Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2023-s1-065

Research Article

Open Access

Effect of Nitrogen and Sulphur Fertilization on Growth, Yield, Quality, and Nutrient Status of Soil of Wheat (*Triticum aestivum*) var. HD3086 (Pusa Gautami) Crop

Akshay Sharma[1], Kunwar Gahlot[1], Koutik Roy[1], Arshdeep Singh[1*], Shimpy Sarkar[2] and Iza Fatima[3]

[1]*Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India*
[2]*Department of Entomology, School of Agriculture, Lovely Professional University, Phagwara, Punjab, India*
[3]*College of Agronomy and Biotechnology, China Agricultural University, Beijing, China*

[*]Correspondence to:
Arshdeep Singh
Department of Agronomy,
School of Agriculture,
Lovely Professional University,
Phagwara, Punjab, India.
Email: arshdeep.27269@lpu.co.in

Received: October 14, 2023
Accepted: November 10, 2023
Published: November 15, 2023

Citation: Sharma A, Gahlot K, Roy K, Singh A, Sarkar S, et al. 2023. Effect of Nitrogen and Sulphur Fertilization on Growth, Yield, Quality, and Nutrient Status of Soil of Wheat (*Triticum aestivum*) var. HD3086 (Pusa Gautami) Crop. *J Food Chem Nanotechnol* 9(S1): S517-S523.

Published by United Scientific Group

Abstract

The optimization of fertilization techniques allows for the attainment of a high-quality and high-yield crop, resulting in economic gains and mitigating any environmental risks. The regulation of nitrogen (N) and sulphur (S) is of paramount importance in wheat cultivation, as both macronutrients play a critical role. Both factors have a substantial influence on the enhancement of growth and yield characteristics. Furthermore, the elements S and N are also crucial in facilitating the augmentation of seed protein levels. Nevertheless, the current requirement is to determine the most suitable application rate in order to attain the highest possible wheat output. Hence, the present study was designed to investigate the effects of varying application rates of S and N on wheat. The experimental design consists of ten treatments, namely: control (no nitrogen (0N) + no sulphur (0S)), 40 kg ha^{-1}N (40 N + 0 S), 80 kg ha^{-1} N (80 N + 0 S), 120 kg ha^{-1} N (120 N + 0 S), 40 kg N ha^{-1} + 15 S, 80 kg N ha^{-1} + 15 S, 120 kg N ha^{-1} + 15 S, 40 kg N ha^{-1} N + 30 S, 80 kg N ha^{-1} + 30 S, and 120 kg N ha^{-1} + 30 S. Each treatment is replicated three times. The findings of the study indicated that the inclusion of 120 kg N ha^{-1} + 30 S resulted in considerable enhancements in many plant characteristics, including plant height (5.77 ± 0.39^a), number of tillers (9.67 ± 0.47^a), fresh weight (54.80 ± 1.55^a), grains per spike (34.00 ± 0.82^a), number of spikes (5.77 ± 0.39^a), and 1000 grain weight (44.97 ± 0.57^a). The efficacy of 120 kg N ha^{-1} + 30 S in improving grain N content (2.95 ± 0.06^a), N uptake (86.37 ± 1.07^a), and protein content (18.44 ± 0.36^a) in wheat was confirmed, highlighting its large impact compared to the absence of N and S fertilization. In summary, the treatment involving the application of 120N + 30S demonstrates superior efficacy in promoting the attainment of optimal wheat production. It is recommended that further investigations be conducted to examine the effects of varying soil textures and meteorological circumstances on wheat growth and yield enhancement. These investigations should be carried out in diverse geographical regions, in order to determine whether this specific amendment is the most effective for promoting wheat growth and improving output.

Keywords

Life on land, Responsible crop production, Zero hunger, Ammonium nitrate, Kieserite, Efficacy of fertilizers, Sustainability, Nutrient use efficiency

Introduction

Wheat, one of the first plants to be domesticated, has been a mainstay of the diets of ancient civilizations spanning Europe, West Asia, and North Africa for a very long time [1]. In many accounts, the domestication of wheat marked a turning point as human societies transitioned from a hunter-gatherer and nomadic pastoralist lifestyle to an active agricultural existence. Humanity's continued existence and prosperity depend critically on wheat farming. Environmental conditions, fertilizer use, and the genotype being cultivated are just a few of the many variables that might affect the crop's quality and yield. Most cultivars are bred for better milling efficiency, higher protein content, and enhanced baking qualities [2]. Wheat, a commodity grown all over the world, is extremely valuable now due to its economic importance. This grain, together with rice and maize, is extremely important as a staple diet because they account for more than 90% of the world's cereal consumption combined. In 2018, 214 million hectares of land were devoted to wheat production around the world. The average yield was about 3.4 tons per acre, resulting in a total production of 734 million tons [3]. Therefore, it is crucial to significantly improve the growth and quality attributes of wheat in order to obtain the potential health advantages associated with wheat grains. Agricultural observations have shown a correlation between efficient nutrient utilization and the commercial yield of cereals.

