N treated plots, higher VCR (3.68) was found for 150 kg N ha$^{-1}$compared to lower N rates, where as sulfur fertilization (15 kg ha$^{-1}$) resulted in higher VCR (3.66). Maximum VCR (3.68) was recorded, when S applied 50% at sowing and 50% at tillering.

Treated plots showed best performance over control plots in this perspective (Table 2).

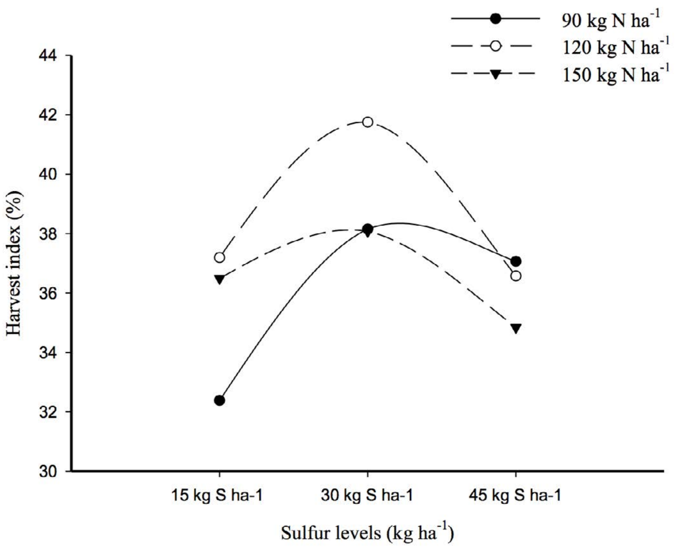


**Figure 2:** *Interaction of nitrogen (N) and sulfur (S) for harvest index (%) of wheat.*

Cereal crops have unique character to produce tillers. Mean values indicated that productive tillers m$^{-2}$ were significantly influenced by nitrogen, sulfur and S application time. Interactions were not significant. Maximum productive tillers m$^{-2}$ was observed in treated plots against control. Highest rate of N produced more productive tillers m$^{-2}$ as compare to lowest. Higher S rate resulted in higher number of productive tillers as compare to low S rates. Sulfur application time had positively attributed. More productive tillers m$^{-2}$ were observed in the plots where sulfur applied 50% at sowing and 50% at tillering as compare to those where it applied full at sowing or full at tillering stage. Applying nutrients at right time greatly influence growth and development of crop hence producing more productive tillers m$^{-2}$. The main reason is application of nitrogen and sulfur at desired stage of plant greatly contributes toward dry matter production and promotes production of chlorophyll which enhanced physiological processes of plant like photosynthesis (Malhi, 2006; Habtegebrial, 2007). Nutrient incorporation at vital time results in more potential and vigor therefore, more amount of assimilates goes to sink and produce higher number of productive tillers m$^{-2}$ in wheat crop (Kibe, 2006). Our observations are also correlated with (Bakht et al., 2010; Otteeson et al., 2007) who recommended that proper supply of nutrients at proper time significantly upsurge the ratio of productive tillers m$^{-2}$.

The effect of only main plot factor nitrogen was found significant over un-productive tiller m$^{-2}$ with sub plot factors S and (AT) as well as all the interactions were insignificant. Less unproductive tillers m$^{-2}$ were perceived in fertilized plots over control. In case of factors higher dose of N reduced unproductive tillers m$^{-2}$ as compare to lowest dose. The application of macro nutrients enhanced the performance of crops. This reduction might be the result of availability of nutrients for long time at different growth stages. Nitrogen also have key role in photosynthesis so as a result it contributed to minimize the number of un-productive tillers. Minimum un-productive tillers m$^{-2}$ is also result of nitrogen supply in split applications. These observations correlated with (Malhi et al., 2006) who exhibited that supply of nitrogen in splits at different growth and development stages reduced unproductive tillers m$^{-2}$ in cereal crops.

