

**RESPONSE OF SULPHUR AND POTASSIUM
APPLICATIONS ON GROWTH, YIELD AND
QUALITY OF GARLIC (*Allium sativum* L.)**

Thesis

**Submitted to Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
HORTICULTURE (VEGETABLE SCIENCE)
(Minor Subject: Soil Science)**

By

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2022

CERTIFICATE – I

This is to certify that the thesis entitled, “**Response of sulphur and potassium applications on growth, yield and quality of garlic (*Allium sativum* L.)**” submitted for the degree of **M.Sc.**, in the subject of **Vegetable Science** (Minor subject: **Soil Science**) to the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Sangram Singh Sandhu (L-2020-H-227-M)** under my supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled, “**Response of sulphur and potassium applications on growth, yield and quality of garlic (*Allium sativum* L.)**” submitted by **Sangram Singh Sandhu (L-2020-H-227-M)** to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.**, in the subject of **Vegetable Science** (Minor subject: **Soil Science**) has been approved by the Student’s Advisory Committee along with the External Examiner after an oral examination on the same.

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ABSTRACT

The present investigation was conducted at vegetable research farm, biochemistry laboratory and soil science laboratory, Punjab Agricultural University, during rabi seasons of 2020-21 and 2021-22 to standardize the potassium and sulphur dose for growth, yield and quality of garlic. The experiment was laid in randomized complete block design and replicated thrice. Variety 'PG-18' was used as plant material. The experiment comprised of sixteen treatment combinations with four levels of potassium (0, 20, 40 and 60 kg K ha⁻¹) and sulphur (0, 10, 20 and 30 kg S ha⁻¹). Potassium and sulphur were applied as basal dose at bed preparation and all the agronomic practices were followed in accordance with package of practice. It was observed from the results that with the application of 60 kg of potassium along with 30 kg sulphur, growth parameters like, plant height (82.8 cm), bulb diameter (5.24 cm), total bulb yield (14.17 t ha⁻¹), quality parameters like allicin (12.64 mg g⁻¹) was recorded highest. Highest Benefit Cost ratio was also observed with same treatment combination. It was observed that highest bulb yield was in the same combination of treatments with highest nutrient uptake status. Therefore, from the results it was found that 60 kg of potassium along with 30 kg sulphur treatment was found beneficial for growth, yield and quality of garlic and it is recommended for North Indian conditions.

Keywords: Garlic, Potassium, Sulphur, Allicin, TSS, Nitrogen, Soil status, Uptake

Signature of the major advisor

Signature of the student

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ਸਾਰ ਅੰਸ਼

ਮੌਜੂਦਾ ਅਧਿਐਨ ਲਸਣ (*Allium sativum* L.) ਦੇ ਵਿਕਾਸ, ਝਾੜ ਅਤੇ ਗੁਣਵਤਾ ਲਈ ਸਲਫਰ ਅਤੇ ਪੋਟਾਸ਼ੀਅਮ ਦੀਆਂ ਮਿਕਦਾਰਾਂ ਦਾ ਅਨੁਕੂਲਨ ਕਰਨ ਲਈ ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਸਬਜ਼ੀ ਖੋਜ ਫਾਰਮ, ਜੀਵ-ਰਸਾਇਣਕ ਪ੍ਰਯੋਗਸ਼ਾਲਾ ਅਤੇ ਭੂਮੀ ਵਿਗਿਆਨ ਪ੍ਰਯੋਗਸ਼ਾਲਾ ਵਿਖੇ ਸੰਨ 2020-21 ਅਤੇ 2021-22 ਦੀ ਹਾੜੀ ਰੁੱਤੇ ਕੀਤਾ ਗਿਆ। ਤਜਰਬਾ ਰੈਂਡਮਾਈਜ਼ਡ ਕੰਪਲੀਟ ਬਲਾਕ ਡਿਜ਼ਾਈਨ ਵਿਧੀ ਤਹਿਤ ਤਿੰਨ ਵਾਰ ਦੁਹਰਾਇਆ ਗਿਆ। ਤਜਰਬੇ ਦੌਰਾਨ ਲਸਣ ਦੀ 'PG-18' ਕਿਸਮ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ। ਤਜਰਬੇ ਦੌਰਾਨ ਪੋਟਾਸ਼ੀਅਮ (0, 20, 40 ਅਤੇ 60 ਕਿ.ਗ੍ਰਾ. ਪੋਟਾਸ਼ੀਅਮ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਅਤੇ ਸਲਫਰ (0, 10, 20 ਅਤੇ 30 ਕਿ.ਗ੍ਰਾ. ਸਲਫਰ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ) ਦੇ ਚਾਰ ਪੱਧਰਾਂ ਵਾਲੇ ਕੁੱਲ ਸੋਲਾਂ ਉਪਚਾਰਾਂ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਗਈ। ਬਿਜਾਈ ਲਈ ਬੈਂਡ ਤਿਆਰ ਕਰਨ ਸਮੇਂ ਪੋਟਾਸ਼ੀਅਮ ਅਤੇ ਸਲਫਰ ਦੀ ਮੁੱਢਲੀ ਮਾਤਰਾ ਦਾ ਉਪਯੋਗ ਕੀਤਾ ਗਿਆ ਅਤੇ ਪੈਕੇਜ ਆਫ ਪ੍ਰੈਕਟਿਸ ਦੀਆਂ ਸਿਫਾਰਿਸ਼ਾਂ ਅਨੁਸਾਰ ਸਾਰੇ ਦੋ ਸਾਰੇ ਫਸਲੀ ਗਤੀਵਿਧੀਆਂ ਕੀਤੀਆਂ ਗਈਆਂ। ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਤੋਂ ਇਹ ਦੇਖਿਆ ਗਿਆ ਕਿ 60 ਕਿ.ਗ੍ਰਾ. ਪੋਟਾਸ਼ੀਅਮ ਅਤੇ 30 ਕਿ.ਗ੍ਰਾ. ਸਲਫਰ ਦੀ ਸਾਂਝੀ ਵਰਤੋਂ ਨਾਲ ਪੌਦੇ ਦੇ ਵਿਕਾਸ ਦੇ ਮਾਪਦੰਡ ਜਿਵੇਂ ਕਿ ਪੌਦੇ ਦੀ ਉਚਾਈ (82.8 ਸੈ.ਮੀ.), ਗੰਡੀ ਦਾ ਵਿਆਸ (5.24 ਸੈ.ਮੀ.), ਗੰਡੀਆਂ ਦਾ ਕੁੱਲ ਝਾੜ (14.17 ਟਨ ਪ੍ਰਤੀ ਹੈਕਟੇਅਰ), ਗੁਣਵਤਾ ਮਾਪਦੰਡ ਜਿਵੇਂ ਕਿ ਐਲੀਸਨ (12.64 ਮਿ.ਗ੍ਰਾ. ਪ੍ਰਤੀ ਗ੍ਰਾਮ) ਦੀ ਮਾਤਰਾ ਸਭ ਤੋਂ ਵਧੇਰੇ ਸੀ। ਇਸੇ ਉਪਚਾਰ ਨਾਲ ਹੀ ਲਾਭ ਲਾਗਤ ਅਨੁਪਾਤ ਵੀ ਸਭ ਤੋਂ ਵਧੇਰੇ ਦਰਜ ਕੀਤਾ ਗਿਆ। ਅਧਿਐਨ ਦੌਰਾਨ ਇਹ ਵੀ ਦੇਖਿਆ ਗਿਆ ਕਿ ਇਸੇ ਉਪਚਾਰ ਅਧੀਨ ਹੀ ਗੰਡੀਆਂ ਦਾ ਝਾੜ ਅਤੇ ਪੌਸ਼ਟਿਕ ਤੱਤਾਂ ਦਾ ਗ੍ਰਹਿਣ ਵੀ ਸਭ ਤੋਂ ਵਧੇਰੇ ਹੋਇਆ। ਇਸ ਲਈ, ਮੌਜੂਦਾ ਅਧਿਐਨ ਦੇ ਨਤੀਜਿਆਂ ਦੇ ਅਧਾਰ ਤੇ ਇਹ ਪਤਾ ਚੱਲਿਆ ਕਿ 60 ਕਿ.ਗ੍ਰਾ. ਪੋਟਾਸ਼ੀਅਮ ਅਤੇ 30 ਕਿ.ਗ੍ਰਾ. ਸਲਫਰ ਦੀ ਸਾਂਝੀ ਵਰਤੋਂ ਲਸਣ ਦੇ ਵਿਕਾਸ, ਝਾੜ ਅਤੇ ਗੁਣਵਤਾ ਲਈ ਸਭ ਤੋਂ ਵਧੇਰੇ ਲਾਭਦਾਇਕ ਹੈ ਅਤੇ ਉੱਤਰੀ ਭਾਰਤ ਦੇ ਫਸਲੀ ਹਲਾਤਾਂ ਅਧੀਨ ਲਸਣ ਦੀ ਕਾਸ਼ਤ ਦੌਰਾਨ ਇਸ ਦੀ ਵਰਤੋਂ ਕੀਤੀ ਜਾ ਸਕਦੀ ਹੈ।

ਮੁੱਖ ਸ਼ਬਦ: ਲਸਣ, ਪੋਟਾਸ਼ੀਅਮ, ਸਲਫਰ, ਐਲੀਸਨ, ਟੀ ਐਸ ਐਸ, ਨਾਈਟ੍ਰੋਜਨ, ਮਿੱਟੀ ਦੀ ਸਥਿਤੀ, ਗ੍ਰਹਿਣ ਕਰਨਾ

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CHAPTER I

INTRODUCTION

Garlic (*Allium sativum* L.) is the second most important bulb crop in the world after onion (Purseglove 1985). In China and India, it has been utilized for more than 5000 years, whereas in Egypt it has been used since 2000 B.C. (Kamenetsky and Rabinowitch 2001). Garlic is cultivated in China, India, Bangladesh, South Korea, Egypt, Spain, USA, Algeria, Uzbekistan, Ukraine, of which China alone contributes ~75.7% of the total production, followed by India contributing ~9.5%, while other countries contribute only ~14.8% (Anonymous 2021a). In the export market, Spain ranked first with the highest share of ~50.7%, followed by China (~31.8%). The global production of garlic has been reported to be ~30.7 million metric tons (m Mt).

Garlic covers an area of 349.39 thousand ha with production of 2923.15 thousand Mt in India (Anonymous 2021a). In India, Rajasthan has the highest garlic production (~0.582 m Mt), followed by Uttar Pradesh, Gujarat and Punjab. In Punjab, garlic is grown on an area of 8.87 thousand ha with production of 96.77 thousand Mt (Anonymous 2021b).

Garlic has been known to be originated in central Asia and north eastern Iran. Garlic being a bulbous crop belongs to the family Alliaceae and is closely related to onion, chives, Welsh onion, shallots, leek and Chinese onion. The use of garlic has been mentioned in history of China, India, Egypt, Persia and other central Asian countries for seasoning, medicinal, and spice purposes. The word 'garlic is derived from old English word Garleac, which means gar (spear) and leek, as a spear shaped leek (Bableswhar *et al* 2017). The use of garlic has spread to whole world and its being used in the kitchen of every household as spice and seasoning purposes, where as some cultures use garlic for medicinal purposes to cure various types of illnesses.

Garlic produces an underground bulb and vegetative part above ground consisting of leaves and flowers (Usman *et al* 2016). It has fibrous roots and bulbs contains a number of small bulbils called cloves, that are agronomically used as propagating material for cultivation (Purseglove 1985). The flower often fails to form viable seeds after fertilization, hence individual cloves are used to propagate the crop rather than seeds. This also makes the breeding for garlic cultivars hard since viable seeds aren't often formed, so mostly selection and mutation breeding methods are used. It is mainly used as a spice, seasoning and a flavoring agent worldwide in food industry, using both its green tops and bulbs due to its pungent flavor (Tadese 2009).

Garlic has long been cultivated by ancient civilizations and its use as spice and medicinal crop has been well researched. Garlic cloves are an outstanding source of nutrition

and immunity. The edible portion of garlic is composed of 62.8% moisture, 6.3% protein, 29% carbohydrates, 13 mg 100g⁻¹ vitamin C, 0.03% calcium, 0.31% phosphorus, 0.0031% iron and pyruvic acid content of 35-60 micro moles g⁻¹ (Magray *et al* 2017). Its medicinal value has been well recognized in the treatment and control of hypertension, worms, rheumatism, germs, bacteria, fungal diseases, diabetes, ulcer and cancer (Kilgori *et al* 2007; Samavatean *et al* 2011). Garlic can be consumed in various forms including raw, oil, extracts and powder with different benefits (Lanzotti *et al* 2014).

Garlic contains a transparent, odorless, and water-soluble amino acid called 'allin' (Magray *et al* 2017). When garlic tissue is injured or damaged, this amino acid is converted into "allicin" by the enzyme alliinase. The allicin generated is unstable and quickly degenerates into Sulphur (S) containing compounds such as diallyl-, triallyl-, methyl allyl- and dipropyl- mono-, di-, tri- and tetra- sulphides which are formed due to breakdown of thiosulfinates (Lanzotti *et al* 2014). Allin is a part of defence mechanism against attacks of pests on the plant (Hile *et al* 2004). Along with providing the flavor of garlic, these S containing compounds play an important role in the medicinal properties, and also increase the accumulation of glutathione which is a very beneficial antioxidant in garlic (Banerjee *et al* 2003). The increase in the amount of allin will increase the yield quality, pungency, and storage life of garlic. Allin is a S containing amino-acid, hence, S applications can help in boost up of garlic quality and yield.

Productivity of garlic depends upon cultural practices followed during the cultivation, out of which nutrient management has a crucial role. For producing one ton of garlic bulbs, crop removes 9.49kg of N, 1.21kg of P and 3.8kg of K and 0.9kg of S (Thangasamy *et al* 2018). Garlic crop takes about around 185 days from sowing to harvesting, therefore it is important to get the best yields possible from a crop consuming half a year of cropping time. In Punjab state, the recommended doses of nitrogen (N) and phosphorus (P) are 50 kg and 25 kg acre⁻¹, respectively along with 20 tons of FYM acre⁻¹ (Anonymous 2021). Despite of its importance, research relating to nutrition requirements of this crop is limited, which in part makes it difficult to increase productivity in the region. The recommendation of potassium (K) and sulphur (S) is not given, since there is a good amount of potassium present in the soils of Punjab because they contain Illite as the dominant clay mineral although, being low in sulphur.

Garlic is very sensitive to deficiency of nutrients because of shallow root system. In earlier times, the farmers were more dependent on use of Farm Yard Manure before the advent of HYVs and inorganic fertilizers, which prevented the deficiencies of many macro and micro elements. But in the recent years, the nutrients are being depleted from soils due to exhaustive cropping cycles and reduced applications of organic manures and composts.

There is a need to test the response of potassium and sulphur applications on the yield and quality attributes of garlic crop. Potassium is regarded as a primary macro nutrient and is consumed in hefty amounts by the plants. It plays an important role in the movement of water, nutrients and carbohydrates within plant tissue. Potassium is said to increase the post-harvest life as well as improve color, glossiness and dry matter content (Dorais *et al* 2001).

Potassium prevents lodging of plants and increases resistance against insects and diseases in plants and has an important role in metabolism of plant and therefore named as 'quality element' (Magray *et al* 2017). It improves the root growth, maintains turgor, controls the stomatal movements, reduces water loss, imparts drought tolerance and therefore helps in increasing the overall yield and quality of the plant. It has been researched that garlic on an average removes 125-180 kg K₂O ha⁻¹ during its cultivation period (Bertoni *et al* 1988, Zink 1963). In many research experiments conducted worldwide, an increase in yield was observed with higher applications of K (Sing and Verma 2001; Sharma *et al* 2003; Bybordi and Malakouti 2003; Linux and Niwuzhang 1997; Jiang *et al* 1998 and Melzer *et al* 1999).

Sulphur being a secondary macro nutrient is also consumed in high amounts right after N, P and K. Bulb crops including garlic are S loving crops and the requirement is high for its proper growth and yield. It is a very important nutrient for the synthesis of major S containing amino acids (cystine, methionine and cysteine) and involved in many metabolic activities in plants (Magray *et al* 2017). Sulphur is recognized as an important nutrient for higher yield and better quality of bulbs. Apart from NPK fertilizers, use of sulphur fertilizers can significantly improve the yield in garlic (Ahmed *et al* 1988). The sulphur containing proteins synthesized in garlic are directly dependent upon amount of sulphur available in soil. Sulphur is essential for formation of proteins, enzymes, vitamins and chlorophyll in plants. Sulphur is beneficial for N uptake by plant and hence improves the yield.