The capacity of plants to maximize their uptake of nutrients from the soil is referred to as nitrogen usage efficiency (NUE). It also helps agricultural plants store, use, and redistribute nutrients via their internal transport channels. Plants grown on a mix of organic and inorganic soil substrates have a higher NUE because of their structural properties and root growth [4]. Furthermore, NUE is significantly influenced by irrigation and fertilizer management. Therefore, fertilizers have been refined to provide the highest possible concentration of nutrients. When it comes to growing plants, N is the most crucial of all the necessary nutrients. An important part of chlorophyll is. The biological process of photosynthesis serves an essential purpose. The application of N fertilizer management practices has been found to provide large gains in grain weight and total crop productivity, notably in cereal crops. However, increasing the amount of protein in wheat grains is frequently seen as an essential part of quality because of the positive effects it can have on human health. The increase in protein content is also reported to have a beneficial link with the delivery of N fertilizer [5]. As a result, controlling N levels is essential for wheat farming. Plant-based amino acids like methionine and cysteine contain S in considerable amounts. By improving the reduction mechanism, the S balance update slows down oxidative activities. More importantly, it facilitates increased grain output, which is a major factor in increasing wheat productivity. Optimal N utilization, especially in protein component synthesis, is credited in the literature to S presence [6]. Because N activity can't reach its peak without S, the production of protein-rich biosynthetic output is dependent on its existence. As a result, the current research was conceived with S and N significance to wheat in mind. The goal of this research was to increase wheat grain protein content and yield quality by filling up the knowledge gap on the best way to apply balanced S and N as a standalone amendment or in tandem. Our research shows that there is a dearth of information about how much N and S should be applied to wheat fields in order to maximize yields [7]. This investigation is the first of its kind to examine the synergistic effects of N and S amendments on wheat grain quality and yield. The primary goal of this research was to examine the effects of N and S on wheat growth and yield, specifically looking for beneficial and detrimental effects. There exists a notion stating that the simultaneous application of N and S may act as a more effective technique for improving both crop yield and protein levels in wheat.

Materials and Method

Experimental location and layout

A field experiment was conducted at the research farm of the agronomy department of Lovely Professional University, Phagwara with latitude.

The farm is located at an elevation of 250 m, near the intersection of latitude 310° 22′ 31.81″ North and longitude 750° 23′ 03.02″ East and 20 Km away from Jalandhar city in Punjab, India. The experiment was laid out in a randomized complete block design with a set of 10 treatments to perform the study trial.

Key objectives of the study

- To study the effect of different N and S fertilizer rates and their interactions on the time course of N uptake during wheat ontogeny.
- To assess the effect of different N and S fertilizers and their interaction on nutrient use efficiency and its components.

Chemical details

N - 40 kg N, 80 kg N, and 120 kg N ha^{-1} {N applied from ammonium nitrate (34% N)} and S - 0 kg, 15 kg, and 30 kg

Application of fertilizers

40 kg N applied from ammonium nitrate before sowing. 80 kg N - 40 kg N at sowing + 40 kg at beginning of shooting. 120 kg N - 40 kg N at sowing + 40 kg N at beginning of shooting and 40 kg N at heading stage.

S 15 kg - (10 + 5 kg)

10 kg S applied before sowing in form of Kieserite ($MgSO_4.H_2O$). 5 kg S applied in form of ($MgSO_4.7H_2O$) as foliar application.

S 30 kg (20 + 10 kg)

20 g applied before sowing in form of kieserite. 10 g applied inform of ($MgSO_4.7H_2O$) as foliar application.

Instruments used for experiments

- Kjeldahl method (for N).
- Spectrophotometer (for phosphorous).
- Flame photometer (for potash).
- Oven (for soil drying).
- Spectrophotometric tubes or cuvettes (for S estimation).
- pH meter (for soil pH).
- Ec meter (for soil Ec).

Soil characteristics

To conduct a physiochemical examination of the pre-experimental soil, three replicates of the sample were obtained. The region receives an average of 630 mm yr^{-1} rainfall, about 80% of which occurs from June to September. Mean maximum and minimum temperatures are respectively 43 ˚C and 18 ˚C during the year. Soil pH, electrical conductivity, organic carbon, phosphorus, and potassium content in surface (0-15 cm) soil layer of the experimental sites ranged from 7.5 - 8.0, 0.13 - 0.24 ds m^{-1}, 4.7 - 5.5 g kg^{-1}, 13.1 - 28.5 kg ha^{-1} and 111 - 145 kg ha^{-1}, respectively. The composite sample was prepared by combining all the duplicates, and subsequent characterization was conducted following established techniques. Soil samples were obtained from each plot for the post-experiment setup.

Wheat seeds

Wheat variety HD 3086 was used in the experiment. A new bread wheat variety, HD 3086 (pusa gautami) has been released and notified by the central sub-committee on crop standards, notification, and release of varieties for agricultural crops, Government of India for commercial cultivation under timely sown irrigated conditions of Northwestern Plains Zone (NWPZ) of the country. Initially, weak, and damaged seeds were screened out manually before sowing.