Data regarding plant height reported was significant for nitrogen, sulfur and their application timing with no significant results obtained for their interaction. Treated plots elevated higher than untreated plots. Nitrogen at highest dose applied produced tallest plants rather than no nitrogen applied plots. This might be the reason of role of N in photosynthesis by translocation of more photo assimilates to the stem of wheat. Another possible reason is that the prolong supply of nitrogen maximized the dry matter production therefore, internodes length increases and plants gained maximum length. These arguments also supported by (Bakht et al., 2010; Khan et al., 2009; Hussein and Alva, 2014). Sulfur applied 50% at sowing and 50% tillering at its highest rate increased plant height (cm) in respect to lowest, when applied 100 % at sowing or 100% at tillering. It might be associated with the phenomenon that sulfur promotes efficient utilization of nitrogen. Beside this application of sulfur in split doses at different stages maximized the availability of nutrients and also maintained the health of soil. So, wheat plant gained maximum height by sufficient availability of nutrients. These findings were supported by (Jarvan et al., 2008).

Photo assimilates greatly contributes toward grain size and weight. Therefore, it has a direct relation with grain yield. Data obtained from treated plots got the value over control. Thousand grains weight (g) had significantly affected by N and S as well as their interaction. Higher mean value was observed at maximum dose of nitrogen. The same trend also found in case of sulfur. With increase in nutrients rate greater

**Table 2:** *Economic analysis of wheat as affected by management of nitrogen sulfur and application timings of sulfur.*

| Nitrogen (kg ha$^{-1}$) | Sulfur (kg ha$^{-1}$) | AT | Grain yield (kg ha$^{-1}$) | Grain yield value (Rs) | Straw yield (kg ha$^{-1}$) | Straw yield value (Rs) | Gross income (Rs) | S-Cost (Rs) | N-Cost (Rs) | Uniform cost (Rs) | Total cost (Rs) | Net income (Rs) | (VCR) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | 0 | 0 | 2528.0 | 80897 | 4833.9 | 53172 | 134069 | 0 | 7020 | 37000 | 44020 | 90049 | 3.05 |
| 90 | 15 | 1 | 2684.6 | 85906 | 5509.6 | 60606 | 146511 | 5250 | 3209 | 37000 | 45459 | 101052 | 3.22 |
| 90 | 15 | 2 | 2730.5 | 87377 | 6005.3 | 66058 | 153435 | 5250 | 3209 | 37000 | 45459 | 107976 | 3.38 |
| 90 | 15 | 3 | 2907.3 | 93032 | 5891.1 | 64802 | 157834 | 5250 | 3209 | 37000 | 45459 | 112375 | 3.47 |
| 90 | 30 | 1 | 3168.5 | 101393 | 5055.9 | 55614 | 157007 | 10500 | 2136 | 37000 | 49636 | 107371 | 3.16 |
| 90 | 30 | 2 | 3228.1 | 103298 | 5235.9 | 57595 | 160893 | 10500 | 2136 | 37000 | 49636 | 111257 | 3.24 |
| 90 | 30 | 3 | 3371.7 | 107895 | 5585.5 | 61441 | 169336 | 10500 | 2136 | 37000 | 49636 | 119700 | 3.41 |
| 90 | 45 | 1 | 3366.2 | 107718 | 5511.5 | 60627 | 168345 | 15750 | 1065 | 37000 | 53815 | 114530 | 3.13 |
| 90 | 45 | 2 | 3574.8 | 114394 | 6456.5 | 71022 | 185415 | 15750 | 1065 | 37000 | 53815 | 131600 | 3.45 |
| 90 | 45 | 3 | 3667.4 | 117357 | 6085.3 | 66938 | 184295 | 15750 | 1065 | 37000 | 53815 | 130480 | 3.42 |
| 120 | 0 | 0 | 2610.7 | 83542 | 5183.5 | 57018 | 140560 | 0 | 9360 | 37000 | 46360 | 94200 | 3.03 |
| 120 | 15 | 1 | 3023.9 | 96763 | 5377.7 | 59154 | 155917 | 5250 | 5550 | 37000 | 47800 | 108117 | 3.26 |
| 120 | 15 | 2 | 3246.7 | 103894 | 5452.7 | 59979 | 163874 | 5250 | 5550 | 37000 | 47800 | 116074 | 3.43 |
| 120 | 15 | 3 | 3227.6 | 103282 | 5888.5 | 64773 | 168055 | 5250 | 5550 | 37000 | 47800 | 120255 | 3.52 |
| 120 | 30 | 1 | 3428.8 | 109722 | 5325.5 | 58580 | 168302 | 10500 | 4476 | 37000 | 51976 | 116326 | 3.24 |
| 120 | 30 | 2 | 3577.9 | 114491 | 4744.7 | 52191 | 166682 | 10500 | 4476 | 37000 | 51976 | 114706 | 3.21 |
| 120 | 30 | 3 | 3738.5 | 119632 | 5331.2 | 58643 | 178275 | 10500 | 4476 | 37000 | 51976 | 126299 | 3.43 |
| 120 | 45 | 1 | 3490.6 | 111700 | 6005.6 | 66062 | 177762 | 15750 | 3405 | 37000 | 56155 | 121607 | 3.17 |
| 120 | 45 | 2 | 3584.5 | 114704 | 6265.8 | 68923 | 183627 | 15750 | 3405 | 37000 | 56155 | 127472 | 3.27 |
| 20 | 45 | 3 | 3725.4 | 119212 | 6481.8 | 71299 | 190511 | 15750 | 3405 | 37000 | 56155 | 134356 | 3.39 |
| 150 | 0 | 0 | 2717.9 | 86972 | 5300.3 | 58303 | 145275 | 0 | 11700 | 37000 | 48700 | 96575 | 2.98 |
| 150 | 15 | 1 | 3269.0 | 104609 | 6406.2 | 70468 | 175077 | 5250 | 7890 | 37000 | 50140 | 124937 | 3.49 |
| 150 | 15 | 2 | 3434.0 | 109887 | 5430.0 | 59730 | 169617 | 5250 | 7890 | 37000 | 50140 | 119477 | 3.38 |
| 150 | 15 | 3 | 3580.0 | 114560 | 6270.5 | 68976 | 183536 | 5250 | 7890 | 37000 | 50140 | 133396 | 3.66 |
| 150 | 30 | 1 | 3510.6 | 112338 | 5913.0 | 65043 | 177381 | 10500 | 6816 | 37000 | 54316 | 123065 | 3.27 |
| 150 | 30 | 2 | 3880.4 | 124172 | 5990.8 | 65898 | 190070 | 10500 | 6816 | 37000 | 54316 | 135754 | 3.50 |
| 150 | 30 | 3 | 3972.0 | 127102 | 6633.9 | 72973 | 200075 | 10500 | 6816 | 37000 | 54316 | 145759 | 3.68 |
| 150 | 45 | 1 | 3532.7 | 113046 | 6289.6 | 69186 | 182232 | 15750 | 5745 | 37000 | 58495 | 123737 | 3.12 |
| 150 | 45 | 2 | 3717.9 | 118972 | 7229.4 | 79524 | 198496 | 15750 | 5745 | 37000 | 58495 | 140001 | 3.39 |
| 150 | 45 | 3 | 3796.6 | 121491 | 7187.2 | 79059 | 200550 | 15750 | 5745 | 37000 | 58495 | 142055 | 3.43 |