Sulphur deficiency during bulb development can cause serious reduction in the allicin and other sulphur containing proteins (Chattoo *et al* 2019). A long term of cultivation of crops has led to sulphur deficiencies due to uptake and is becoming a majorly deficient nutrient worldwide (Aulakh *et al* 2003). Sulphur deficiency in Indian soils has become more widespread also due to use of sulphur free fertilizers (Chattoo *et al* 2019).

The optimum amount of nutrients required for garlic production depends on soil conditions, climatic factors, irrigation system and crop management systems. The lack of proper management of nutrients will adversely affect the yield and quality of the crop as it is required for the synthesis of various proteins, vitamins, and co-enzymes. Thus, there is a need to develop a nutrient management strategy for garlic based on regions that will not only improve nutrient use efficiency but also improve yield and quality of the produce.

With increasing population pressure and limited land for food production, the need to produce more quantity of quality food by improving the cultural practices including adequate and balanced fertilization of the crop is necessary. With balanced dose of primary and secondary nutrients, the yield and quality potential as well as the economics of garlic cultivation can be improved considerably.

There hasn't been much research conducted on the garlic crop with regard to K and S application in Punjab state. The research will be novel and beneficial for the farmers of region with regards to increasing the yield, quality and overall income. So, the proposed investigation will be undertaken to study the effect of K and S on growth, yield and quality of garlic.

Objectives

1. To determine the effect of potassium and sulphur on growth, yield and quality of garlic
2. To work out the economics of garlic cultivation

CHAPTER II

REVIEW OF LITERATURE

In an effort to improve the production and quality of garlic, experiments have been conducted to check the response of various nutrients on garlic and other bulb crops by various researchers. The main emphasis was given on to improvement of yield and quality of the crop by use of adequate amount and type of nutrients. And the effect of using potassium and sulphur along with recommended doses of N, P and FYM and its effect on garlic has been discussed below.

2.1 Potassium

2.1.1 Effect of potassium on growth contributing parameters

The role of potassium on the yield contributing characters of garlic has been researched upon by many scientists to elaborate its role. For evaluating the response of potassium on plant height, Farooqui *et al* (2009) observed maximum plant height of 50.94 cm by using 60 kg K ha⁻¹. In another experiment, Arisha *et al* (2017) used 125 kg K₂O ha⁻¹ to get maximum plant height of 84.03cm. A similar result in a similar experiment was observed by Zyada and Bardisi (2018) who used 150 kg K fed⁻¹ to get maximum plant height of 74.70 cm. The results were further confirmed while experimentation by Barakat *et al* (2019) who concluded that 96 kg K₂O fed⁻¹ gave maximum plant height of 93.97cm.

In a research trial for checking role of potassium in garlic growth, Yadav *et al* (2007) using K @150 kg ha⁻¹ got highest leaf number per plant (7.5). In another experiment conducted by Arisha *et al* (2017) found that 125 kg K₂O ha⁻¹ gave highest leaf number per plant (9.26). A similar result in a similar experiment was observed by Zyada and Bardisi (2018) who concluded that 150 kg K fed⁻¹ gave the maximum leaf number per plant (8.37). The results were further confirmed while experimentation by Barakat *et al* (2019) who testified that 96 kg K₂O fed⁻¹ gave highest leaf number per plant (9.57). Research conducted by Veer *et al* (2021) concluded that 60 kg ha⁻¹ K gave maximum leaf number per plant (8.44).

In a different research experiment to check the influence of potassium on neck thickness, Farooqui *et al* (2009) got maximum neck thickness of 0.72cm by using 45 kg ha⁻¹ of K. The findings were also in accordance with research experiment conducted by Magray *et al* (2017) who observed maximum neck thickness of 1.28cm by using 100kg K and 30 kg S ha⁻¹. The results were further confirmed while experimentation by Zyada and Bardisi (2018) who used 150 kg ha⁻¹ of K fed⁻¹ to get maximum neck thickness of 1.50cm.

To check the influence of potassium on bulb radial diameter, Yadav *et al* (2007) used K @150 kg ha⁻¹ to get maximum bulb diameter of 14.5cm. In a different research experiment

to check the influence of potassium on bulb radial diameter, Magray *et al* (2017) observed maximum bulb polar diameter of 4.30cm by using 100 kg K and 45 kg S per ha. In another experiment evaluated by researchers Zyada and Bardisi (2018) who used 150 kg fed⁻¹ of K and observed maximum bulb radial diameter of 2.90cm. The findings were also in accordance with research experiment conducted by Jiku *et al* (2020) who used K @200 kg ha⁻¹ to get maximum (2.74cm) bulb radial diameter.

2.1.2 Effect of potassium on yield contributing parameters

In an effort to understand the role of potassium as a quality element on the yield contributing characters of garlic, many scientist have conducted research experiments to elaborate its role.

For evaluating the response of potassium on number of clove per bulb, research conducted by Yadav *et al* (2007) revealed that, use of potassium @150 kg ha⁻¹ gave maximum number of cloves per bulb (31.1). While experimenting, a similar result in a similar experiment was observed by Arisha *et al* (2017) using 125 kg K₂O fed⁻¹ to get the greatest number of cloves per bulb (19.50). In a research trial for checking role of sulphur and potassium in garlic production, Magray *et al* (2017) observed highest clove number (10.85) by using 100 kg potassium and 45 kg sulphur ha⁻¹. The results were further confirmed while experimentation by Barakat *et al* (2019) who used 96 kg K₂O fed⁻¹ to get highest clove number per bulb (16.08). Research conducted by Jiku *et al* (2020) received highest clove number (19.12) per bulb using potassium @200 kg ha⁻¹.

In an experiment to check the effect of potassium on clove weights, Yadav *et al* (2007) used potassium @150 kg ha⁻¹ to observe maximum bulb weight of 23.7g. Farooqui *et al* (2009) observed highest 20 cloves weight of 36.67g using 60 kg ha⁻¹ of potassium, which depicts crucial role of the quality element in increasing the weight of the produce. While experimenting, a similar result in a similar experiment was observed by Farooqui *et al* (2009) getting maximum bulb weight of 48.06g using 60 kg ha⁻¹ potassium, thus confirming the findings of others. In a research trial for checking role of sulphur and potassium in garlic production, Magray *et al* (2017) recorded maximum bulb weight of 41.96g by 100 kg potassium and 45 kg sulphur ha⁻¹. In a research trial for checking role of sulphur and potassium in garlic production, Magray *et al* (2017) applied 100 kg potassium and 45 kg sulphur ha⁻¹ to get highest marketable yield of 22.1 ton ha. In a different research experiment to check the influence of potassium on bulb weight, Barakat *et al* (2019) concluded use of 96 kg K₂O fed⁻¹ to get highest bulb weight of 104.6g.

In a research conducted by Yadav *et al* (2007) also observed similar trends in yield after using potassium @150 kg ha⁻¹ to get maximum total yield of 6.1 ton ha⁻¹. Farooqui *et al*

(2009) recorded 16.54 ton ha⁻¹ total yield was observed using 60 kg ha⁻¹ potassium. While experimenting, a similar result in a similar experiment was observed by Arisha *et al* (2017) who used 125 kg K₂O to get maximum total yield of 10.38 ton fed⁻¹. The findings were also in accordance with research experiment conducted by Zyada and Bardisi (2018) who used 150 kg potassium fed⁻¹ to get maximum total yield of 8.01 ton fed⁻¹. The results were further confirmed while experimentation by Barakat *et al* (2019) who used 96 kg K₂O fed⁻¹ to get highest total yield of 7.63 tons fed⁻¹.

2.1.3 Effect of potassium on quality parameters

In an effort to understand the role of potassium as a quality element on the quality characters of garlic many scientist have conducted research experiments to elaborate its role. For evaluating the response of potassium on TSS, Arisha *et al* (2017) used 125 kg K₂O fed⁻¹ to get maximum TSS of 32.00°Brix. The results were further confirmed while experimentation by Zyada and Bardisi (2018), by using 150 kg potassium fed⁻¹ gave the highest TSS of 37.77°Brix. While experimenting with various sulphur doses in garlic, Divyasree *et al* (2021) who used K₂SO₄ @ 60 kg ha⁻¹ recorded highest TSS of 43.16°Brix. In the same experiment evaluated by Divyasree *et al* (2021) to find the effect of potassium application on phenol content in garlic, used potassium sulphate @ 60 kg ha⁻¹ to get maximum phenols (0.49 mg per g).

In an experiment to check the effect of potassium on ascorbic acid content in garlic, Arisha *et al* (2017) used 125 kg K₂O fed⁻¹ to get maximum ascorbic acid (25 mg per 100g dry weight). The results were further confirmed while experimentation by Divyasree *et al* (2021) who used potassium sulphate @ 60 kg ha⁻¹ to get maximum ascorbic acid (20.81 mg per 100g dry weight).

Castellanos *et al* (2002) investigated the potassium requirements for garlic during fertigation. He saw that garlic required very little K during the first 50 days of growth, but that it rose significantly after that. The crop absorption of K₂O in the furrow irrigation trial was 175 kg per ha, but it was 295 kg per ha in the fertigation experiment. In the furrow irrigated trial, crop yields were 19.1 tonnes per ha, while in the fertigation experiment, crop yields were 29 tonnes per ha. The fertigated crop's improved yield potential boosted plant needs for K by about 70 per cent. Based on these findings, it was determined that for every tonne of garlic produced, the crop absorbs 9.1 to 10.1 kg of K₂O.

Dilruba (2006) performed an experiment to view the impact of various N and K levels on onion cv BARI peaj bulb attributes that contribute to yield. All other bulb traits—aside from dry matter content—were strongly impacted by the individual application of various N and K doses. The highest fresh bulb weight (35.29 g), bulb dry weight (3.21 g), bulb diameter

(3.98 cm), and yield per plot (1.68 kg) were produced using 100 kg N ha⁻¹, while the lowest fresh bulb weight (18.93 g), bulb dry weight (148 g), bulb diameter (2.02 cm), and yield plot⁻¹ were produced by the control of N. (0.95 kg). Compared to N, K had a less impact on the characteristics and yield of the bulbs (0-120 kg K₂O ha⁻¹). There is no interaction between N and K in the influence of character expression. The treatment using 100 kg N and 120 kg K₂O ha⁻¹ produced the best overall results out of all the combinations.

Aftab *et al* (2017) to examined the impact of four K concentrations (0,60,120,180 kg ha⁻¹) on onion development and yield, they discovered a considerable increase in yields. The highest bulb weight (78.44 g), maximum radial diameter (5.20 cm), and maximum yield (24.67 t ha⁻¹) were obtained using K @120 kg ha⁻¹, whereas control method gave the lowest yield (10.40 t ha⁻¹).

In an experiment by Bekele (2018), three replications of the potassium sulphate fertilizer (TSP) were utilized at amounts of 0, 40, 80, and 120 kg ha⁻¹. According to the findings, applying potassium fertilizer at various rates had a significant impact on all crop physical and quality parameters. Similarly, administration of K at various doses had a significant impact on the post-harvest life of crop. At ambient storage temperatures and humidity levels for two months, the maximum potassium application (120 kg ha⁻¹) considerably reduced post-harvest losses.

Ozkan *et al* (2018) investigated how K₂SO₄ (SOP), KCl (MOP), and polyhalite affected onion bulb yield, nutrient uptake, and bulb quality characteristics. MOP, SOP, polyhalite, and a combination of polyhalite and SOP were used as equal doses of 270 kg K₂ O ha⁻¹, and they were compared to a control that used N and P fertilizers. S fertilizers contributed additional yield improvements ranging from 12 to 22 % when compared to the control, in addition to MOP's 28 % increase in bulb size and output. All of the fertilizers boosted K availability during the onion crop cycle, which was their main impact. The application of polyhalite produced the best yield, most likely as a result of its slow-release nature, which maintained steady soil K availability throughout the crop cycle. High yield or high quality did not correspond with high S application rates. Although the beneficial agronomic efficiency of polyhalite was clear, appropriate rates of application are still dependent on economic factors.

In a study published by Astaneh *et al* (2018), investigated the effects of selenium (0, 4, 8 and 16 mg L⁻¹) on hydroponically grown garlic plants that were subjected to salt stress (0, 30, 60, and 90 mM NaCl). Salinity resulted in a decreased pigment concentrations. RWC was raised by use of 16 mg L⁻¹ Se under 90 mM NaCl to garlic leaves after Se applications of 8 mg L⁻¹ in 30 mM NaCl salinity and 4 mg L⁻¹ in 60 mM NaCl salinity considerably improved

pigment concentrations. Further additions of Se under 30 mM NaCl also caused the K concentration in leaves to rise. Na concentration rises with increasing salinity. They came to the conclusion that under salt stress, K absorption increased and Na uptake decreased.

Shamim *et al* (2018) investigated the interactive response of N and K on growth and yield-related parameters in 2 garlic genotypes. Four amounts of nitrogen (0, 100, 200, 300 kg per ha) and K were evaluated on the two-germplasm accession G19 and G20 (0, 100, 200, 300 kg per ha). The findings revealed that there were substantial differences amongst the therapies evaluated. Garlic growth and yield increased significantly after a single application of both N and K. Garlic bulb yields were best when 200 kg per ha N and K₂O were used (9.62 and 8.61 tonnes per ha respectively). The treatment combination of accession G20 with 200 kg per ha of N and 200 kg per ha of K was indicated in the study.

Mukhim *et al* (2019) studied garlic under three levels of K (0, 25, 50 kg per ha) and three levels of S (0, 15, 30 kg per ha) and found that K @100 kg per ha and S @100 kg per ha provided the maximum plant height 76cm, bulb length 5.8cm, bulb diameter 7.8cm, and total bulb yield 13.55 tonnes per ha. It also improved the physical attributes of the soil's post-harvest quality, such as percent pore space, bulk and particle density, and demonstrated a steady decrease in pH, organic carbon (OC) per cent, and N, P, K, and S values in the soil after harvest.

Awad-Allah *et al* (2020) conducted a field experiment to check the response of foliar spray with plant-based bio stimulants (with or without 3 per cent yeast extract), three levels of proline (0, 25, 50 mM), and K fertilisers (0, 117, 234 kg per ha) on physical and quality parameters of crop. They concluded that foliar spray with 3 per cent yeast extract and 50mM proline combined with K@ 234 kg per ha gave the highest vegetative growth, mineral concentrations (N, P, K, S, Ca, Mg in leaves), and proline content in garlic. Stress tolerance-inducing substances like yeast extract and proline, combined with adequate K fertiliser administration during the garlic crop's growing season, can help to reduce soil salt stress.

Octaviany *et al* (2020) investigated the influence of various K doses and fertiliser sources on garlic bulb formation rate and time . The first consideration was the K fertiliser dose, which was divided into four categories: 60, 120, 180, and 240 kg K₂O per ha. The second factor was the K supply, which included KCl, ZK, and KNO₃. The study concluded that applying ZK and KNO₃ fertilisers @240 kg per ha improved the growth rate and relative growth rate. With a higher fertiliser dose, the bulb's K absorption increased, slowing the bulb's formation time.

In order to find the most effective and cost-effective K fertilizer dose, Wang *et al* (2022) investigated the effects of applying various K fertilizers at various rates to garlic. They

also compared the response of using KCl and K₂SO₄ in garlic in order to find best treatment. The findings showed that KCl fertilization enhanced garlic's biomass and vegetation index and encouraged the nutrient movement, improving yield. Use of KCl resulted in an increase in clove production, larger clove and bulb diameters, and less variance in bulb size. But too much KCl fertilizer reduces crop yields, character traits, and nutritional value. When compared to KCl fertilizer, the garlic yield rose by only 0.1 to 22.5 % when the same rate of K fertilizer in the form of K₂SO₄ was applied alone. K₂SO₄: KCl of 5:3 ratio produced the maximum yields, aesthetic qualities, and nutritional quality in this study. The authors suggest 252.5 kg ha⁻¹ K₂O (K₂SO₄ being 61.6 %), to assure the highest economic value.