Experimental Detail

The total number of treatments were 10 and the plot size was (5 m × 4 m) with a row-to-row distance of 22.5 cm. Each treatment was replicated three times. The treatments were: T_0: no fertilization (control); T_1, T_2, T_3 - 40 kg N, 80 kg N, and 120 kg N ha^{-1} respectively, with 0 S fertilization as N applied from ammonium nitrate (34% N); T_4, T_5, T_6 - 40 kg N, 80 kg N, and 120 kg N ha^{-1} with 15 kg S ha^{-1} was introduced with fertilizer A (ammonium nitrate and Kieserite , 26% N and 22.2 % SO_3), T_7, T_8, T_9 - 40 kg N, 80 kg N, and 120 kg N ha^{-1} with 30 kg S ha^{-1} was introduced with fertilizer B (ammonium nitrate and Kieserite + $MgSO_4.7H_2O$). The N source utilized in this study was ammonium nitrate. Prior to sowing, 10 kg and 20 kg of S were applied in the form of Kieserite. Additionally, 5 kg and 10 kg of S were applied as a foliar spray in the form of $MgSO_4.7H_2O$. Phosphorus was administered prior to the seeding of wheat at a rate of 387 kg/ha^{-1} of single superphosphate (SSP). N was administered at the initial stage of spring vegetation, with a dosage of 50%. It was also supplied before the commencement of the stem elongation phase, with a dosage of 30%. Additionally, N was administered prior to heading, with a dosage of 20%. The wheat crop was harvested when the grains reached full maturity, and thereafter, the quantity of grain yield was assessed. Four different irrigation methods were utilized in the growing of wheat. The sequence of the watering schedule consisted of four stages: crown root initiation, tillering stage, heading stage, and milky stage/soft dough. The process of harvesting was conducted after the plant reached its physiological maturity. The data was collected in accordance with the methodology outlined below.

Growth parameters

Data on plant height (cm), flag leaf length (cm), number of tillers, fresh weight (g), dry weight (g), chlorophyll index (SPAD) was recorded by five randomly selected plants from each subplot, and after that, the average values were determined.

Yield attributes

Number of spikes per plant, length of spikelet and number of grains per spike: Number of spikes per plant and length of spike was measured. Randomly, 10 plants were selected and threshed, and grains were counted independently per spike and the average was taken.

Test weight (g), grain yield, straw yield, biological yield and harvest index: The determination of the thousand grain weight involved the process of separating and weighing 1000 grains from each subplot using an electronic scale. The plants obtained from four central rows for the purpose of measuring grain yield were subjected to the process of sun-drying, threshing, and cleaning. The resulting weight of the grains was then duly documented. The conversion of grain weight was performed to express the measurement in kg/ha^{-1}. The concept of biological yield refers to the quantity of biomass produced by a living organism or a biological system. In each subplot, the plants were harvested and afterwards subjected to a drying process. Following the drying process, the plants were weighed, and the measurements were converted into kg/ha^{-1}.

N content in the soil (mineral N)

The Kjeldahl method was employed to ascertain the presence of mineral N in the soil. A soil sample weighing 2 gm was collected and placed into a flask, followed by the addition of 100 milliliters of a 1 molar potassium chloride (KCl) solution. Subsequently, the flask was subjected to mechanical agitation in a shaker for a duration of 1 h to ensure thorough mixing. Following the shaking process, the soil solution underwent filtration using a Whatman 42 filter paper. Subsequently, a quantity of 20 ml from the filtered sample was transferred into a wolf bottle, to which 0.2 g of MgO and 0.1 g of Devarda's alloy were introduced for the purpose of reclaiming mineral N. Subsequently, the substance underwent distillation in the presence of a 5 ml solution containing a mixture of boric acid and an indicator. When the volume of the flask reached 70 ml, the distillation process was halted. Subsequently, the solution in the conical flask was titrated against a 0.005 N HCl solution until a bright pink color was observed. Subsequently, the titration process was halted, and the measurement was duly recorded [8].

S content in the soil

A soil sample weighing 25 g was collected and placed in a conical flask with a volume of 250 ml. Subsequently, it was combined with 50 ml of a $CaCl_2$ extracting reagent with a concentration of 0.001 M. The mixture in the flask underwent agitation for a duration of 30 min, followed by filtration using a Whatman 42 filter paper. The 1 ml extracted sample was put into a 50 ml test tube and subsequently diluted to a final volume of 6 ml using distilled water. Subsequently, a volume of 3 ml of a composite acid reagent was introduced and well mixed with 1 ml of acid sulphate. Next, a quantity of 0.5 grammes of $BaCl_2.2H_2O$ crystal was introduced into the mixture, ensuring full mixing. The resulting solution was then left undisturbed for a duration of 3 min. Subsequently, 1 milliliter of the gum acacia reagent was added to the mixture and once again stirred completely. The spectrophotometer was utilized to measure the absorbance of SO_4-S at a wavelength of 420 nm, employing a standard solution [9].

N content in grains

The determination of N content in grains was conducted using Kjeldahl's technique. In this experimental procedure, a total of 0.2 grammes of finely powdered samples were collected and placed into a digestion tube. To this, 3 ml of concentrated $HClO_4$ were added, along with 0.01 grammes of a digestion mixture consisting of $CuSO_4.K_2SO_4$ and selenium powder. The combination was then heated at a temperature of 45 $^{\circ}$C for a duration of 4 to 5 h. Following the process of digestion, the resulting volume was adjusted to 100 ml using distilled water. Subsequently, a quantity of 20 ml from the digested sample was transferred into a wolf bottle, to which 4 ml of NaOH was introduced. This combination was then subjected to distillation against 5 ml of a boric acid mixture indicator solution. When the capacity of the flask reached 70 ml, the distillation process was terminated. Subsequently, the solution in the conical flask was subjected to titration using a 0.005 N HCl solution until a faint pink coloration was observed. Subsequently, the titration process was ceased, and the measurement was duly recorded. The concentration of N was determined using 1 ml of 0.005 N hydrochloric acid (HCl), which is equivalent to 70 µg of N. The process of S uptake in plants. The S concentration in the plant was quantified and afterwards multiplied by the biological yield of plants collected from the field, divided by 100, in order to calculate the overall uptake of S in the plant [9].