**AT1:** *100% at sowing time;* **AT2:** *100% at tillering stage;* **AT3:** *50% at sowing time + 50% at tillering stage.*

value for thousand grains weight may be associated with prolong availability of essential macro nutrients to wheat. Another possible reason might be the result of assimilation of more photosynthetic products. It might be related to plant physiological traits like expanded leaf area, greater leaf area index and taller plants. Therefore, they upsurge the supply of assimilates toward the sink after completing their requirements of food. These observations are also supported by (Asif et al., 2010; Neuberg et al., 2010) they reported an association of hormonal activity between N and S. Interactive effects of N and S was best when applied at their highest rates as compare to lowest. It might be the result of an association between N and S which justified that S promotes the efficient utilization of nitrogen and maintained soil health. Another possible reason is that N and S has synergistic effect, hence the attributes which associated with higher nitrogen contributes toward maximum thousand grain weight. This theory was also supported by the findings of (Karamanos et al., 2013).

Grain yield directly relates to photo assimilates which highly contributes toward grain size and weight. Data obtained from plots treated with maximum dose of N had an edge over control with no N supplied. Thousand grains weight (g) was significantly affected by N and S as well their interactions. Higher mean value was observed at maximum dose of nitrogen. The same trend also found in case of sulfur. With increase in nutrients rate greater value for thousand grains weight may be associated with prolong availability of essential macro nutrients to wheat. Another possible reason might be the result of assimilation of more photosynthetic products. It might be related to plant physiological traits like expanded leaf area, greater leaf area index and taller plants. Therefore, they upsurge the supply of assimilates toward the sink after completing their requirements of food. These observations are also supported by (Asif et al., 2010; Neuberg et al., 2010). They demonstrated an association of hormonal activity between N and S. Interactive effects of N and S was best when applied at their highest rates as compare to lowest. It might be the result of an association between N and S which justified that S promotes the efficient utilization of nitrogen and maintained soil health. Another possible reason is that N and S has synergistic effect, hence the attributes which associated with higher nitrogen contributes toward maximum thousand grain weight. This theory also supported by the outcomes of (Karamanos et al., 2013).