2.2 Sulphur

2.2.1 Effect of sulphur on growth contributing parameters

In an effort to understand the role of sulphur on the growth contributing characters of garlic many scientist have conducted research experiments to elaborate its role. For evaluating the response of sulphur on plant height, Zaman *et al* (2011) observed maximum plant height (70.8cm) using 30 kg S ha⁻¹. In a research trial for checking role of sulphur in garlic production, El-Sayed *et al* (2018) observed maximum plant height of 83.34cm with 450 kg S fed⁻¹. While experimenting, a similar result in a similar experiment was observed by Divyasree *et al* (2021) concluded that magnesium sulphate @ 60 kg ha⁻¹ gave maximum plant height of 67.13cm. The results were further confirmed while experimentation by Veer *et al* (2021) who got maximum plant height of 62.84cm by using of 60 kg ha⁻¹ of S.

In another experiment evaluated by Hore *et al* (2014), he observed maximum plant height of 67.15cm by using 60 kg ha⁻¹ of S. The results were further confirmed while experimentation by Patidar *et al* (2017) used 75 kg ha⁻¹ S to get maximum plant height of 78.2cm. The findings were also in accordance with research experiment conducted by Chattoo *et al* (2019), who observed maximum plant height of 76.40cm by using 45 kg ha⁻¹ of S.

In a different research experiment to check the influence of sulphur on leaf number per plant, research conducted by Hore *et al* (2014) concluded that maximum leaf number per plant (10.77) were observed by 60 kg ha⁻¹ of S. While experimenting, a similar result in a similar experiment was observed by Patidar *et al* (2017) found that 75 kg ha⁻¹ of S gave maximum leaf number per plant (8.7). Bableshwar *et al* (2017), observed highest leaf number per plant (7.25) by using 60 kg S ha⁻¹. In a research trial for checking role of sulphur in garlic production, El-Sayed *et al* (2018) got maximum leaf number per plant (11.13) per plant by applications of 450 kg S fed⁻¹. Also, Chattoo *et al* (2019) found that 45 kg ha⁻¹ of S gave the highest leaf number per plant (12.88). The results were similar with the experiment conducted

by Divyasree *et al* (2021) who found that magnesium sulphate @ 60 kg ha⁻¹ gave highest leaf number per plant (6.88).

To check the influence of sulphur on neck thickness, Patidar *et al* (2017) used 75 kg ha⁻¹ of S to get maximum neck thickness of 1.17cm. The results were similar with the research conducted by Chattoo *et al* (2019) found that 45 kg ha⁻¹ of S gave maximum neck thickness of 1.54cm. While experimenting, a similar result in a similar experiment was observed by Divyasree *et al* (2021) who used magnesium sulphate @ 60 kg ha⁻¹ to get maximum neck thickness of 1.92cm, thus enunciating the crucial effect of Sulphur on growth of garlic.

In another experiment evaluated by Zaman *et al* (2011), he observed maximum bulb radial diameter of 3.56cm by using 45 kg ha⁻¹ S. For evaluating the response of sulphur on bulb radial diameter, Bableshwar *et al* (2017) recorded maximum bulb radial diameter of 3.62 cm with 60 kg ha⁻¹ of S. Research conducted by El-Sayed *et al* (2018) found maximum bulb radial diameter of 5.66cm with 450 kg fed⁻¹ of S. The results were similar with the research conducted by Divyasree *et al* (2021) who used magnesium sulphate @ 60 kg ha⁻¹ to get maximum bulb radial diameter of 4.75cm.

In a research conducted by Hore *et al* (2014), radial diameter was maximum (3.70cm) using 60 kg ha⁻¹ of S. In an experiment to check the effect of sulphur and potassium on garlic, Magray *et al* (2017) got maximum radial diameter of 5.29cm by using 100 kg K and 45 kg ha⁻¹ S. While experimenting, a similar result in a similar experiment was observed by Patidar *et al* (2017) who used 75 kg ha⁻¹ S to get maximum radial diameter of 5.18cm. The findings were also in accordance with research experiment conducted by Chattoo *et al* (2019) who used 45 kg ha⁻¹ of S to get maximum radial diameter of 6.84cm.

In a research conducted by Zaman *et al* (2011), 45 kg ha⁻¹ S gave maximum bulb polar diameter (3.06cm). Also, Hore *et al* (2014) observed maximum polar diameter of 3.47cm using 60 kg ha⁻¹ of S. In a different research experiment to check the influence of sulphur on bulb polar diameter, Patidar *et al* (2017) used 75 kg S ha⁻¹ to observe maximum polar diameter (4.45cm). The results were further confirmed while experimentation by Chattoo *et al* (2019) who used 45 kg ha⁻¹ of S to get maximum polar diameter of 6.55cm. The results were similar with the research conducted by Divyasree *et al* (2021) who used magnesium sulphate @ 60 kg ha⁻¹ to get highest polar diameter of 4.46cm.

2.2.2 Effect of yield contributing parameters

In an effort to understand the role of sulphur on the yield contributing characters of garlic many scientist have conducted research experiments to elaborate its role. For evaluating the response of sulphur on clove number per bulb, Bableshwar *et al* (2017) observed

maximum number of cloves (21.75) using 60 kg sulphur ha⁻¹. The results were further confirmed while experimentation by Divyasree *et al* (2021) who used magnesium sulphate @ 60 kg ha⁻¹ to get greater cloves number per bulb (17.67).

A similar result in a similar experiment was observed by Hore *et al* (2014) who got maximum number of cloves (30.77) using 60 kg ha⁻¹ sulphur. The results were further confirmed while experimentation by Patidar *et al* (2017) who used 75 kg sulphur ha⁻¹ to get maximum number of cloves per bulb (39.8). Research conducted by El-Sayed *et al* (2018) concluded that using 45 kg sulphur fed⁻¹ gave the greatest number of cloves per bulb (15.0). In a research trial for checking role of sulphur in garlic production, Veer *et al* (2021) observed maximum number of cloves per bulb (14.92) using 40 kg sulphur ha⁻¹.

In a research trial for checking role of sulphur in garlic production, Bableshwar *et al* (2017) observed maximum 10 cloves weight of 10.23g using 60 kg sulphur ha⁻¹. The results were further confirmed while experimentation by Patidar *et al* (2017) who used 75 kg sulphur ha⁻¹ to get maximum 20 cloves weight of 35.7g. In another research conducted by Divyasree *et al* (2021), magnesium sulphate 4@ 60 kg ha⁻¹ gave maximum 10 cloves weight of 14.74g.

For evaluating the response of sulphur on bulb weight, Hore *et al* (2014) concluded using 60 kg ha⁻¹ of sulphur gave maximum bulb weight of 29.22g. In an experiment to check the effect of sulphur on garlic bulb weight, Patidar *et al* (2017) used 75 kg ha⁻¹ of sulphur to get maximum bulb weight of 52.7g. In another research experiment, Chattoo *et al* (2019) used 45 kg ha⁻¹ of sulphur to get maximum bulb weight of 93.43g.

In a research trial for checking role of sulphur and potassium in garlic production, Magray *et al* (2017) applied 100 kg potassium and 45 kg sulphur ha⁻¹ to get highest marketable yield of 22.1 ton ha⁻¹. Bableshwar *et al* (2017) used various doses of sulphur to attain highest marketable yield of 5.19 t ha⁻¹ using 60 kg sulphur ha⁻¹. The results were further confirmed while experimentation by Chattoo *et al* (2019) who used 45 kg ha⁻¹ of sulphur to get highest marketable yield of 452.51 q/ha. A similar result in a similar experiment was observed by Malik *et al* (2021) got the highest marketable bulb yield of 14.70 ton ha⁻¹ using 45 kg sulphur ha⁻¹.

In another experiment, Zaman *et al* (2011) observed highest total yield of 7.22 ton ha⁻¹ by using 45 kg sulphur ha⁻¹ thus enunciating the crucial effect of Sulphur on total yield of garlic. In another experiment evaluated by Bableshwar *et al* (2017) to find the effect of sulphur on garlic productivity, they observed highest total yield of 5.79 t ha⁻¹ using 60 kg sulphur ha⁻¹. The results were further confirmed while experimentation by El-Sayed *et al* (2018) who observed highest total yield of 7.72 ton fed⁻¹ using 450 kg sulphur fed⁻¹. While experimenting, a similar result in a similar experiment was observed by Divyasree *et al*

(2021), who concluded that magnesium sulphate @ 60 kg ha⁻¹ gave highest total yield of 16.78 t ha⁻¹.

The results were further confirmed while experimentation by Hore *et al* (2014) who observed highest total yield of 6.51 tons ha⁻¹ using 60 kg ha⁻¹ sulphur. In a research trial for checking role of sulphur and potassium in garlic production, Magray *et al* (2017) used 100 kg potassium and 45 kg sulphur ha⁻¹ to get maximum total yield of 24.03 ton ha⁻¹. In another experiment, Patidar *et al* (2017) used 75 kg sulphur ha⁻¹ to get a maximum total yield of 8.94 ton ha⁻¹. The findings were also in accordance with research experiment conducted by Chattoo *et al* (2019) who used 45 kg ha⁻¹ of sulphur to get maximum total yield of 483.03 q ha⁻¹.

2.2.3 Effect of Sulphur on quality parameters

In an effort to understand the role of sulphur as a quality element on the quality characters of garlic many scientist have conducted research experiments to elaborate its role. For evaluating the response of sulphur on allicin, Bloem *et al* (2010) used 45 kg ha⁻¹ sulphur to get maximum of 15.7 mg per g of allicin content. In the same experiment evaluated by, Bloem *et al* (2010), he got maximum dry matter of 31.1 % by using 45 kg ha⁻¹ sulphur. The results were further confirmed while experimentation by, Diriba-Sheferaw *et al* (2014) who observed highest (39.76%) dry matter by using 60 kg ha⁻¹ sulphur. For evaluating the response of sulphur on total protein content in garlic, Diriba-Sheferaw *et al* (2014) recorded maximum protein content (12.17%) using 60 kg ha⁻¹ sulphur.

The effect of sulphur on TSS has been studied by many researchers in an effort to understand the relation of nutrient with increase in TSS. For evaluating the response of sulphur on TSS in garlic, Diriba-Sheferaw *et al* (2014) observed maximum (21.73°Brix) TSS by using 60 kg ha⁻¹ sulphur. The results were further confirmed while experimentation by, Patidar *et al* (2017) who used 75 kg sulphur ha⁻¹ to get maximum TSS of 36.3°Brix. While in another experiment, Singh *et al* (2018) observed a maximum TSS of 30.51°Brix using sulphur @60kg ha⁻¹.

In an experiment conducted by El-Sayed *et al* (2018), maximum TSS of 39.83°Brix was observed by using 450 kg sulphur fed⁻¹. Also confirming to the results, was the research conducted by Chattoo *et al* (2019) who used 45 kg ha⁻¹ of sulphur to get maximum TSS of 11.54°Brix. A similar result in a similar experiment was observed by Malik *et al* (2021), who got highest TSS of 40.81°Brix by using 45 kg sulphur ha⁻¹.

Nasreen *et al* (2007) studied the response of S and N fertilisation in onion (var. BARI Piaz-1) uptake and yield performance, and concluded that N @120 kg per ha and S @40 kg per ha while using 90 kg per ha P₂O₅, 90 kg per ha K₂O, and 5 kg Zn per ha, as well as 5

tonnes of cow dung per ha, produced highest yield and maximum uptake. Only when N and S were administered combined at greater rates, did the antagonistic response of N and S, on absorption and yield become apparent.

Singh (2008) investigated the influence of S on yields and S uptakes by onion and garlic cultivated in Ranchi's acid alfisols, found that S treatment up to 40 kg per ha increased onion bulb output by 37.8q per ha and garlic bulb yield by 18.8q per ha over the recommended amount of NPK fertilisers. Sulfer 95 was found to be superior to gypsum in terms of meeting the S requirements of onion and garlic on S-deficient soils. These two crops S utilisation efficiency was found to be higher with Sulfer 95 than with gypsum application.

Al-Fraihat (2009) checked response of three levels of N (100, 150, and 200 kg ha⁻¹) and three levels of S (0, 50, and 100 kg ha⁻¹) on physical and quality parameters of onion bulbs of the Giza 20 cultivar. The findings demonstrated that, at various phases of onion growth, increasing N and S considerably improved growth and yield characteristics. Using 200 kg N ha⁻¹ and 100 kg S ha⁻¹ in both seasons, proved to be best treatment for improving yield and quality. Lowest percent of pickles yield was recorded with the highest level of N and S fertilizers.

Verma and Singh (2012) investigated how potassium and sulphur affected onion yield and nutrient uptake. Four levels of K and S were used as treatments. They found that raising levels of K and S, both separately and in different combinations, significantly enhanced fresh weight per bulb, bulb size, and dry matter yield. The yield and amount of protein in onion bulbs rose due to K and S. With rising levels of K and S, the intake of nutrients (N, P, K, and S) rose considerably. K and S levels had a synergistic influence on onion bulb output and absorption.

Tripathy *et al* (2013) investigated impact of S sources and concentrations on onion growth, yield, and quality. Treatments uses Factorial RBD with three replications and includes two sources of S and four amounts of S. In comparison to elemental S, gypsum had improved the crop growth parameters. By lowering PLW, rotting, and sprouting, gypsum also improves onion shelf life by minimizing the development of doubles and bolters. S levels at 30 kg ha⁻¹ produced plants with considerably higher plant heights (54.51 cm), leaf counts (14.8), polar and equatorial diameters (5.17 cm), bulb weights (60.83 g), yield (211.23 q ha⁻¹), and TSS (11.90%) than other levels. But for the aforementioned parameters, statistical parity was seen when applying S at 15 and 30 kg ha⁻¹. Using gypsum @30 kg ha⁻¹ of S may be advised for onion crops to get increased bulb yields with improved keeping qualities.

Brown (2014) reported lack of significant interactions between variety and S amendment level with garlic after completing a study on the response of S amendments on

yield and quality in Alliums. Plant vigour, per cent of culled bulbs after curing, and the number and size of marketable cured bulbs were all used to assess the effect of S. In Rhode Island, S had no discernible effect on garlic. S fertilisation did not improve yields or minimise rot in Allium crops. These findings were surprising because the region's soil S levels were low, and other researchers have found that higher S levels improve bulb size, pungency, and storage life.

Tripathy *et al* (2015) checked effectiveness of onion S feeding. Gypsum and elemental S were the two sources of S in the treatment combination, which also included four amounts of S. Combined data from three years showed that gypsum was much more effective than elemental S in terms of polar diameter (3.13 cm), bulb weight (48.37 g), and marketable bulb yield (101.39 q ha⁻¹). In a similar manner, S @ 30 kg ha⁻¹, regardless of the source, resulted in significantly higher plant height (55.78 cm), number of leaves per plant (11.08), bulb weight (67.34 g), bulb yield (marketable, 160.71 q ha⁻¹, and total, 224.52 q ha⁻¹), TSS (12.03 %), higher BC ratio (1.47), and longer shelf life. It may be advised to apply S @ 30 kg ha⁻¹ as gypsum to the onion crop in order to increase bulb yield, BC ratio, and keeping quality.

The impact of various sources and amounts on onion growth, yield, and S uptake was examined by Nayak *et al* in 2016. (cv. Nasik Red). Elemental gromor sulphate and gypsum are the two sources of S in the treatment, and there are three amounts of S as well as a control using RBD with three replications. The findings showed that, in both S sources, growth parameters grew significantly up to 35 kg S ha⁻¹ and then decreased. Use of 35 kg ha⁻¹ of S gave maximum bulb output; this was much higher than control, 20 kg S ha⁻¹, and 50 kg S ha⁻¹ from either source. Gypsum and gromorsulphur bulb yields increased by 3.8 t ha⁻¹ and 5.4 t ha⁻¹, respectively, over control, following the application of 35 kg S ha⁻¹. The crop's ability to utilize S increased up to 35 kg S ha⁻¹ before beginning to decline in both sources. The use of 35 kg S ha⁻¹ in both S sources resulted in the highest net return and benefit cost ratio. Gromorsulphur outperformed gypsum in terms of growth, bulb yield, sulphate use efficiency, and economics.

Singh *et al* (2017) conducted an experiment with 16 treatment combinations. The outcome showed that the greater bulb output of 303 q ha⁻¹ was greatly increased by applying 50:45:100 kg NPK ha⁻¹ and inoculating the field with 1.25 kg ha⁻¹ Azotobacter and 0.62 kg ha⁻¹ PSB.