Protein content in the grain

To ascertain the protein content, the initial step was recording the total N content present in the samples. The recorded N data was multiplied by a factor of 6.25 in order to determine the protein level present in the grain [8].

Statistical analysis

The standard statistical procedure was used for the statistical analysis of data. SPSS 22 vs. software was chosen for the analyses of variance (ANOVA), Pearson correlation, and the mean was compared (i.e., interactive effect of N and S) using the least significant difference test at $p \leq 0.05$.

Results and Discussion

Growth parameters

Plant height, tiller count, and total weight were all noticeably influenced by whether or not N and S were applied together or separately. The height of the plant is the most important factor in its development and productivity (Table 1). Plant height varied noticeably across all treatments. The results were much better with the addition of 40, 80, and 120 kg N compared to having neither N nor S. Increased N assimilation in plants likely accounted for the highest plant height (96.51 cm) in the 120 kg N + 30 kg S ha^{-1} treatment, which was also tied with the 120 kg N + 15 kg S treatment (96.01 cm) due to an increase in leaf surface area and the synthesis of chlorophyll. The ideal synthesis of photosynthate in the plants was achieved by increasing both the leaf surface area and the chlorophyll content. Boosting photosynthate production provides plants with more energy, which in turn causes them to grow taller. This finding agrees with those of Dhillon et al. [10]

Table 1: Effect of N and S fertilization on growth of wheat.

Treatments	Plant height (cm)	Chlorophyll index (SPAD)	Fresh weight (g)	Dry weight (g)	Tillers per plant	Flag leaf length (cm)
T0 - Control	76.80 ± 1.18^{g}	38.80 ± 1.71^{d}	33.97 ± 1.37^{e}	8.08 ± 0.90^{f}	3.33 ± 0.47^{f}	9.80 ± 1.10^{g}
T1 - 40 kg N + 0 kg S	84.09 ± 1.30^{f}	41.07 ± 2.20^{d}	43.83 ± 1.36^{d}	15.37 ± 0.96^{e}	3.33 ± 0.47^{f}	11.47 ± 1.12^{f}
T2 - 80 kg N + 0 kg S	86.30 ± 0.45^{e}	41.24 ± 1.6^{c}	45.50 ± 0.98^{cd}	17.29 ± 0.41^{cde}	4.48 ± 0.41^{e}	12.00 ± 0.66^{ef}
T3 - 120 kg N + 0 kg S	91.46 ± 0.84^{d}	45.59 ± 1.25^{c}	46.90 ± 1.26^{c}	17.90 ± 0.96^{cd}	6.67 ± 0.47^{c}	13.40 ± 1.37^{cde}
T4 - 40 kg N + 15 kg S	86.27 ± 0.83^{e}	46.23 ± 0.83^{c}	45.50 ± 0.70^{cd}	17.41 ± 0.87^{cde}	5.00 ± 0.82^{e}	12.10 ± 0.62^{def}
T5 - 80 kg N + 15 kg S	91.52 ± 0.82^{d}	46.72 ± 1.11^{c}	46.67 ± 0.94^{cd}	18.38 ± 0.63^{cd}	6.33 ± 0.47^{cd}	14.67 ± 0.90^{abc}
T6 - 120 kg N + 15 kg S	96.01 ± 1.0^{9a}b	47.83 ± 1.52^{c}	47.63 ± 0.90^{c}	19.23 ± 1.10^{bc}	8.33 ± 0.47^{b}	15.27 ± 0.49^{ab}
T7 - 40 kg N + 30 kg S	93.77 ± 1.19^{c}	50.62 ± 0.87^{b}	43.90 ± 0.50^{d}	17.03 ± 0.59^{de}	5.33 ± 0.47^{de}	13.67 ± 0.32^{bcd}
T8 - 80 kg N + 30 kg S	94.16 ± 1.20^{bc}	52.29 ± 0.86^{b}	49.57 ± 0.69^{b}	20.53 ± 1.30^{b}	8.33 ± 0.47^{b}	15.27 ± 0.95^{ab}
T9 - 120 kg N + 30 kg S	96.51 ± 0.82^{a}	54.94 ± 1.25^{a}	54.80 ± 1.55^{a}	24.26 ± 1.16^{a}	9.67 ± 0.47^{a}	16.03 ± 0.76^{a}

Note: Data is in the form of mean ± SDM at $p \leq 0.05$. The mean followed by different letters was significantly different at $p \leq 0.05$, according to DMRT for separation of means.