Biological yield of wheat had significantly responded to N, S and application time of sulfur (AT). Interactions were observed not significant. Maximum biological yield was noted in treated plots over control. Higher yield was attained with the highest N dose as compare to lowest dose production. Possibly, it might be resulted from accumulation of more nitrogen in vegetative parts like stem and husk of spike as well as in leaves of plant. Another possible reason is that presence of more assimilates in grain also is a factor for higher biological yield. Beside this N also promotes the vegetative cover which contributed toward the accelerated physiological process. These findings are in line with (Ali et al., 2008) who demonstrated that N upsurge the biomass of wheat. Sulfur and its application time were showed a linear increase in biological yield as the rate of S increased at sowing time and tillering stage. This might be the result of availability of sulfur at right time which enables crop to efficiently utilize the uptake of nutrients at vegetative as well as reproductive stage. These results are in coincidence with those of Zhang et al. (1999). They noted that when different levels of sulfur applied at different stages remarkably upsurge the yield of wheat.

Harvest index (%) associated with yield parameters of crop. It has the importance to analyze the performance of a crop in total yield and final yield perspectives. Treated plots presented maximum value for harvest index over control. Harvest index showed more value as the rate of N increased as compare to the value obtained at lower dose of nitrogen. This phenomenon associated with more accumulation of nitrogen toward vegetative as well as reproductive growth of the crop. These outcomes are in match with (Bakht et al., 2010) who demonstrated that higher biological yield and grain yield enhanced the harvest index of wheat crop. Sulfur supplementation also revealed that harvest index directly related with biological and grain yield of wheat. Greater value for harvest index was found at increased level of sulfur. It may be the product of N and S activity which promote the action of one another. Hence, physiological performance of crop enhances and potential to produce higher yield also aggrandizes. These outcomes are co related with (Malhi et al., 2006) who noted that sulfur promote the availability of N which in turn produces greater harvest index, due to higher value of biological and grain yield. Interactive effect of N and S provide base of performance for each other because of synergistic effect in between. Therefore, N availability via the presence of S produced more yield of wheat. The lines are in correlation with (Habtegebrial et al., 2007; Kibe et al., 2006) they exhibited that prolonged supply of N was enhanced by the presence of sulfur.

Economic analysis of wheat crop was appreciable in term of value cost ratio. The higher rates of nutrients N and S as well as their timely application returned best yield. Producing higher yield may be the results of efficient utilization of nutrients at different growth stages. Therefore, crop performed best under the synergistic effect of nitrogen and sulfur, when supplemented at sowing time as well as in later stages. Our outcomes are justified by (Saeed et al., 2013; Asif et al., 2010). They found synergistic effect and a close hormonal activity in N and S.

## Conclusions

It is concluded from the analysis that nitrogen, sulfur and application timings of sulfur had positively contributed to the economics, biomass yield and yield attributes of wheat. Most parameters significantly elevated with 150 kg ha$^{-1}$ N and 45 kg ha$^{-1}$ S application. Sulfur incorporated at 50% at sowing and 50% at tillering derived best results. Based on the experimental conclusion, N at the rate of 150 kg ha$^{-1}$ along with S at the rate of 30 kg ha$^{-1}$ applied 50% at sowing and 50% at tillering recommended for better performance and higher yield of wheat in Khyber Pakhtunkhwa.

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## Authors' Contribution

Conceived and designed the experiment: Shahen Shah, Performed the experiment: Manzoor Hussain, Analyzed the data: Shahen Shah, Mohammad Sayyar Khan, Arshad Jalal and Muhammad Ilyas, Contributed reagents/ materials/ analysis tools: Shahen Shah, Mohammad Sayyar Khan, Muhammad Uzair. Wrote the paper: Arshad Jalal, Muhammad Ilyas and Tariq Shah.

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