Jain (2018) checked response of N and S doses on onion growth, yield, and quality. Treatments included four levels of S and three levels of N. Using S @120 kg ha⁻¹, significantly maximized onion growth, yield, and quality characteristics. The maximum values of onion growth, yield, and quality attributes were obtained with a 60 kg S ha⁻¹

application. They concluded that “Using 120 kg N + 60 kg S ha⁻¹, the combined response of N and S significantly affected the fresh weight of the shoot, fresh weight of the bulb, horizontal diameter, vertical diameter, bulb yield, and pyruvic acid content along with the highest gross income, net income, and cost-benefit ratio were also discovered”.

To investigate the impact of various sources and graded amounts of S on bellary onion development, yield characteristics, and yield, an experiment was conducted by Vivek *et al* (2019). Three sources of S were used as treatments, with quantities of S ranging from 0, 30, and 60 kg S ha⁻¹. The appropriate fertilizer doses were used in accordance with the crop production manual. Findings demonstrated that growth, quality and yield parameters significantly increased up to 45 kg S ha⁻¹ and then decreased in all sources of S. Application of 45 kg S ha⁻¹ gave maximum bulb production, which was considerably higher than 30 kg S ha⁻¹ and on par with 60 kg S ha⁻¹ across all sources of S. When it comes to application techniques, soil application with 45 kg S ha⁻¹ is superior to using a nutria-pellet pack.

In order to determine how N and S fertilizers affected onion growth, yield, quality, and nutrient uptake, Tilahun *et al* (2021) experimented with five S rates and four N rates. The interaction between N and S showed a considerable increase in growth, yield, and quality metrics. Maximum yield (42.6 t ha⁻¹) and bulb weight (193.6g) were achieved with the application of 200 kg N ha⁻¹ and 45 kg S ha⁻¹. Use of 200 kg N ha⁻¹ and 45 kg S ha⁻¹ gave maximum N and S uptake. For the production of high yielding and high-quality onions, the use of 200 kg N ha⁻¹ and 45 kg S ha⁻¹ is suggested.

2.3 Influence of potassium and sulphur on nutrient uptake

For evaluating the response of potassium and sulphur on nitrogen uptake, Magray *et al* (2017) conducted an experiment in which he concluded that application of 100 kg potassium and 45 kg sulphur ha⁻¹ resulted in highest N uptake of 105.29 kg ha⁻¹. In another experiment evaluated by Chattoo *et al* (2019) to find the effect of sulphur application on nitrogen uptake, they used 45 kg ha⁻¹ of sulphur to get maximum N uptake of 94.44 kg ha⁻¹. While experimenting with various sulphur doses in garlic, Malik *et al* (2021) got maximum N uptake of 153.21 kg ha⁻¹ by using 45 kg sulphur ha⁻¹.

In an experiment to check the role of potassium and sulphur for phosphorus uptake in garlic, Magray *et al* (2017) applied 100 kg potassium and 45 kg ha⁻¹ sulphur to get highest phosphorus uptake of 30.84 kg ha⁻¹. For evaluating the response of sulphur on phosphorus uptake, Chattoo *et al* (2019) used 45 kg ha⁻¹ of sulphur to get highest phosphorus uptake of 23.89 kg ha⁻¹. In a research trial for checking role of sulphur in garlic production, Malik *et al* (2021) observed highest phosphorus uptake of 20.06 kg ha⁻¹ using 45 kg sulphur ha⁻¹.

While experimenting with various doses of potassium, Arisha *et al* (2017) testified use of 125 kg K₂O resulted in maximum 615.19 mg per plant of potassium uptake. In an experiment to check the role of potassium and sulphur for potassium uptake in garlic, Magray *et al* (2017) applied 100 kg potassium and 45 kg ha⁻¹ sulphur to get maximum potassium uptake of 83.90 kg ha⁻¹. For evaluating the response of sulphur on potassium uptake, Chattoo *et al* (2019) used 45 kg ha⁻¹ of sulphur to get highest potassium uptake of 78.65 kg ha⁻¹. In a research trial for checking role of sulphur in garlic production, Malik *et al* (2021) observed highest potassium uptake of 163.15 kg ha⁻¹ by using 45 kg sulphur ha⁻¹.

In an experiment to check role of sulphur in garlic, 16.6 mg per g of sulphur uptake was observed by Bloem *et al* (2010) using 45 kg ha⁻¹ sulphur. In an experiment to check the role of potassium and sulphur for sulphur uptake in garlic, Magray *et al* (2017) applied 100 kg potassium and 45 kg ha⁻¹ sulphur to get highest sulphur uptake of 38.73 kg ha⁻¹. For evaluating the response of sulphur, Chattoo *et al* (2019) used 45 kg ha⁻¹ of sulphur to get highest sulphur uptake of 32.54 kg ha⁻¹. In a research trial for checking role of sulphur in garlic production, Malik *et al* (2021) got highest sulphur uptake of 17.74 kg ha⁻¹ using 60 kg sulphur ha⁻¹.

2.4 Economics

In an experiment to evaluate response of sulphur, Zaman *et al* (2011) found that 43.6kg ha⁻¹ of sulphur showed most economic yield in garlic. While studying role of sulphur and nitrogen in garlic cultivation, Hore *et al* (2014) witnessed maximum B:C ratio of 1.92 and maximum net returns of Rs 1,48,038 by using 60 kg of sulphur and 200 kg of nitrogen ha⁻¹. Diriba-Shiferaw *et al* (2015), while investigating optimum dose of NPS fertilizers for achieving optimum bulb yield of garlic in Andosols, testified use of 30 kg of sulphur per ha gave the highest B:C ratio of 6.44 and highest net returns.

Magray *et al* (2017) experimented upon economics of producing garlic and received highest B:C ratio of 5.67 and maximum net returns of Rs 7,42,272 by using 100 kg potassium + 45 kg sulphur ha⁻¹. Malik *et al* (2021) checked the response of sulphur supplementation on economics of garlic and found that using 60 kg S ha⁻¹ gave the highest B:C of 2.61, and hence is the most profitable treatment.

CHAPTER III

MATERIALS AND METHODS

3.1 Experiment Site

The present investigation entitled, “RESPONSE OF SULPHUR AND POTASSIUM APPLICATIONS ON GROWTH, YIELD AND QUALITY OF GARLIC (*Allium sativum* L.)” was conducted at the Research farm of Vegetable science, Biochemistry laboratory and Soil testing laboratory PAU, Ludhiana during rabi seasons of 2020-21 and 2021-22. The study of the details of material and methods implemented in this research procedure has been given in this chapter.

3.2 Weather and climate

Located at 30.54° N latitude and 75.48° E longitude with an average mean height of 247 m above sea level, Ludhiana generally has extremely hot and dry summers after which a season of hot and humid monsoon persists followed by severely cold winters (Annexure 1). The average rainfall of this area is 600mm. About 70% of the total rainfall is received during the period of July to September.

3.3 Soil analysis

Experimental site had a loamy sand, fertile and normal in reaction. To assess the physiological properties of soil, composite soil samples to a depth of 0-15 cm were collected before sowing of the crop. Analysis of soil revealed that the soil had low organic carbon and available nitrogen, high phosphorus and medium potash. The results on various physiological properties of soil are depicted in Table 3.1.

Table 3.1: Physicochemical properties of soil in experimental field

S. No.	Particulars	Level/content	
		2020-21	2021-22
1	Soil Texture	Loamy sand	Loamy sand
2	Soil pH	7.6	7.8
3	Organic Carbon (%)	0.26	0.32
4	Electrical conductivity (mmhos/cm)	0.20	0.21
5	Available Nitrogen (kg ha ⁻¹)	140	142
6	Available Phosphorus (kg ha ⁻¹)	32	30.2
7	Available Potassium (kg ha ⁻¹)	62.5	63.0
8	Available Sulphur (ppm Sulphate)	13.7	13.9

3.3.1 Soil texture

The soil texture was checked using international pipette method given by Piper (1966). The clay (<0.02-2.0mm) particles were separated from silt using 0.1 N solution of Sodium hexametaphosphate as dispersing agent. The USDA size fraction for separation of sand (0.02-2.0 mm) by gravity deposit method was invented by Day (1965). 70-mesh sieve was used to check sand content.

3.3.2 Soil pH

The pH was measured by Beckman's glass electrode pH meter in 1:2 soil water suspensions (Jackson 1967). It gives an estimation of H^+ ions in the solution.

3.3.3 Soil Organic Carbon

It was developed by Walkley and Black (1934) through Rapid titration method. In this method, 2g dried soil is mixed with 1N $K_2Cr_2O_7$ 10 ml solution followed by 20ml of concentrated H_2SO_4 . Resting for 30 minutes followed by adding 2 g of NaF, 100ml water and 10 drops of diphenylamine indicator. This solution was titrated against 0.5N ferrous ammonium sulphate solution. Change of color from violet to bright green through blue color was the end point.

3.3.4 Electrical conductivity

It was measured by Solubridge conductivity meter in 1:2 water suspensions (Jackson 1967). The conductivity of current was directly proportional to the salts dissolved in solution. The EC was indicated as deci siemens per meter ($dS\ m^{-1}$).

3.3.5 Available Nitrogen

It's determined by alkaline potassium permanganate method by Subbiah and Asija (1956). 5g of soil aliquot is used in kjeldahl distillation flask. 25ml of 2.5% NaOH solution is added. NH_3 evolved is absorbed in 10ml of 0.02N H_2SO_4 . 30ml extract is mixed with 3drops of methyl red indicator for identification of end point. Excess of H_2SO_4 is titrated against 0.02N NaOH until change of color from pink to yellow.

3.3.6 Available Phosphorus

It's estimated by the technique given by Olsen *et al* (1954). 1g of aliquot was taken out with 20 ml of 0.5 N $NaHCO_3$ solution (pH 8.5). Soil sample was shaken for 30 minutes. 5 ml extract is mixed with ammonium molybdate and ascorbic acid. Ammonium molybdate develop blue color and ascorbic acid that formed heteropoly complexes with soluble phosphate ions. Strength of blue color developed was indication of concentration of phosphate ions examined on spectrophotometer at wavelength of 760 nm.

3.3.7 Available Potassium

It was determined with ammonium acetate and estimated by Hange's flame photometer (Jackson 1967). Aliquot was reacted with neutral 1N $\text{CH}_3\text{COONH}_4$ solution (25 ml) from a 150 ml conical flask. Galvanometer reading indicated the concentration of potassium in the solution.

3.3.8 Available Sulphur

It was determined after treating with barium chloride along with gum acacia solution (Chesnin and Yien 1950). Sulphate precipitates and gum acacia acts as stabilizing agent. Observations are recorded using blue filter at 420nm.

3.4 Experiment details

There were three replications comprising each with sixteen treatments consisting of four K applications (0, 20, 40 and 60 kg ha^{-1}) and four S applications (0, 10, 20 and 30 kg ha^{-1}). The application of potassium through muriate of potash and sulphur through elemental sulphur was given as basal dose at the time of bed preparation before planting.

3.5 Methodology

3.5.1 Land preparation

The experiment field was ploughed well with disc harrow and cultivated followed by planking. Soil samples were collected from the experimental site before bed preparation and after the crop harvesting for calculating the soil nutrient uptake. Plots were arranged as per the plan before transplanting. Farmyard manure at the rate of 50 tonnes per ha was used for the experiment. The fertilization with N at the rate of 125 kg per ha and P at the rate of 67.5 kg per ha was done. Full dose of P and half dose of N was applied at time of field preparation and remaining half as top dressing 4 weeks after planting.

The application of K and S was done according to formulated treatments and applied as basal dose during bed preparation before planting.

3.5.2 Plant Material

The experimental material comprises of garlic cultivar PG18. According to the institute "Plants have a soft neck (non-bolting) with green leaves. Bulbs are large (4.55cm diameter), attractive and white with average bulb weight of 24.8 g. Cloves are medium to large sized, white and average clove number of 26 per bulb. It has dry matter of 38% and allicin content of 1.15%. Average yield is 51q acre^{-1} ."

3.5.3 Treatment detail

Treatment details are given below

Table 3.2: Treatment detail

Sr. No.	Treatment
T ₁	0 kg K ha ⁻¹ + 0 kg S ha ⁻¹
T ₂	0 kg K ha ⁻¹ + 10 kg S ha ⁻¹
T ₃	0 kg K ha ⁻¹ + 20 kg S ha ⁻¹
T ₄	0 kg K ha ⁻¹ + 30 kg S ha ⁻¹
T ₅	20 kg K ha ⁻¹ + 0 kg S ha ⁻¹
T ₆	20 kg K ha ⁻¹ + 10 kg S ha ⁻¹
T ₇	20 kg K ha ⁻¹ + 20 kg S ha ⁻¹
T ₈	20 kg K ha ⁻¹ + 30 kg S ha ⁻¹
T ₉	40 kg K ha ⁻¹ + 0 kg S ha ⁻¹
T ₁₀	40 kg K ha ⁻¹ + 10 kg S ha ⁻¹
T ₁₁	40 kg K ha ⁻¹ + 20 kg S ha ⁻¹
T ₁₂	40 kg K ha ⁻¹ + 30 kg S ha ⁻¹
T ₁₃	60 kg K ha ⁻¹ + 0 kg S ha ⁻¹
T ₁₄	60 kg K ha ⁻¹ + 10 kg S ha ⁻¹
T ₁₅	60 kg K ha ⁻¹ + 20 kg S ha ⁻¹
T ₁₆	60 kg K ha ⁻¹ + 30 kg S ha ⁻¹

3.5.4 Raising of crop

The crop was planted on 8th October 2020 and 10th October 2021 in two seasons. The plot (bed) size was 1m wide and 2.2m long with 8 rows 15 cm apart with plant-to-plant distance of 7.5 cm. The normal cultural practices for irrigation, nutrition and pest control were followed as per standard agronomic practices (Anonymous 2021b).

3.5.5 Layout

- Number of treatments: 16
- Design: Randomized complete block design (2-factors)
- Replications: 3
- Total number of plots: 16×3 = 48

Randomized Complete Block Design

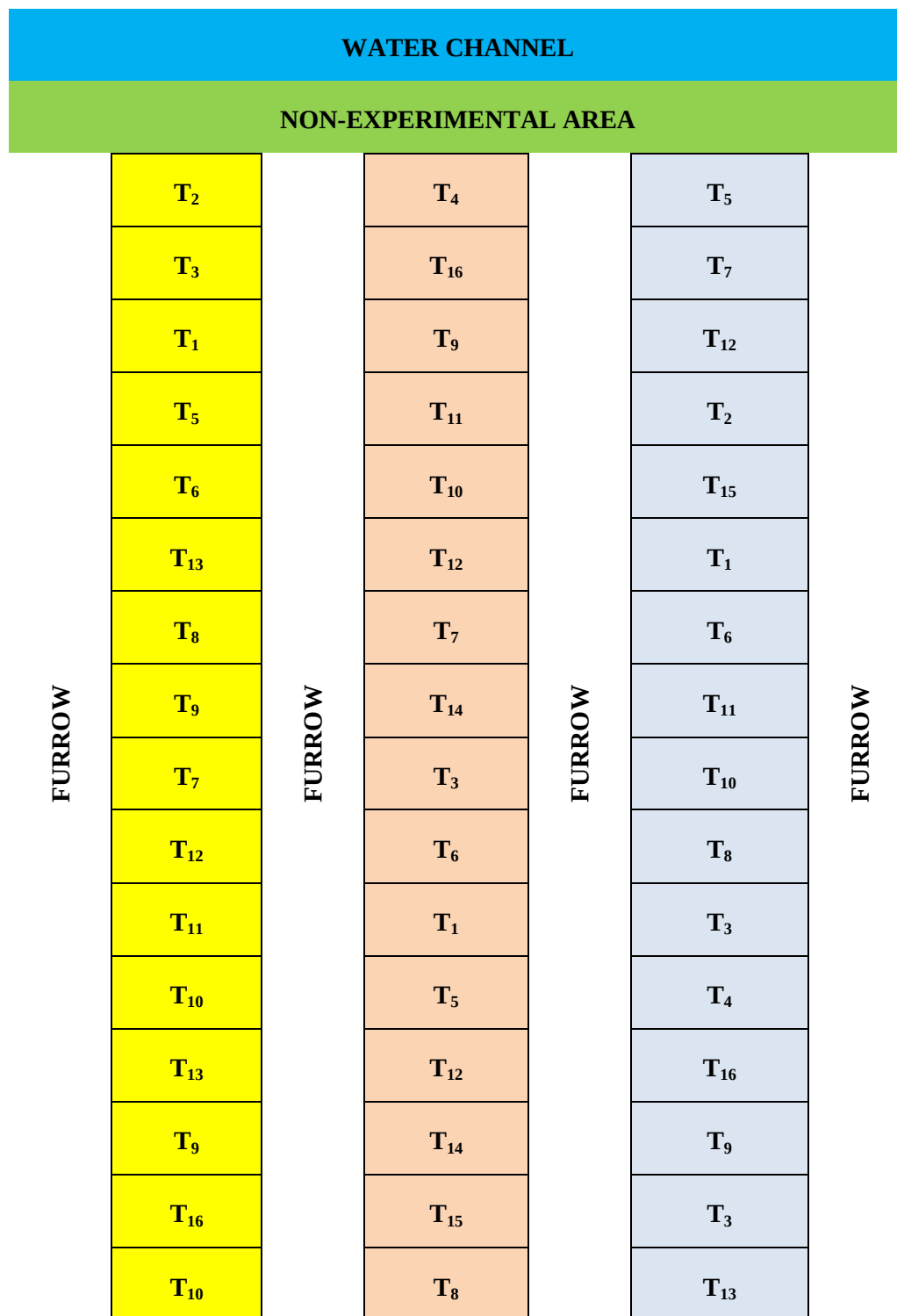


Fig. 3.1: Layout of field for both the seasons 2020-21 and 2021-22

3.5.6 Observations recorded

The plants were selected randomly from each plot apart from border plants in each replication for recording observations and the data was recorded with respect to the following traits:

3.6 Physical parameters

3.6.1 Plant height (cm)

Ten plants were selected at random from each plot to measure their height at full growth before maturity. It was recorded in centimeters from base of the plant to the top most point using meter rod and an average value was worked out for each plot.