and Järvan et al. [11]. 80 kg N + 30 kg S ha^{-1} yielded the second-tallest plants (94.16 cm). In the control plots, plant height was measured at its lowest (76.8 cm). The chlorophyll index is proportional to the degree to which a plant is green. The 80 kg N + 30 kg S ha^{-1} treatment produced the second-highest chlorophyll index (52.29 SPAD), after the 120 kg N + 30 kg S ha^{-1} treatment (54.94 SPAD). Plants need to take in a lot of N's because it's a macronutrient they can't survive without. It aids in the promotion of vegetative growth, which includes the expansion of roots and leaves. Protein and chlorophyll synthesis in wheat cannot occur without N. Because of its presence in many amino acids and proteins, S plays a crucial function in promoting plant growth. It plays an important role in photosynthesis [12]. The lowest chlorophyll readings were found in the control group (38.80 SPAD). It is possible that the presence of N and S, which is of great importance due to the need to maintain equilibrium between these elements, led to the highest fresh weight and dry weight, respectively (54.8 g and 24.26 g), in the 120 kg N + 30 kg S plot, followed by the 80 kg N + 30 kg S plot, with 49.57 g and 20.53 g. Wheat requires S for proper N utilization in order to grow. Together, these two crucial substances promote protein synthesis and stimulate development throughout plants. Least fresh weight and dry weight (33.9 g, 8.08 g) was reported in the control plot due to no application of fertilizers. The weight of a plant can be increased by the development of tillers, which are lateral branches. The number of tillers showed wide ranges of variance. Tillers per plant were highest in the 120 kg N + 30 kg S ha^{-1} plots (9.67), then in the 80 kg N + 30 kg S ha^{-1} plots (8.33), possibly because N stimulates cell division. It has been discovered that cell division plays a critical role in promoting the development and expansion of plant shoots. The findings in Belete et al. [13] and Salvagiotti and Miralles [14] are consistent with this outcome. Lowest number of tillers (3.33) recorded in control plot. The 120 kg N + 30 kg S ha^{-1} treatment resulted in the longest flag leaf length (16.03 cm), while the control due to no fertilizer application resulted in the shortest (9.8 cm).

Yield parameters

All the parameters that may be used to predict the yield showed substantial variation. The key factors that determine yield are the number of spikes, the number of grains per spike, and the length of the spike. The highest number of spikes (5.77 ha^{-1}) were found in plots that had 120 kg of N and 30 kg of phosphorus applied per hectare. This was followed by plots that had 80 kg of N and 30 kg of phosphorus applied per hectare, suggesting that adequate provision of these essential nutrients may encourage vigorous vegetative growth, leading to increased tiller production and, ultimately, a greater number of grain sites. This finding is consistent with the conclusions of Salvagiotti and Miralles [14]. Control showed the fewest spikes (1.83). The longest spikes were found in the control group (17.57 cm), which was on par with the 80 kg N + 30 kgs ha^{-1} group (16.07 cm) (Table 2). The presence of both N and S is essential for wheat to grow and develop to its full potential, resulting in the construction of a strong and high-yielding spike. Use of these vital minerals to their full potential helps the wheat spike expand, which in turn increases grain production [15]. Least spike length (6.37 cm) was found in control where no fertilizer applied. Since the creation of a favorable environment for tiller growth and the provision of adequate nutrients for the crop, the concurrent use of the S and N balance approach resulted in a significant increase in the quantity of grains/spikes observed in wheat, with a maximum of 34 grains/spike recorded in 120 kg N + 30 kg S ha^{-1}. The combination of 80 kg N and 30 kg S ha^{-1} yielded the second highest value (32). There were fewer grains per spike in the control group (19.61). As a result of the need for adequate amounts of N and S in the process of grain-filling, the highest test weight (44.9 g) was obtained in 120 kg N + 30 kg S ha^{-1}. The nutrients play a significant function in aiding the wheat plant's ability to develop larger and more substantial grains, thereby boosting both the overall yield and quality of the grain, and lowest observed in those plots where no fertilizer applied. The research in Carciochi et al. [16] was similar. Maximum grain production and straw yield (4784.67 kg ha^{-1} and 6237 kg ha^{-1}) was obtained in those plots where 120 kg N and 30 kg S applied. The control group had the lowest yields of both grain and straw (2495.6 g ha^{-1} and 3625.33 g ha^{-1}). Grain and straw yield are added together to form the biological yield. The plots that received the least amount of fertilizer (-6121 kg N + 30 kg S ha^{-1}) had the lowest biological yield (6121 kg ha^{-1}) and the highest (11021.67 kg ha^{-1}). Wheat requires both N and S to grow to its full potential, hence the availability of both elements is crucial to wheat farming. S aids N utilization, thus applying a proper amount of it is important for preventing nutritional imbalances and fostering both grain and straw growth. This result is consistent with that of Shi et al. [17].

Table 2: Effect of N and S fertilization on yield parameters and yield of wheat.