3.6.2 Leaf length (cm)

Length of 10 healthy leaves were measured from a plot. The length was recorded from base till leaf tip. The average of these 10 observations was worked out and stated as leaf length.

3.6.3 Number of leaves

Leaves number was calculated from the base of the plant by taking 10 plants from each plot. The mean of these 10 plants were taken to calculate the number of leaves. The observations were recorded before maturity of crop at full growth stage.

3.6.4 Leaf area index

Leaf area index was recorded at full growth stage before maturity by using Sunscan leaf area meter suggested by Sone *et al* (2009). Instrument was calibrated and readings were taken between 12-2 pm thrice from a plot and average of those was considered as LAI.

3.6.5 Neck thickness (mm)

From the harvested garlic plants of every plot, 10 healthy plants were carefully chosen after harvesting. Neck thickness was measured by using digital vernier caliper. The average of those plants was considered as neck thickness.

3.6.6 Bulb Diameter-Radial (cm)

From the harvested garlic plants of every plot, 10 healthy plants were carefully chosen after harvesting. Bulb diameter radial was measured by using digital vernier caliper. The average of those bulbs was considered as radial bulb diameter.

3.6.7 Bulb Diameter-Polar (cm)

From the harvested garlic plants of every plot, 10 healthy plants were carefully chosen after harvesting. Bulb diameter polar was measured by using digital vernier caliper. The average of those bulbs was considered as polar bulb diameter.

3.6.8 Cloves per bulb

The number of cloves per bulb were counted from 10 sample bulbs randomly picked from a harvested plot. The average of those 10 observations was taken as cloves per bulb.

3.6.9 50 clove weights (g)

The harvested bulbs from a plot were divided into cloves randomly. Weight of 50 cloves was derived from that cluster three different times and the average of those three observations was taken as 50 cloves weight.

3.6.10 Bulb weight (g)

Weight of 10 garlic bulbs harvested from one plot was calculated and the average bulb weight was worked out from each plot.

3.6.11 Marketable yield (tonnes per ha)

The yield per plot was calculated after harvesting by using a digital weighing balance for every plot. The marketable portion of the yield was picked out separately and the data was recorded. The data was worked out to calculate the yield in terms of ton ha⁻¹.

3.6.12 Total yield (tonnes per ha)

The yield per plot was calculated after harvesting by using a digital weighing balance for every plot. The data was worked out to calculate the yield in terms of ton ha⁻¹.

3.7 Quality parameters:

3.7.1 Allicin (mg per g)

For estimation of allicin content, 1 g fresh weight sample is ground and soaked in 10 ml of cold distilled water. Then it is refrigerated for 24 hours at 0-5°C. Afterwards it is filtered using whatman no. 42 under vacuum and the filtrate is kept back in fridge for maintaining low temperature. The absorbance is checked at 240 nm. The extinction coefficient ϵ for allicin in H₂O is 145.4 (1cm cell @ 240 nm), therefore,

$$E = \text{Absorbance} \times \frac{10000}{C \left(\frac{\mu g}{ml} \right)}$$

$$C = \text{Absorbance} \times 10000 \div 145.4$$

3.7.2 TSS (per cent)

The total soluble solids of garlic extract were estimated using hand-held refractometer. The crushed extract from each treatment was poured onto the screen of refractometer and the readings were noted down and an average was calculated.

3.7.3 Ascorbic acid (mg per 100g dry weight)

2ml juice of the fresh sample is mixed with 2ml of MPA. The solution is then titrated against dye and NaHCO_3 and reading is noted at color change.

3.7.4 Total minerals (mg per 100g dry weight)

The dry sample is weighed and kept in furnace for 6 hours and allowed to cool till next day. The weight of ash is measured accurately and gives us the total minerals.

3.7.5 Dry Matter (per cent)

To evaluate dry matter, garlic cloves free from any defects as well as pest or disease damage were taken and cut into the small slices. Weight of petri dish along with fresh sample was recorded. Sample was dried in the oven for about 2-3 days with airflow of 70°C until constant weight was attained. After drying, the sample weight along with petri dish was recorded.

$$\text{Dry matter content (\%)} = \frac{\text{Final dry weight of sample}}{\text{Original fresh weight of sample}} \times 100$$

3.7.6 Total protein (mg per g)

Lowry method was used for estimation of total protein. 0.5g sample is mixed with 30ml NaOH and shaken for 30 minutes. The liquid is collected and 10-15ml of NaOH is added and then centrifuged. 5ml of 10% TCA is added and kept for an hour and centrifuged again. 10ml of 0.1N NaOH is added. 0.1ml of sample is mixed with 0.9ml water and 5ml mixture of (50ml lowry A and 1ml lowry B) followed by 30 minutes rest then add 0.5ml of diluted Folin Ciocalteu reagent. Observations are recorded at 520nm.

3.7.7 Phenols (mg per g)

Ground dried sample of 0.5 g is mixed in 25 ml of 80% methanol and extracted for two hours on boiling water bath. The samples are then filtered and the volume of filtrate is made up to 25 ml with 80% methanol. Then it is evaporated to make the volume around 10 ml and 0.5 ml phenol reagent is added. Rest for 3 minutes after adding 6.5 ml water. Then 1 ml of Na_2CO_3 is added and the volume is made up to 10 ml by distilled water. Then solution is left in dark for 1 hour and the absorbance is checked at 760 nm.

3.7.8 Total sugars (mg per g)

Total sugar can be estimated by mixing 0.5g of sample with 80% ethanol and boiling it for two hours on water bath followed by filtering. Add 5 ml lead acetate and rest for 30 minutes. Add sodium oxalate and filter by Whatman filter paper. Then the total volume is made upto 100ml using distilled water. 10ml of sample is centrifuged for 10 minutes. Then take 0.2 ml of sample and add 0.8 ml of water followed by 1 ml of 5% phenol and 4ml of H_2SO_4 and read the absorbance at 490 nm.

3.7.9 Reducing sugars (mg per g)

For estimation of reducing sugars, 0.5 g dry sample is mixed in 15-20 ml of 80% ethanol and kept on boiling water bath for two hours. It is treated with lead acetate and kept for 30 minutes followed by filtering it and then treating with sodium oxalate and kept for 5 min followed by filtering. After the last filter with Whatman paper, volume is made to 100ml with distilled water. 1ml of the sample is mixed with 2ml of DNS and 10 ml of distilled water. After cooling the absorbance is checked at 500nm.

3.8 Nutritional parameters

3.8.1 N uptake by plants

For estimation of plant concentration of N, 0.5g of sample is treated with conc. H_2SO_4 along with catalyst mixture (K_2SO_4 : CuSO_4 : HgO : Se powder= 500g:20g:3g:1g). The sample is digested at 350°C for 6 hours. Sample's volume is increased to 50ml using distilled water. Pipette out 5ml extract and add 10 ml of 40% NaOH and distillate it for 3 minutes. Absorb the distillate in 5ml of 4% Boric acid. Pink color of boric acid changes to green. Then titrate the distillate with N/70 H_2SO_4 and again color will change to pink.

$$\text{Total N (\%)} = (y - x) \times 0.392$$

The N % is multiplied with total dry matter yield per ha of crop to get N uptake of crop.

3.8.2 P uptake by plants

0.5 g of sample is treated with 10 ml of HNO_3 : HClO_4 (3:1) and digested. The volume is made upto 50 ml. 5 ml of extract is pipette into 5ml of Ammonium Molybdate Metavandate solution and the volume is made 25 ml using distilled water. A blank solution is checked at 470 nm followed by the sample. The P % is multiplied with total dry matter yield per ha of crop to get P uptake of crop.

3.8.3 K uptake by plants

For estimation K concentration, 0.5g of sample is added into 10 ml of HNO_3 : HClO_4 (3:1) and digested. Sample's volume is increased to 50ml using distilled water and pipette out 1ml extract and make the volume 25 ml and check the reading at 470 nm. The K % is multiplied with total dry matter yield per ha of crop to get K uptake of crop.

3.8.4 S uptake by plants

The S uptake estimation in plants is done by turbidimetric method after wet digestion with concentrated nitric acid and perchloric acid (Chesnin and Yien 1950). In an aliquot of the test solution barium sulphate turbidity is developed in the presence of sodium acetate acetic

acid buffer and gum acacia by dissolving barium chloride crystals. The absorbance of barium sulphate turbidity is measured at 420 nm on spectrophotometer. The content of sulphur is estimated by reference to standard calibration curve. The K % is multiplied with total dry matter yield per ha of crop to get K uptake of crop.

3.9 Nutrient status of soil at time of planting and harvesting

3.9.1 Available Potassium in soil

It was estimated using ammonium acetate and flame photometer (Jackson 1967)

3.9.2 Available Sulphur in soil

It was determined after treating with barium chloride along with gum acacia solution (Chesnin and Yien 1950).

3.10 Cost-Benefit ratio

A benefit-cost ratio is an indicator, which is used in cost benefit analysis. It helps to summarize the economic feasibility of any practice i.e., how much returns are obtained for any rupee spent. B:C is defined as a ratio of net returns to the total cost of cultivation. It was calculated by the formula given below:

$$B: C = \frac{\text{Net returns (ha)}}{\text{Total cost of cultivation (ha)}}$$

3.11 Statistical analysis

Recorded data was statistically analysed according to the procedure outlined by Steel and Torrie (1981) using CPCS1 software. Comparison of the mean values of different treatments was made at 5% level of significance.

ANOVA table

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F- ratio
Replication (r=3)	(r-1) =2	SSR	MSR=SSR/(r-1)	MSR/MSE
Treatment A (ta=4)	(ta-1) =3	SSTA	MSTA=SSTA/(ta-1)	MSTA/MSE
Treatment B (tb=4)	(tb-1) =3	SSTB	MSTB=SSTB/(tb-1)	MSTB/MSE
Interaction A×B	(ta-1) (tb-1) =9	SSI	MSI=SSI/(ta-1) (tb-1)	MSI/MSE
Error	(r-1) (t-1) =30	SSE	MSE=SSE/(r-1) (t-1)	
Total	(rt-1) =47	TSS		

*SSR= Sum of square due to replications, SSTA= Sum of square due to factor A, SSTB= Sum of square due to factor B, SSI= Sum of square due to interaction of factors, SSE= Sum of square due to error, TSS= Total sum of square, MSR= Mean sum of square due to replications, MSTB= Mean sum of square due to factor B, MSI= Mean sum of square due to interaction of factors, MSE= Mean sum of square due to error.

CHAPTER IV

RESULTS AND DISCUSSION

The present investigation entitled, “RESPONSE OF SULPHUR AND POTASSIUM APPLICATIONS ON GROWTH, YIELD AND QUALITY OF GARLIC (*Allium sativum* L.)” was conducted at the Research farm of Vegetable science, Biochemistry laboratory and Soil testing laboratory PAU, Ludhiana during rabi seasons of 2020-21 and 2021-22. In this chapter the observations recorded are presented in the form of tables and graphs, and discussed after analysis of data as following

4.1 PHYSICAL PARAMETERS

4.1.1 Plant height

Height of plant is an important parameter depicting the health of the plant. Yield of any plant can be estimated from plant height. Plant height is most important growth factor to depict the performance of plant in field. The effect of potassium and sulphur treatments on the plant height can be seen in Table 4.1

Table 4.1: Influence of various levels of potassium and sulphur on plant height (cm)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	62.2	61.7	61.9
K₂₀	K @20 kg ha ⁻¹	72.6	72.0	72.3
K₄₀	K @40 kg ha ⁻¹	76.8	77.1	76.9
K₆₀	K @60 kg ha ⁻¹	82.6	83.0	82.8
LSD (<i>p</i><0.05) K		3.4	4.1	2.7
S₀	S @0 kg ha ⁻¹	71.2	70.8	71.0
S₁₀	S @10 kg ha ⁻¹	73.5	73.7	73.6
S₂₀	S @20 kg ha ⁻¹	74.5	75.0	74.7
S₃₀	S @30 kg ha ⁻¹	75.1	74.2	74.6
LSD (<i>p</i><0.05) S		NS	NS	2.6
LSD (<i>p</i><0.05) K×S		NS	NS	NS

Pooled data of both seasons showed maximum plant height using 60 kg ha⁻¹ K (82.8cm) which was higher significantly. The use of 20 kg S gave the highest mean plant height (74.7cm) among sulphur treatments which was significantly higher from all other treatments.

During year 2020-21, maximum plant height was obtained by using 60 kg ha⁻¹ K (82.6cm) followed by 40 kg ha⁻¹ (76.8cm) being significantly higher than other treatments. No significant difference observed with use of different sulphur treatments for season 2020-21.

In year 2021-22, 60 kg ha⁻¹ K (83.0cm) followed by 40 kg ha⁻¹ (77.1cm) gave the maximum plant height being significantly different from all treatments. No significant difference observed with use of different sulphur treatments for season 2021-22.

The results were found in accordance with research conducted by Bableshwar *et al* (2017) in which they achieved maximum plant height of 43.71cm using 60 kg S ha⁻¹. In research conducted by Divyasree *et al* (2021), use of magnesium sulphate @ 60 kg ha⁻¹ gave maximum plant height of 67.13cm. El-Sayed *et al* (2018) observed maximum plant height of 83.34cm with 450 kg S fed⁻¹. In another experiment, Veer *et al* (2021) found out maximum plant height of 62.84cm by using of 60 kg ha⁻¹ of S.

Findings of Zaman *et al* (2011) found maximum plant height (70.8cm) using 30 kg S ha⁻¹. Also, Zyada and Bardisi (2018) used 150 kg K fed⁻¹ to get maximum plant height of 74.70 cm. In another experiment, Arisha *et al* (2017) used 125 kg K₂O ha⁻¹ to get maximum plant height of 84.03cm. Barakat *et al* (2019) concluded that 96 kg K₂O fed⁻¹ gave maximum plant height of 93.97cm. In a research conducted by Chattoo *et al* (2019) maximum plant height of 76.40cm was achieved by using 45 kg ha⁻¹ of S. Farooqui *et al* (2009) observed maximum plant height of 50.94cm by using 60 kg K ha⁻¹. In another experiment, Hore *et al* (2014) observed maximum plant height of 67.15cm by using 60 kg ha⁻¹ of S. Patidar *et al* (2017) used 75 kg ha⁻¹ S to get maximum plant height of 78.2cm.

4.1.2 Leaf length

Leaf length is an important character depicting the health and vigor of plant. The leaf length depicts the surface area available for photosynthesis and hence helps in understanding relation between yield and growth parameters of a plant. The leaf length has a direct relation to the amount of photosynthates accumulated by the plant which ultimately represent the yield of the crop.

The data pertaining to the different treatments of potassium and sulphur on leaf length is presented in Table 4.2. Pooled data of both seasons showed maximum leaf length using 60 kg ha⁻¹ K (44.1cm) which was higher significantly. The use of 30 kg S gave the highest mean leaf length (42.8cm) among sulphur treatments which was significantly higher from control.

During year 2020-21, maximum leaf length was obtained by using 60 kg ha⁻¹ K (43.7cm) followed by 40 kg ha⁻¹ (43.3cm) being at par statistically but significantly higher than other treatments. No significant differences were obtained with use of different sulphur treatments for season 2020-21.

In year 2021-22, 60 kg ha⁻¹ K (44.3cm) followed by 40 kg ha⁻¹ (42.5cm) gave the maximum leaf length being significantly different from all treatments. No significant difference observed by using sulphur treatments in season 2021-22.

Table 4.2: Influence of various levels of potassium and sulphur applications on garlic leaf length (cm)

Treatments		2020-21	2021-22	Pooled mean
K₀	K 0 kg ha ⁻¹	40.9	40.2	40.6
K₂₀	K 20 kg ha ⁻¹	41.0	41.4	41.2
K₄₀	K 40 kg ha ⁻¹	43.3	42.5	42.9
K₆₀	K 60 kg ha ⁻¹	43.7	44.3	44.1
LSD (<i>p</i><0.05) K		1.8	0.8	1.0
S₀	S 0 kg ha ⁻¹	41.2	41.6	41.4
S₁₀	S 10 kg ha ⁻¹	42.1	41.9	42.1
S₂₀	S 20 kg ha ⁻¹	42.6	42.3	42.5
S₃₀	S 30 kg ha ⁻¹	43.1	42.6	42.8
LSD (<i>p</i><0.05) S		NS	NS	NS
LSD (<i>p</i><0.05) K×S		NS	NS	NS

4.1.3 Number of leaves

The leaf number per plant is a crucial growth parameter depicting health, vigor and probable yield of plant. The higher leaf numbers will directly increase the leaf surface area available for the process of photosynthesis, which is the basis of growth of any plant. Thus, a greater leaf number per plant will depict healthy and adequately sized bulb and increase the overall yield. Results showing leaf number per plant as influenced by various doses of potassium and sulphur is shown in Table 4.3.

Pooled data of both seasons showed maximum leaf number using 60 kg ha⁻¹ K (8.87) which was higher significantly. The use of 30 kg S gave the highest mean leaf number (7.98) among sulphur treatments which was significantly higher from rest.

During year 2020-21, maximum leaf number was obtained by using 60 kg ha⁻¹ K (8.91) followed by 40 kg ha⁻¹ (7.59) being at par statistically but higher significantly than rest. Maximum leaf number was obtained by using 30 kg ha⁻¹ S (7.85) followed by 20 kg ha⁻¹ (7.56) being at par statistically but higher significantly than rest.

In year 2021-22, 60 kg ha⁻¹ K (8.82) followed by 40 kg ha⁻¹ (7.66) gave the maximum leaf number being at par with each other but significantly higher than rest. Maximum leaf number was obtained by using 30 kg ha⁻¹ S (8.11) followed by 20 kg ha⁻¹ (7.75) being significantly higher than rest.

Table 4.3: Influence of various levels of potassium and sulphur applications on number of leaves

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	6.10	6.91	6.51
K₂₀	K @20 kg ha ⁻¹	7.07	7.02	7.05
K₄₀	K @40 kg ha ⁻¹	7.59	7.66	7.62
K₆₀	K @60 kg ha ⁻¹	8.91	8.82	8.87
LSD (<i>p</i><0.05) K		0.47	0.25	0.26
S₀	S @0 kg ha ⁻¹	7.03	7.05	7.04
S₁₀	S @10 kg ha ⁻¹	7.24	7.51	7.37
S₂₀	S @20 kg ha ⁻¹	7.56	7.75	7.65
S₃₀	S @30 kg ha ⁻¹	7.85	8.11	7.98
LSD (<i>p</i><0.05) S		0.46	0.24	0.25
LSD (<i>p</i><0.05) K×S		NS	NS	NS

The results were similar with the experiment conducted by Bableshwar *et al* (2017), where they observed highest leaf number per plant (7.25) by using 60 kg S ha⁻¹. Divyasree *et al* (2021) found magnesium sulphate @ 60 kg ha⁻¹ gave highest leaf number per plant (6.88). In another experiment, El-Sayed *et al* (2018) got maximum leaf number per plant (11.13) by application of 450 kg S fed⁻¹. Research conducted by Veer *et al* (2021) concluded that 60 kg ha⁻¹ K gave maximum leaf number per plant (8.44).

Zyada and Bardisi (2018) concluded that 150 kg K fed⁻¹ gave the maximum leaf number per plant (8.37). In another experiment conducted by Arisha *et al* (2017) found that 125 kg K₂O ha⁻¹ gave highest leaf number per plant (9.26). Barakat *et al* (2019) concluded that 96 kg K₂O fed⁻¹ gave highest leaf number per plant (9.57). Also, Chattoo *et al* (2019) found that 45 kg ha⁻¹ of S gave the highest leaf number per plant (12.88). Research conducted by Hore *et al* (2014) concluded that maximum leaf number per plant (10.77) were observed by 60 kg ha⁻¹ of S. Patidar *et al* (2017) found that 75 kg ha⁻¹ of S gave maximum leaf number per plant (8.7). Yadav *et al* (2007), using K @150 kg ha⁻¹ got highest leaf number per plant (7.5).

4.1.4 Leaf area index

Leaf area index is defined as the ratio of leaf area per unit of ground area. Instrument operated to measure the leaf area Index is sunscan leaf area meter which is based on the principle of Beer-Lambert law. Leaf area index plays an important role to determine the

photosynthetically active area and transpiration area as well as acts as a primary trait in plant ecology to depict foliage cover around the plant. The impact of LAI on growth of a plant is prominent through various physiological processes and biomass accumulation. (Patil *et al* 2018).

Table 4.4: Influence of various levels of potassium and sulphur applications on leaf area index (LAI)

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K ₀	2.09	2.55	2.42	3.33	2.60
K ₂₀	2.57	3.22	3.60	3.83	3.31
K ₄₀	2.64	3.66	3.89	3.45	3.41
K ₆₀	2.31	3.73	4.22	5.19	3.86
Mean	2.40	3.29	3.53	3.95	
LSD (<i>p</i> <0.05)	0.33 (K)	0.33 (S)	0.67 (K×S)		
2021-22					
K ₀	2.16	2.56	3.36	3.25	2.83
K ₂₀	2.90	2.78	3.33	3.93	3.24
K ₄₀	2.68	3.88	3.91	3.53	3.50
K ₆₀	2.93	4.02	5.22	5.59	4.44
Mean	2.67	3.31	3.95	4.07	
LSD (<i>p</i> <0.05)	0.46 (K)	0.46 (S)	0.93 (K×S)		
Pooled data					
K ₀	2.13	2.56	2.90	3.29	2.71
K ₂₀	2.74	3.01	3.47	3.89	3.27
K ₄₀	2.67	3.77	3.47	3.89	3.45
K ₆₀	2.62	3.88	4.73	5.39	4.15
Mean	2.53	3.30	3.74	4.01	
LSD (<i>p</i> <0.05)	0.28 (K)	0.26 (S)	0.55(K×S)		

Pooled data of both seasons showed maximum LAI using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (5.39) which was higher significantly than rest followed by 60 kg ha⁻¹ K + 20 kg ha⁻¹ S (4.73) being second best treatment.

During year 2020-21, maximum LAI was obtained by using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (5.19) which was higher significantly than rest, followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (4.22) being second best treatment.

In year 2021-22, using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S maximum LAI (5.59) was observed followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (5.22) being at par with each other but higher significantly than rest.

4.1.5 Neck thickness (mm)

Neck thickness of the bulb represents its vigor, growth, health and overall performance in field. With a greater neck thickness, it can be concluded that the bulb is of adequate size and weight. But, the post-harvest life of bulbs has an inverse relation with neck thickness. It is generally observed that bulbs with greater neck thickness have shorter post-harvest life and vice versa. The results regarding neck thickness of bulbs due to different doses of potassium and sulphur are shown in Table 4.5.

Table 4.5: Influence of various levels of potassium and sulphur applications on neck thickness (mm)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	8.18	8.01	8.09
K₂₀	K @20 kg ha ⁻¹	7.60	7.46	7.53
K₄₀	K @40 kg ha ⁻¹	7.82	7.96	7.89
K₆₀	K @60 kg ha ⁻¹	8.06	8.09	8.07
LSD (<i>p</i><0.05) K		0.40	NS	0.32
S₀	S @0 kg ha ⁻¹	7.97	7.90	7.93
S₁₀	S @10 kg ha ⁻¹	7.71	7.85	7.78
S₂₀	S @20 kg ha ⁻¹	7.94	7.97	7.95
S₃₀	S @30 kg ha ⁻¹	8.04	7.80	7.92
LSD (<i>p</i><0.05) S		NS	NS	NS
LSD (<i>p</i><0.05) K×S		NS	NS	NS

Pooled data of both seasons showed minimum neck thickness using 20 kg ha⁻¹ K (7.53mm) which was higher significantly. No significant differences observed using different sulphur treatments for pooled data.

During year 2020-21, minimum neck thickness was obtained by using 20 kg ha⁻¹ K (7.60mm) followed by 40 kg ha⁻¹ (7.82mm) being at par with each other but significantly

different than other treatments. No significant differences observed using different sulphur treatments for season 2020-21.

In year 2021-22, no significant differences observed with potassium and sulphur treatments in neck thickness. The use of different sulphur treatments failed to achieve any significant differences in neck thickness during both seasons (2020-21 and 2021-22) and their pooled mean.

The results were found in harmony with Divyasree *et al* (2021) who used MgSO_4 @ 60 kg ha^{-1} to get highest neck thickness of 1.92cm. In another experiment, Zyada and Bardisi (2018) used 150 kg ha^{-1} of K fed⁻¹ to get maximum neck thickness of 1.50cm. Research conducted by Chattoo *et al* (2019) found that 45 kg ha^{-1} of S gave maximum neck thickness of 1.54cm. Farooqui *et al* (2009) got maximum neck thickness of 0.72cm by using 45 kg ha^{-1} of K. Magray *et al* (2017) observed maximum neck thickness of 1.28cm by using 100 kg K and 30 kg S ha^{-1} . Patidar *et al* (2017) used 75 kg ha^{-1} of S to get maximum neck thickness of 1.17cm.

4.1.6 Bulb radial diameter

The bulb radial diameter is an important measure of quality of bulb. The higher the radial diameter of a bulb, higher will be its weight. The radial diameter of bulb is an important parameter to differentiate the total harvest into various grades of marketable yield. The higher the bulb diameter the better the quality and market price of the bulb. The influence of various doses of potassium and sulphur on radial bulb diameter has been shown in Table 4.6.

Pooled data of both seasons showed maximum bulb radial diameter using 60 kg ha^{-1} K and 30 kg ha^{-1} S (5.24cm) which was higher significantly than rest followed by 60 kg ha^{-1} K + 20 kg ha^{-1} S (4.65cm) being second best treatment.

During year 2020-21, maximum bulb radial diameter was obtained by using 60 kg ha^{-1} K and 30 kg ha^{-1} S (5.26cm) which was higher significantly than rest followed by 60 kg ha^{-1} K + 20 kg ha^{-1} S (4.73cm) being second best treatment.

In year 2021-22, maximum bulb radial diameter was obtained by using 60 kg ha^{-1} K and 30 kg ha^{-1} S (5.21cm) which was higher significantly than rest followed by 60 kg ha^{-1} K + 20 kg ha^{-1} S (4.57cm) being second best treatment.

The results found were in conformity with Bableshwar *et al* (2017) observing greatest bulb radial diameter of 3.62 cm using 60 kg ha^{-1} of S. Divyasree *et al* (2021) used MgSO_4 @ 60 kg ha^{-1} to get greatest bulb radial diameter of 4.75cm. Research conducted by El-Sayed *et al* (2018) found maximum bulb radial diameter of 5.66cm with 450 kg fed^{-1} of S. Zaman *et al* (2011) observed maximum bulb radial diameter of 3.56cm by using 60 kg ha^{-1} of K.

Researchers Zyada and Bardisi (2018) used 150 kg fed⁻¹ of K which gave maximum bulb radial diameter of 2.90cm. Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get maximum radial diameter of 6.84cm. In a research conducted by Hore *et al* (2014), radial diameter was maximum (3.70cm) using 60 kg ha⁻¹ of S. Jiku *et al* (2020) used K @200 kg ha⁻¹ to get maximum (2.74cm) bulb radial diameter. While experimenting, Magray *et al* (2017) got maximum radial diameter of 5.29cm by using 100 kg K + 45 kg ha⁻¹ S. Patidar *et al* (2017) used 75 kg ha⁻¹ S to get maximum radial diameter of 5.18cm. Yadav *et al* (2007) used K @150 kg ha⁻¹ to get maximum bulb diameter of 14.5cm.

Table 4.6: Influence of various levels of potassium and sulphur applications on bulb radial diameter (cm)

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K ₀	2.76	3.36	3.56	3.93	3.40
K ₂₀	2.53	2.93	3.16	3.26	2.97
K ₄₀	3.73	3.56	3.93	4.16	3.85
K ₆₀	3.66	3.96	4.73	5.26	4.40
Mean	3.17	3.45	3.85	4.15	
LSD (<i>p</i> <0.05)	0.17 (K)	0.16 (S)	0.34 (K×S)		
2021-22					
K ₀	2.74	3.02	3.34	3.62	3.18
K ₂₀	2.98	3.26	3.32	3.23	3.20
K ₄₀	3.53	3.71	3.82	4.06	3.78
K ₆₀	3.88	4.28	4.57	5.21	4.48
Mean	3.28	3.57	3.76	4.03	
LSD (<i>p</i> <0.05)	0.18 (K)	0.15 (S)	0.35 (K×S)		
Pooled data					
K ₀	2.76	3.2	3.45	3.78	3.29
K ₂₀	2.76	3.10	3.25	3.25	3.08
K ₄₀	3.63	3.64	3.88	4.11	3.81
K ₆₀	3.78	4.13	4.65	5.24	4.44
Mean	3.23	3.51	3.80	4.09	
LSD (<i>p</i> <0.05)	0.12 (K)	0.11 (S)	0.24 (K×S)		

4.1.7 Bulb polar diameter

The bulb polar diameter can be defined as the distance from pole to pole of a bulb and is an important measure of quality of bulb. The adequate polar diameter of bulb gives the bulb its flattened shape. The higher the polar diameter of a bulb, higher will be its weight. The polar diameter of bulb is an important parameter to differentiate the total harvest into various grades of marketable yield. The higher the bulb diameter the better the quality and market price of the bulb. The effect of different doses of potassium and sulphur on polar bulb diameter has been shown in Table 4.7.

Table 4.7: Influence of various levels of potassium and sulphur applications on bulb polar diameter (cm)

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K ₀	2.63	3.43	3.23	3.36	3.16
K ₂₀	2.76	3.06	3.16	3.06	3.01
K ₄₀	3.06	3.23	3.46	3.56	3.33
K ₆₀	3.16	3.76	4.03	4.46	3.85
Mean	2.90	3.37	3.47	3.61	
LSD (<i>p</i> <0.05)	0.20 (K)	0.19 (S)	0.38 (K×S)		
2021-22					
K ₀	2.87	3.19	3.37	3.43	3.22
K ₂₀	3.10	3.13	3.45	3.39	3.27
K ₄₀	3.43	3.66	3.74	3.52	3.59
K ₆₀	3.47	3.97	4.37	4.43	4.06
Mean	3.22	3.49	3.73	3.69	
LSD (<i>p</i> <0.05)	0.14 (K)	0.13 (S)	0.26 (K×S)		
Pooled data					
K ₀	2.75	3.32	3.31	3.40	3.19
K ₂₀	2.94	3.10	3.31	3.23	3.14
K ₄₀	3.25	3.45	3.60	3.55	3.46
K ₆₀	3.32	3.87	4.20	4.45	3.96
Mean	3.06	3.43	3.60	3.65	
LSD (<i>p</i> <0.05)	0.12 (K)	0.11 (S)	0.22 (K×S)		

Pooled data of both seasons showed maximum bulb polar diameter using 60 kg ha⁻¹ K + 30 kg ha⁻¹ S (4.45cm) which was higher significantly than rest followed by 60 kg ha⁻¹ K + 20 kg ha⁻¹ S (4.20cm) being second best treatment.