Treatments	Number of spikes	Length of spike (cm)	Grains per spike	Test weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Harvest index (%)
T0 - Control	1.83 ± 0.24^{g}	6.37 ± 0.86^{d}	19.67 ± 1.25^{f}	37.97 ± 0.54^{f}	2495.67 ± 39.63^{i}	3625.33 ± 99.06^{i}	6121.00 ± 135.37^{h}	40.78 ± 0.36^{g}
T1 - 40 kg N + 0 kg S	3.67 ± 0.09^{f}	11.30 ± 1.34^{c}	24.00 ± 0.82^{e}	40.22 ± 0.31^{e}	3378.33 ± 33.59^{h}	4486.00 ± 57.91^{h}	7864.33 ± 91.08^{g}	42.96 ± 0.09^{cde}
T2 - 80 kg N + 0 kg S	3.77 ± 0.15^{ef}	14.17 ± 1.03^{c}	26.00 ± 0.82^{d}	41.86 ± 0.30^{d}	3604.67 ± 44.58^{g}	4840.00 ± 53.05^{g}	8444.67 ± 96.13^{f}	42.69 ± 0.10d^{e}
T3 - 120 kg N + 0 kg S	4.50 ± 0.26^{cd}	14.87 ± 0.66^{bc}	28.33 ± 0.94^{c}	42.19 ± 0.51^{cd}	4371.00 ± 36.67^{c}	5660.33 ± 91.07c	10031.33 ± 119.28^{c}	43.58 ± 0.29^{ab}
T4 - 40 kg N + 15 kg S	3.90 ± 0.14^{def}	14.03 ± 0.38^{c}	23.67 ± 0.47^{e}	41.39 ± 0.70^{de}	3575.00 ± 29.63^{g}	5066.67 ± 79.67^{de}	8641.67 ± 108.83^{f}	41.37 ± 0.19^{f}
T5 - 80 kg N + 15 kg S	4.38 ± 0.30^{cde}	15.57 ± 0.60^{bc}	26.67 ± 0.94^{cd}	42.50 ± 0.53^{bcd}	3709.67 ± 55.84^{f}	4887.67 ± 8.73^{fg}	8597.33 ± 60.14^{f}	43.15 ± 0.35^{bcd}
T6 - 120 kg N + 15 kg S	4.83 ± 0.28^{bc}	16.33 ± 1.06^{ab}	31.67 ± 1.25^{b}	43.73 ± 0.77^{ab}	4475.67 ± 31.48^{b}	6061.00 ± 63.94^{b}	10536.67 ± 94.81^{b}	42.48 ± 0.10^{e}
T7 - 40 kg N + 30 kg S	4.63 ± 0.11^{bc}	15.17 ± 1.03^{bc}	28.00 ± 0.82^{cd}	42.47 ± 0.71^{bcd}	3940.00 ± 46.88^{e}	5040.33 ± 59.72^{ef}	8980.33 ± 91.00^{e}	43.87 ± 0.31^{a}
T8 - 80 kg N + 30 kg S	5.19 ± 0.55^{ab}	16.07 ± 0.76^{abc}	32.00 ± 0.82^{b}	43.60 ± 1.02^{abc}	4073.33 ± 53.54^{d}	5218.33 ± 91.19^{d}	9291.67 ± 137.33^{d}	43.84 ± 0.26^{a}
T9 - 120 kg N + 30 kg S	5.77 ± 0.39^{a}	17.57 ± 0.54^{a}	34.00 ± 0.82^{a}	44.97 ± 0.57^{a}	4784.67 ± 83.05^{a}	6237.00 ± 86.98^{a}	11021.67 ± 170.00^{a}	43.41 ± 0.08^{abc}

Note: Data is in the form of mean ± SDM at $p \le 0.05$. The mean followed by different letters was significantly different at $p \le 0.05$, according to DMRT for separation of means.

Soil nutrient status

Soil mineral N concentrations (in mg per kg) showed substantial variance between treated and untreated plots. The plots that received 120 kg N+ 30 kg S ha^{-1} had the highest concentration of mineral N (17.10 mg). 80 kg N + 30 kg S ha^{-1} had the second greatest concentration of mineral N (13.30 mg). The lowest amount of mineral N was found in the control group (7.2 mg). When applied to soil, ammonium nitrate-derived N undergoes a transition that results in the mineral form as ammonium (NH_4^+) ions. Ammonium N is readily available for use in the rapid expansion of wheat and is readily taken up by plants. Application of 120 kg of N has the ability to raise mineral N concentrations in the soil. The increased availability of this mineral N can help stimulate vigorous vegetative growth and the maturation of grains. Plots that received an external application of S had a higher soil S concentration (mg kg^{-1}) than control plots that received no S. Soil samples taken from 120 kg N + 30 kg S ha^{-1} applied plots showed the highest value of soil mineral S (32.87 mg), while the control samples showed the lowest S concentration (15.4 mg). Since kieserite is a naturally occurring mineral composed of magnesium sulphate ($MgSO_4$), the S it yields is already in a mineralized form. Sulphate (SO_4^{2-}) ions, which are provided by kieserite when it is worked into the soil, are a readily available source of S for plant uptake. S plays a critical part in several physiological processes within plants, spanning the creation of amino acids, proteins, and enzymes. Sufficient amounts of S are necessary for optimal wheat development and grain quality [10, 11].

Nutrient uptake by plants

Compared to other doses (Table 3), grain and straw nutrient absorption increased up to 120 kg N and 30 kg S administered. The 120 kg N + 30 kg S ha^{-1} treatment resulted in the highest grain N content (2.95%), followed by the 120 kg N + 15 kg S ha^{-1} treatment (2.55%). The control grain sample had the lowest N concentration (0.41%). Protein content ranged from a high of 18.44% in 120 kg N + 15 kg S ha^{-1} to a low of 2.54% in the control. Where 120 kg N + 15 kg S ha^{-1} was treated, plant N absorption was highest (86.37 kg ha^{-1}), whereas it was lowest (23.3 kg ha^{-1}) in control plots. The 120 kg N + 15 kg S ha^{-1} treatment resulted in the highest uptake of S (24.7 kg ha^{-1}), followed by the 120 kg N + 15 kg S ha^{-1} treatment at 22.93 kg ha^{-1} S. S absorption was lowest (2.91 kg ha^{-1}) in unfertilized areas. Both the wheat leaves and the wheat grains have more protein after being fertilized with N. The protein content of both grains and leaves was observed to increase after S treatment. Plants are able to take in more N because of the boost in protein content. S is essential in protein synthesis. In addition, it stimulates vitamin production and the activation of numerous enzymes that are essential in the synthesis of amino acid structures. Ultimately, it was the increase in amino acid synthesis that led to higher protein content in plants. There is a statistically significant link between increased N supply and a rise in all protein components. However, the impact of this correlation on the quality of grain protein is dependent upon the exact type of crop being farmed. This is because of differences in how the N in the soil is used. Findings from Shi et al. [17], and Ghadamkheir et al. [18] were consistent with these studies.