During year 2020-21, maximum bulb polar diameter was obtained by using 60 kg ha⁻¹ K + 30 kg ha⁻¹ S (4.46cm) which was higher significantly than rest followed by 60 kg ha⁻¹ K + 20 kg ha⁻¹ S (4.03cm) being second best treatment.

In year 2021-22, maximum bulb polar diameter was obtained by using 60 kg ha⁻¹ K + 30 kg ha⁻¹ S (4.43cm) followed by 60 kg ha⁻¹ K + 20 kg ha⁻¹ S (4.37cm) being at par with each other but different significantly than rest.

The results found were in conformity with Magray *et al* (2017) who got maximum bulb polar diameter of 4.30cm by using 100 kg K and 45 kg S per ha. In an experiment conducted by Patidar *et al* (2017) using 75 kg S ha⁻¹, polar diameter (4.45cm) was maximum. Divyasree *et al* (2021) used MgSO₄ @ 60 kg ha⁻¹ to get greatest polar diameter of 4.46cm. In a research conducted by Zaman *et al* (2011), bulb polar diameter was maximum (3.06cm). Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get maximum polar diameter of 6.55cm. Also, Hore *et al* (2014) observed maximum polar diameter of 3.47cm using 60 kg ha⁻¹ of S.

4.1.8 Cloves per bulb

Cloves per bulb is an important yield attribute. Although being a varietal character, addition of nutrients to crop tends to increase the clove number to some extent. Higher the clove number, higher will be the bulb yield. The data representing the clove number per bulb as influenced by potassium and sulphur is shown in Table 4.8.

Table 4.8: Influence of various levels of potassium and sulphur applications on cloves per bulb

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	22.7	22.9	22.8
K₂₀	K @20 kg ha ⁻¹	25.1	24.6	24.9
K₄₀	K @40 kg ha ⁻¹	26.2	26.2	26.2
K₆₀	K @60 kg ha ⁻¹	28.0	27.0	27.5
LSD (<i>p</i><0.05) K		2.5	1.1	1.2
S₀	S @0 kg ha ⁻¹	24.6	23.7	24.2
S₁₀	S @10 kg ha ⁻¹	25.2	25.4	25.3
S₂₀	S @20 kg ha ⁻¹	26.0	26.1	26.0
S₃₀	S @30 kg ha ⁻¹	26.1	25.5	25.8
LSD (<i>p</i><0.05) S		NS	1.1	1.2
LSD (<i>p</i><0.05) K×S		NS	NS	NS

Pooled data of both seasons showed highest clove number with 60 kg K ha⁻¹ (27.47) which was significantly different. Using 20 kg ha⁻¹ S gave highest mean cloves per bulb among sulphur treatments being at par statistically with 30 and 10 kg ha⁻¹ S.

During year 2020-21, highest clove number were observed by using 60 kg ha⁻¹ K followed by 40 kg ha⁻¹ being at par statistically but higher significantly from other treatments. Whereas, use of sulphur treatments gave insignificant results for number of cloves.

60 kg ha⁻¹ K (26.96) followed by 40 kg ha⁻¹ (26.17) gave greatest clove number per bulb being at par statistically with each other but higher significantly from other treatments in year 2021-22. Use of S@20 kg ha⁻¹ gave highest number of cloves followed by S@30 kg ha⁻¹ among the sulphur treatments being at par statistically with each other but higher significantly from other treatments.

Results found were in conformity with Bableshwar *et al* (2017) who got maximum number of cloves (21.75) using 60 kg S ha⁻¹. In another experiment, Divyasree *et al* (2021) used magnesium sulphate @ 60 kg ha⁻¹ to get greater clove number per bulb (17.67). Research conducted by El-Sayed *et al* (2018) concluded that 450 kg S fed⁻¹ gave the greatest number of cloves per bulb (15.0). Veer *et al* (2021) observed maximum number of cloves per bulb (14.92) using 40 kg S ha⁻¹.

Research conducted by Arisha *et al* (2017) revealed that, using 125 kg K₂O fed⁻¹ gave the greatest number of cloves per bulb (19.50). Barakat *et al* (2019) used 96 kg K₂O fed⁻¹ to get highest clove number per bulb (16.08). Hore *et al* (2014) observed maximum number of cloves (30.77) using 60 kg ha⁻¹ S. Research conducted by Jiku *et al* (2020) received highest clove number (19.12) per bulb using K @200 kg ha⁻¹. Magray *et al* (2017) observed highest clove number (10.85) by using 100 kg K and 45 kg S ha⁻¹. Patidar *et al* (2017) used 75 kg S ha⁻¹ to get maximum number of cloves per bulb (39.8). Yadav *et al* (2007), used K @150 kg ha⁻¹ to get maximum number of cloves per bulb (31.1).

4.1.9 50 cloves weight

Weight of variable numbers of cloves, in our case 50, is determined to depict the quality of the produce, its dry matter content and overall yield. Scientists have determined clove weights of various quantities including 1, 10, 20, 30 and 50 to depict the yield potential of the crop and its quality characteristics. The higher the weight of 50 cloves, the higher will be the yield and quality of the bulbs. The data pertaining to the 50 cloves weights as influenced by potassium and sulphur is shown in Table 4.9 and Fig. 4.1.

Pooled data of both seasons showed maximum 50 cloves weight with 60 kg ha⁻¹ K (52.9g) which was significant. Using 30 kg ha⁻¹ S gave highest mean 50 cloves weight (52.0g) among sulphur treatments which was significantly different from all other treatments.

Table 4.9: Influence of various levels of potassium and sulphur applications on 50 cloves weight (g)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	48.7	49.4	49.0
K₂₀	K @20 kg ha ⁻¹	50.5	50.6	50.5
K₄₀	K @40 kg ha ⁻¹	52.5	52.1	52.3
K₆₀	K @60 kg ha ⁻¹	53.6	52.2	52.9
LSD (<i>p</i><0.05) K		0.7	0.8	0.5
S₀	S @0 kg ha ⁻¹	49.9	50.0	50.0
S₁₀	S @10 kg ha ⁻¹	51.3	51.0	51.2
S₂₀	S @20 kg ha ⁻¹	51.7	51.3	51.5
S₃₀	S @30 kg ha ⁻¹	52.3	51.7	52.0
LSD (<i>p</i><0.05) S		0.6	0.7	0.4
LSD (<i>p</i><0.05) K×S		NS	NS	NS

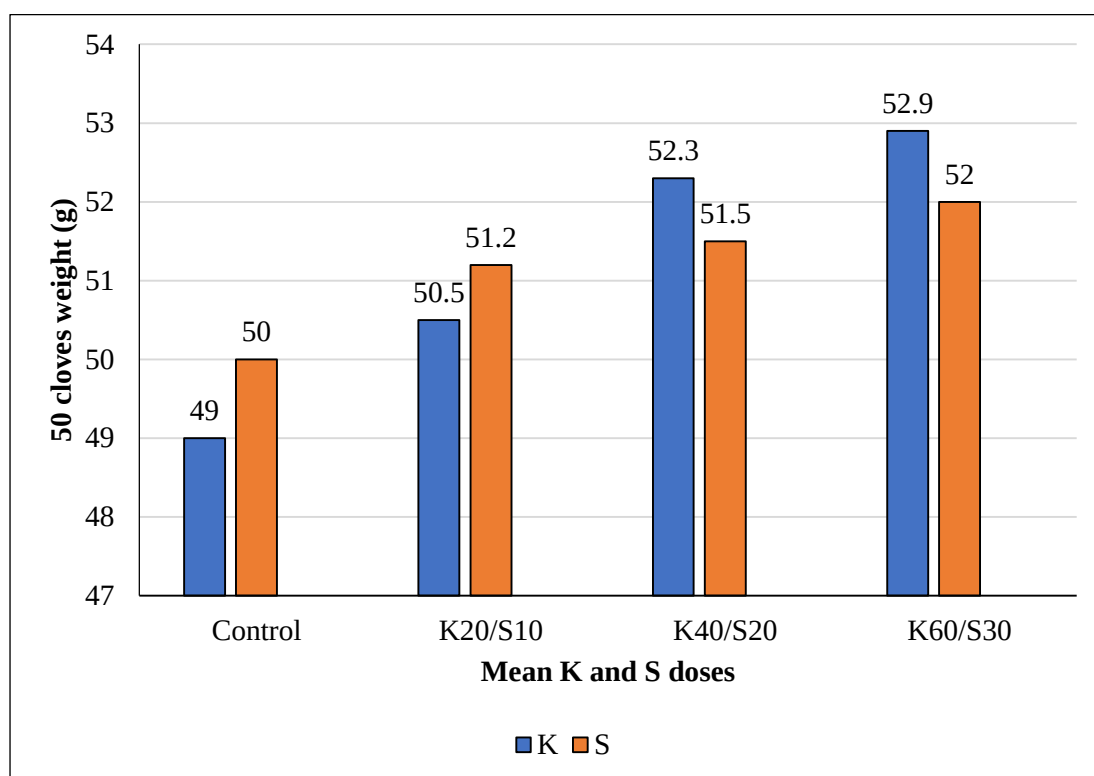


Fig. 4.1: Influence of various levels of potassium and sulphur applications on 50 cloves weight (g)

During year 2020-21, highest 50 cloves weight were obtained by using 60 kg K ha⁻¹ (53.6g) followed by 40 kg ha⁻¹ (52.5g) being significantly higher than other treatments. Use of S 30 kg ha⁻¹ (52.3g) gave highest 50 cloves weight followed by S 20 kg ha⁻¹ (51.7g) being at par statistically but different significantly from other treatments.

60 kg ha⁻¹ K (52.2g) followed by 40 kg ha⁻¹ (52.1g) gave the highest 50 cloves weight being at par statistically but different significantly than rest in year 2021-22. Using S 30 kg ha⁻¹ (51.7g) gave highest 50 cloves weight followed by S 20 kg ha⁻¹ (51.3g) among the sulphur treatments being at par statistically but different significantly than rest.

Results found were in conformity with Bableshwar *et al* (2017) who got maximum 10 cloves weight of 10.23g using 60 kg S ha⁻¹. In another research conducted by Divyasree *et al* (2021), MgSO₄ @ 60 kg ha⁻¹ gave greatest 10 cloves weight (14.74g). Farooqui *et al* (2009) observed highest 20 cloves weight of 36.67g using 60 kg ha⁻¹ of K. While experimenting, Patidar *et al* (2017) used 75 kg S ha⁻¹ to get maximum 20 cloves weight of 35.7.

4.1.10 Bulb weight

The individual bulb weight of garlic depicts its yield, quality and marketable grade. The bulbs with higher weight have better quality and marketable grade, hence increasing its value and market potential. The higher bulb weight also means higher yield of crop. The data regarding bulb weight as influenced by different doses of potassium and sulphur is shown in Table 4.10 and Fig. 4.2.

Table 4.10: Influence of various levels of potassium and sulphur applications on bulb weight (g)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	24.0	24.8	24.4
K₂₀	K @20 kg ha ⁻¹	25.2	26.1	25.7
K₄₀	K @40 kg ha ⁻¹	26.3	26.5	26.4
K₆₀	K @60 kg ha ⁻¹	27.1	28.1	27.6
LSD (<i>p</i><0.05) K		0.8	0.7	0.5
S₀	S @0 kg ha ⁻¹	24.7	25.8	25.3
S₁₀	S @10 kg ha ⁻¹	25.4	26.3	25.8
S₂₀	S @20 kg ha ⁻¹	25.8	26.6	26.2
S₃₀	S @30 kg ha ⁻¹	26.7	26.8	26.7
LSD (<i>p</i><0.05) S		NS	NS	NS
LSD (<i>p</i><0.05) K×S		NS	NS	NS

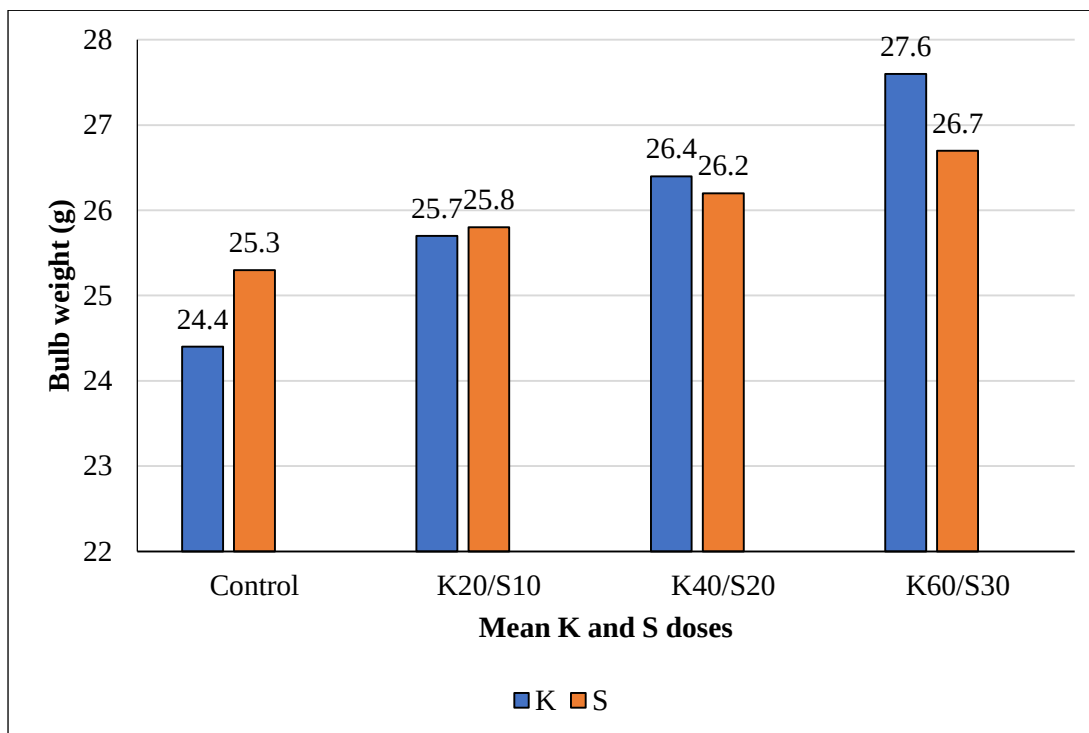


Fig. 4.2: Influence of various levels of potassium and sulphur applications on bulb weight (g)

Pooled data of both seasons showed maximum bulb weight with 60 kg ha⁻¹ K (27.6g) which was significantly different. No significant differences observed using different sulphur treatments.

In 2020-21, highest bulb weight was obtained by using 60 kg K ha⁻¹ (27.1g) followed by 40 kg ha⁻¹ (26.3g) being significantly higher than other treatments. The use of sulphur treatments failed to show any significant increase in weights of bulbs.

60 kg ha⁻¹ K (28.1g) followed by 40 kg ha⁻¹ (26.5g) gave the highest bulb weight being different significantly from other treatments in year 2021-22. The use of sulphur treatments failed to show any significant increase in weights of bulbs.

The results found were in conformity with Bableshwar *et al* (2017) who got highest bulb weight of 11.75g with 60 kg S ha⁻¹. While experimentation by El-Sayed *et al* (2018), highest bulb weight of 67.24g was observed using 450 kg S fed⁻¹. Zyada and Bardisi (2018) used 150 kg K fed⁻¹ to get maximum dry bulb weight of 13.88g. In a research conducted by Arisha *et al* (2017), 125 kg K₂O fed⁻¹ gave highest (67.50g) bulb weight.

Barakat *et al* (2019) used 96 kg K₂O fed⁻¹ to get highest bulb weight of 104.6g. In another experiment, Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get maximum bulb weight of 93.43g. Farooqui *et al* (2009) observed maximum bulb weight of 48.06g using 60 kg ha⁻¹ K. In a research experiment, Hore *et al* (2014) concluded use of 60 kg ha⁻¹ of S gave maximum

bulb weight of 29.22g. Magray *et al* (2017) recorded maximum bulb weight of 41.96g by 100 kg K and 45 kg S ha⁻¹. Patidar *et al* (2017) used 75 kg ha⁻¹ of S to get maximum bulb weight of 52.7g. Yadav *et al* (2007) used K @150 kg ha⁻¹ to observe maximum bulb weight of 23.7g.

4.1.11 Marketable yield

The marketable yield is differentiated from total yield by the quality of bulbs. The radial and polar dimeters, bulb weights, number of cloves per bulb, bulb appearance, etc. form the basis for separating marketable yield from total yield. The higher proportion of marketable yield from the total yield will lead to more profit as it could be sold at higher price for better grade. The data representing the marketable yield as influenced by potassium and sulphur is shown in Table 4.11 and Fig. 4.3.