Correlation

All of the graphical growth and yield metrics in figure 1 were shown to have a positive connection according to Pearson's analysis. The N content of the grain, the soil, and the amount of N taken up by the plant all increased in direct proportion to the amount of N applied in the experiment. Soil S concentration was found to correlate positively with plant S

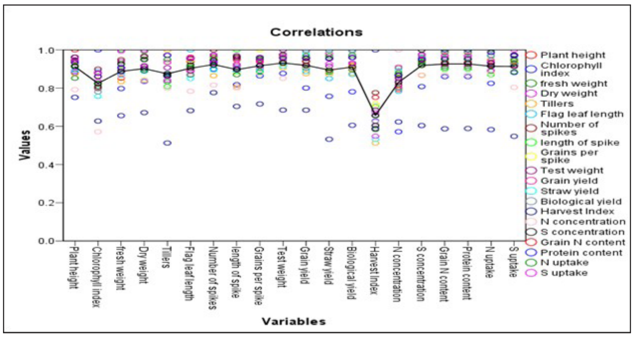

Figure 1: Pearson correlation for studied wheat growth, yield, quality, and soil attributes.

Table 3: Effect of N and S fertilization on soil nutrient status and nutrient uptake by plants.

Treatments	Soil mineral nitrogen(mg/kg)	Soil S concentration (mg/kg)	Grain N content %	Protein content %	N uptake by plant (kg/ha)	S uptake by plant (kg/ha)
T0 – Control	7.20 ± 0.29^{i}	15.40 ± 0.90^{f}	0.41 ± 0.05^{j}	2.54 ± 0.30^{j}	23.30 ± 0.62^{i}	2.91 ± 0.43^{h}
T1 - 40 kg N + 0 kg S	11.37 ± 0.37^{ef}	22.33 ± 0.65^{e}	0.97 ± 0.04^{i}	6.08 ± 0.26^{i}	41.93 ± 0.49^{h}	7.82 ± 0.64^{g}
T2 - 80 kg N + 0 kg S	13.77 ± 0.45^{c}	25.30 ± 0.59^{d}	1.27 ± 0.03^{h}	7.94 ± 0.18^{h}	44.97 ± 0.29^{g}	11.91 ± 0.39^{f}
T3 - 120 kg N + 0 kg S	15.13 ± 0.46^{b}	26.70 ± 0.67^{bcd}	2.06 ± 0.04^{d}	12.90 ± 0.24^{d}	69.37 ± 0.99^{d}	13.97 ± 0.29^{e}
T4 - 40 kg N + 15 kg S	9.63 ± 0.29^{h}	25.47 ± 0.94^{cd}	1.47 ± 0.02^{g}	9.19 ± 0.15^{g}	51.30 ± 1.06^{f}	13.70 ± 0.54^{e}
T5 - 80 kg N + 15 kg S	12.30 ± 0.78^{de}	27.00 ± 0.65^{bc}	1.81 ± 0.05^{e}	11.31 ± 0.33^{e}	52.77 ± 0.58^{ef}	15.90 ± 0.65^{d}
T6 - 120 kg N + 15 kg S	15.73 ± 0.37^{b}	31.70 ± 0.65^{a}	2.55 ± 0.04^{b}	15.94 ± 0.23^{b}	81.23 ± 0.98^{b}	22.93 ± 0.37^{b}
T7 - 40 kg N + 30 kg S	10.90 ± 0.73^{g}	26.50 ± 0.70^{bcd}	1.59 ± 0.04^{f}	9.96 ± 0.26^{f}	53.50 ± 1.15^{e}	15.79 ± 0.75^{d}
T8 - 80 kg N + 30 kg S	13.30 ± 0.70^{cd}	27.63 ± 0.58^{b}	2.26 ± 0.06c	14.13 ± 0.37c	71.90 ± 1.42^{c}	18.80 ± 0.65^{c}
T9 - 120 kg N + 30 kg S	17.10 ± 0.65^{a}	32.87 ± 0.34^{a}	2.95 ± 0.06a	18.44 ± 0.36a	86.37 ± 1.07^{a}	24.70 ± 0.29^{a}

Note: Data is in the form of mean ± SDM at $p \le 0.05$. the mean followed by different letters was significantly different at $p \le 0.05$, according to DMRT for separation of means.

concentration and with the amount of S applied to plants. It was also found that the biological yield, grain yield, and 1000 grain weight were all positively correlated with the number of applications (N). However, the S level biological yield, grain yield, and 1000 grain weight demonstrated a positive, albeit statistically insignificant, association. The S levels in soil and plants were, however, strongly correlated. The 120 N force applied. The remaining growth and yield characteristics showed more variation when 120 N was applied.

Conclusion

As a whole, India imports a great deal of N fertilizer to meet the demands of its farmers. After the green revolution, farmers' minds were set on the idea that using the most fertilizer possible would boost crop yields. This explains why fertilizer use continues to rise among farmers. In conclusion, it is reasonable to assume that both S and N have the potential to increase wheat's growth, enhance yield qualities, and raise protein levels. Growers of wheat can improve their yields by applying a mixture of 120 N + 30 S kg ha^{-1} to increase the plant's ability to absorb N and S. This well-rounded treatment has been shown to stimulate the expansion of wheat harvests. The combination of 120 N + 30 S has the potential to significantly increase wheat grain yields. The optimal ratio of N to S for increasing wheat output is 120 kg of N to 60 kg of S. More research on different wheat varieties in different soil textures is recommended to determine if 120 N + 60 S is the best treatment for maximizing crop yield.

Acknowledgements

Author is thankful to Lovely Professional University, Phagwara, India.

Conflict of Interest

None.

References

1. Zhao FJ, Stroud JL, Eagling T, Dunham SJ, McGrath SP, et al. 2010. Accumulation, distribution, and speciation of arsenic in wheat grain. *Environ Sci Technol* 44(14): 5464-5468. https://doi.org/10.1021/es100765g
2. Souza EJ, Martin JM, Guttieri MJ, O'brien KM, Habernicht DK, et al. 2004. Influence of genotype, environment, and nitrogen management on spring wheat quality. *Crop Sci* 44(2): 425-432. https://doi.org/10.2135/cropsci2004.4250
3. Farooq N, Sarwar G, Abbas T, Bessely L, Nadeem MA, et al. 2019. Effect of drying-rewetting durations in combination with synthetic fertilizers and crop residues on soil fertility and maize production. *Pak J Bot* 52(6): 2051-2058. http://dx.doi.org/10.30848/PJB2020-6(37)
4. Branlard G, Dardevet M, Saccomano R, Lagoutte F, Gourdon J. 2001. Genetic diversity of wheat storage proteins and bread wheat quality. *Euphytica* 119(1): 59-67. https://doi.org/10.1023/A:1017586220359
5. Ghafoor I, Habib-ur-Rahman M, Ali M, Afzal M, Ahmed W, et al. 2021. Slow-release nitrogen fertilizers enhance growth, yield, NUE in wheat crop and reduce nitrogen losses under an arid environment. *Environ Sci Pollut Res* 28(32): 43528-43543. https://doi.org/10.1007/s11356-021-13700-4
6. Adamson A, Järvan M. 2006. The effect of sulphur on yield structure elements and yield of winter wheat. *Transact ERIA* 71: 61-66.
7. Burke JJ, Holloway P, Dalling MJ. 1986. The effect of sulfur deficiency on the organisation and photosynthetic capability of wheat leaves. *J Plant Physiol* 125(3-4): 371-375. https://doi.org/10.1016/S0176-1617(86)80160-2
8. Bremner JM. 1996. Nitrogen-total. *Methods Soil Anal* 5: 1085-1121.
9. Sparks DL, Page AL, Helmke PA, Loeppert RH. 2020. Methods of Soil Analysis. Chemical Methods. John Wiley & Sons.
10. Dhillon J, Dhital S, Lynch T, Figueiredo B, Omara P, et al. 2019. In-season application of nitrogen and sulfur in winter wheat. *Agrosyst Geosci Environ* 2(1): 1-8. https://doi.org/10.2134/age2018.10.0047
11. Järvan M, Edesi L, Adamson A. 2012. Effect of sulphur fertilization on grain yield and yield components of winter wheat. *Acta Agric Scand B Soil Plant Sci* 62(5): 401-409. https://doi.org/10.1080/09064710.2011.630677
12. Wilson TL, Guttieri MJ, Nelson NO, Fritz A, Tilley M. 2020. Nitrogen and sulfur effects on hard winter wheat quality and asparagine concentration. *J Cereal Sci* 93: 102969. https://doi.org/10.1016/j.jcs.2020.102969
13. Belete F, Dechassa N, Molla A, Tana T. 2018. Effect of split application of different N rates on productivity and nitrogen use efficiency of bread wheat (*Triticum aestivum L.*). *Agric Food Secur* 7(1): 1-10. https://doi.org/10.1186/s40066-018-0242-9
14. Salvagiotti F, Miralles DJ. 2007. Wheat development as affected by nitrogen and sulfur nutrition. *Aust J Agric Res* 58(1): 39-45. https://doi.org/10.1071/AR06090
15. Tabak M, Lepiarczyk A, Filipek-Mazur B, Lisowska A. 2020. Efficiency of nitrogen fertilization of winter wheat depending on sulfur fertilization. *Agronomy* 10(9): 1304. https://doi.org/10.3390/agronomy10091304
16. Carciochi WD, Salvagiotti F, Pagani A, Calvo NIR, Eyherabide M, et al. 2020. Nitrogen and sulfur interaction on nutrient use efficiencies and diagnostic tools in maize. *Eur J Agron* 116: 126045. https://doi.org/10.1016/j.eja.2020.126045
17. Shi G, Lu H, Liu, H, Lou L, Zhang, et al. 2020. Sulfate application decreases translocation of arsenic and cadmium within wheat (*Triticum aestivum L.*) plant. *Sci Total Environ* 713: 136665. https://doi.org/10.1016/j.scitotenv.2020.136665
18. Ghadamkheir M, Vladimirovich KP, Orujov E, Bayat M, Madumarov M, et al. 2020. Influence of sulfur fertilization on infection of wheat take-all disease caused by the fungus *Gaeumannomyces graminis* var. tritici. *Res Crops* 21(3): 627-633. http://dx.doi.org/10.31830/2348-7542.2020.098