Pooled data of both seasons showed maximum marketable yield using 60 kg ha⁻¹ K (11.76 t ha⁻¹) being higher significantly. Using 30 kg S gave greatest mean marketable yield (11.21 t ha⁻¹) among sulphur treatments which was significantly higher from all other treatments.

During year 2020-21, highest marketable yield was obtained by using 60 kg ha⁻¹ K (11.91 t ha⁻¹) followed by 40 kg ha⁻¹ (11.43 t ha⁻¹) being significantly higher than other treatments. Use of S 30 kg ha⁻¹ (11.38 t ha⁻¹) gave highest marketable yield followed by S 20 kg ha⁻¹ (11.18 t ha⁻¹) being at par statistically but different significantly than rest.

Table 4.11: Influence of various levels of potassium and sulphur applications on marketable yield (t ha⁻¹)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	9.78	9.50	9.61
K₂₀	K @20 kg ha ⁻¹	10.64	10.39	10.50
K₄₀	K @40 kg ha ⁻¹	11.43	10.82	11.10
K₆₀	K @60 kg ha ⁻¹	11.91	11.56	11.76
LSD (<i>p</i><0.05) K		0.4	0.3	0.2
S₀	S @0 kg ha ⁻¹	10.3	10.11	10.22
S₁₀	S @10 kg ha ⁻¹	10.77	10.33	10.55
S₂₀	S @20 kg ha ⁻¹	11.18	10.81	10.99
S₃₀	S @30 kg ha ⁻¹	11.38	11.03	11.21
LSD (<i>p</i><0.05) S		0.3	0.2	0.2
LSD (<i>p</i><0.05) K×S		NS	NS	NS

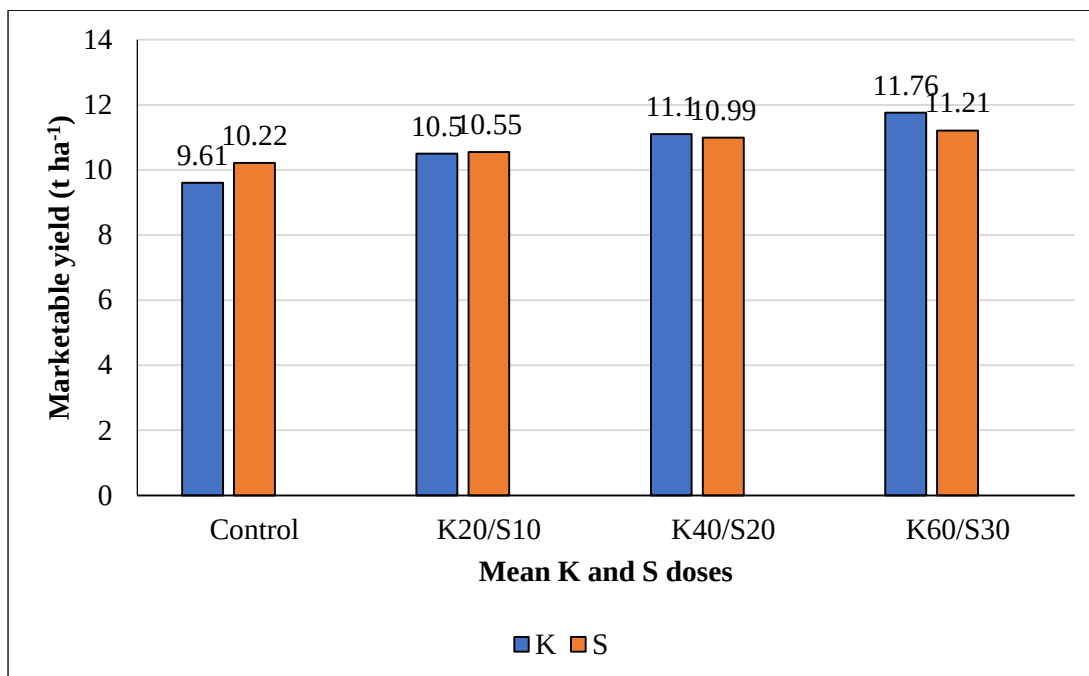


Fig. 4.3: Influence of various levels of potassium and sulphur applications on marketable yield (t ha⁻¹)

In year 2021-22, 60 kg ha⁻¹ K (11.56 t ha⁻¹) followed by 40 kg ha⁻¹ (10.82 t ha⁻¹) gave greatest marketable yield being significantly different than all treatments. Using S @30 kg ha⁻¹ (11.03 t ha⁻¹) gave highest marketable yield followed by S 20 kg ha⁻¹ (10.81 t ha⁻¹) among the sulphur treatments being at par statistically but different significantly than rest.

Results found were in conformity with Bableswhar *et al* (2017) who attained highest marketable yield of 5.19 t ha⁻¹ using 60 kg S ha⁻¹. In another experiment, Malik *et al* (2021) got highest marketable bulb yield of 14.70 ton ha⁻¹ using 45 kg S ha⁻¹. Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get highest marketable yield of 452.51 q/ha. Magray *et al* (2017) applied 100 kg K and 45 kg S ha⁻¹ to get highest marketable yield of 22.1 ton ha⁻¹.

4.1.12 Total yield

The total yield of the crop is influenced by many parameters, but is the most important parameter for attaining profit. The total yield is the overall number of bulbs harvested from the field irrespective of its quality and represents the material in bulk without marketable grades. The higher the total yield will be, higher will be the income of the cultivator. The data relating to total yield as affected by potassium and sulphur is shown in Table 4.12 and Fig. 4.4.

Pooled data of both seasons showed maximum total yield using 60 kg ha⁻¹ K (14.17 t ha⁻¹) being higher significantly from all other treatments. The use of 30 kg ha⁻¹ S led to maximum mean total yield (13.88 t ha⁻¹) among sulphur treatments which was significantly different from all other treatments.

Table 4.12: Influence of various levels of potassium and sulphur applications on total yield (t ha⁻¹)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	12.24	12.36	12.30
K₂₀	K @20 kg ha ⁻¹	13.07	13.12	13.09
K₄₀	K @40 kg ha ⁻¹	13.73	13.74	13.73
K₆₀	K @60 kg ha ⁻¹	14.11	14.24	14.17
LSD (<i>p</i><0.05) K		0.4	0.3	0.3
S₀	S @0 kg ha ⁻¹	12.84	12.81	12.82
S₁₀	S @10 kg ha ⁻¹	13.10	13.12	13.11
S₂₀	S @20 kg ha ⁻¹	13.42	13.55	13.49
S₃₀	S @30 kg ha ⁻¹	13.79	13.97	13.88
LSD (<i>p</i><0.05) S		0.4	0.3	0.3
LSD (<i>p</i><0.05) K×S		NS	NS	NS

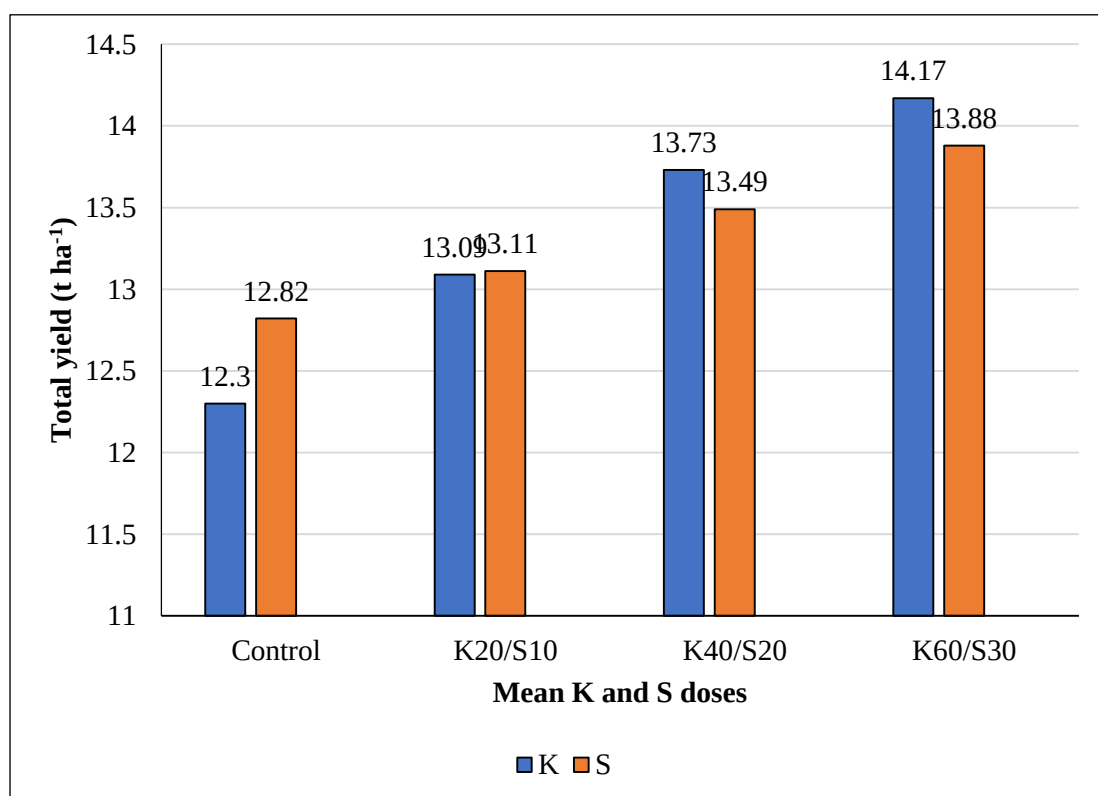


Fig. 4.4: Influence of various levels of potassium and sulphur applications on total yield (t ha⁻¹)

During year 2020-21, highest total yield was obtained by using 60 kg ha⁻¹ K (14.11 t ha⁻¹) followed by 40 kg ha⁻¹ (13.73 t ha⁻¹) being at par statistically with each other but higher significantly compared to other treatments. Use of S@30 kg ha⁻¹ (13.79 t ha⁻¹) gave highest total yield followed by S@20 kg ha⁻¹ (13.42 t ha⁻¹) being at par statistically among each other but significantly different from other treatments.

During year 2021-22, 60 kg ha⁻¹ K (14.24 t ha⁻¹) followed by 40 kg ha⁻¹ (13.74 t ha⁻¹) gave the maximum total yield being significantly different compared to other treatments. Using S@30 kg ha⁻¹ (13.88 t ha⁻¹) maximum total yield followed by S@20 kg ha⁻¹ (13.49 t ha⁻¹) among the sulphur treatments being significantly higher than other treatments.

The results found were in accordance with Bableshwar *et al* (2017) who got highest total yield (5.79 t ha⁻¹) using 60 kg S ha⁻¹. While experimenting Divyasree *et al* (2021), concluded use of magnesium sulphate @ 60 kg ha⁻¹ gave highest total yield (16.78 t ha⁻¹). El-Sayed *et al* (2018) observed highest total yield of 7.72 ton fed⁻¹ using 450 kg S fed⁻¹. In another experiment, Zaman *et al* (2011) observed highest total yield of 7.22 ton ha⁻¹ by using 45 kg S ha⁻¹.

Zyada and Bardisi (2018) used 150 kg K fed⁻¹ to get maximum total yield of 8.01 ton fed⁻¹. In another experiment, Arisha *et al* (2017) used 125 kg K₂O to get maximum total yield of 10.38 ton fed⁻¹. Barakat *et al* (2019) used 96 kg K₂O fed⁻¹ to get highest total yield of 7.63 tons fed⁻¹. Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get maximum total yield of 483.03 q ha⁻¹. In a research conducted by Farooqui *et al* (2009) 16.54 ton ha⁻¹ of total yield was observed using 60 kg ha⁻¹ K. Hore *et al* (2014) observed greatest total yield of 6.51 tons ha⁻¹ using 60 kg ha⁻¹ S. Magray *et al* (2017) used 100 kg K and 45 kg S ha⁻¹ to get maximum total yield of 24.03 ton ha⁻¹. Patidar *et al* (2017) used 75 kg S ha⁻¹ to get a maximum total yield of 8.94 ton ha⁻¹. Yadav *et al* (2007) used K @150 kg ha⁻¹ to observe maximum total yield of 6.1 ton ha⁻¹.

4.2 Quality parameters

4.2.1 Allicin

Garlic contains a colorless, odorless, and water-soluble amino acid called 'allin' (Magray *et al* 2017). When garlic tissue is injured or damaged, this amino acid is converted into "allicin" by the enzyme alliinase. The allicin generated is unstable and quickly degenerates into sulphur (S) containing compounds such as diallyl and triallyl sulphides (Lanzotti *et al* 2014). Use of allicin is important for production of garlic powder, pastes and spices. The higher the allicin content the better the quality of garlic for industrial point of view. The data pertaining to the allicin content as influenced by potassium and sulphur is shown in Table 4.13 and Fig. 4.5.

Table 4.13: Influence of various levels of potassium and sulphur applications on allicin content (mg g^{-1})

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha^{-1}	11.47	11.40	11.43
K₂₀	K @20 kg ha^{-1}	11.79	12.46	12.12
K₄₀	K @40 kg ha^{-1}	11.65	12.80	12.22
K₆₀	K @60 kg ha^{-1}	11.80	12.58	12.19
LSD ($p<0.05$) K		0.3	0.5	0.3
S₀	S @0 kg ha^{-1}	11.31	10.63	10.97
S₁₀	S @10 kg ha^{-1}	11.41	12.43	11.92
S₂₀	S @20 kg ha^{-1}	11.88	13.00	12.44
S₃₀	S @30 kg ha^{-1}	12.10	13.19	12.64
LSD ($p<0.05$) S		0.2	0.4	0.2
LSD ($p<0.05$) K×S		NS	NS	NS

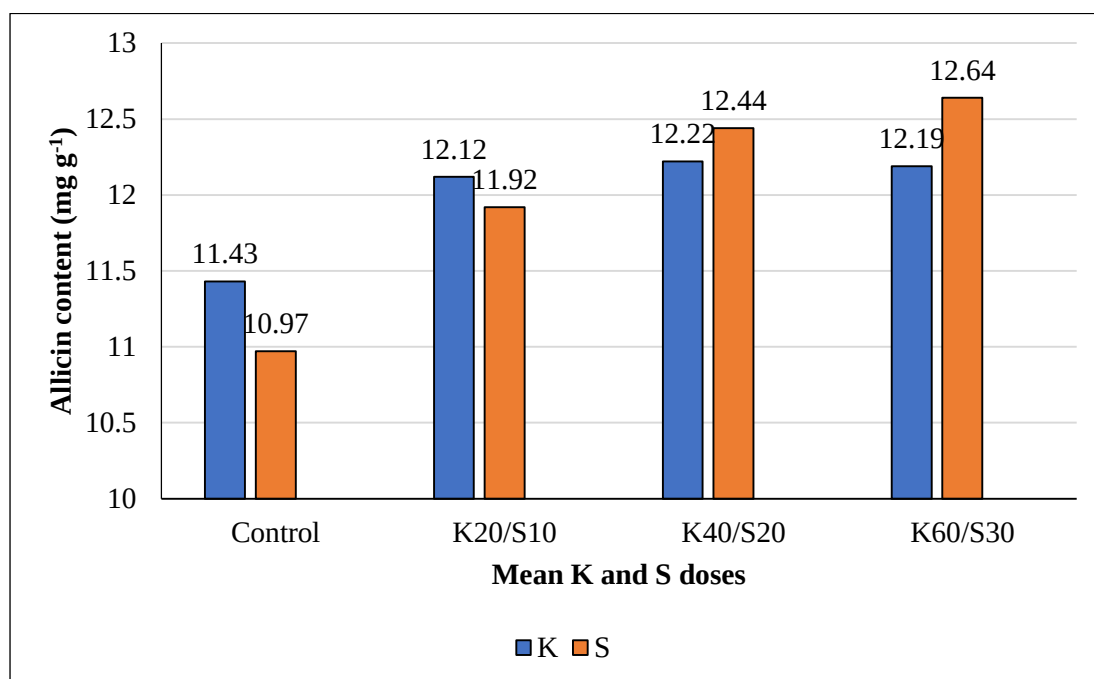


Fig. 4.5: Influence of various levels of potassium and sulphur applications on allicin content (mg g^{-1})

Pooled data of both seasons showed maximum allicin content with 30 kg ha^{-1} S (12.64 mg g^{-1}) followed by 20 kg ha^{-1} S (12.44 mg g^{-1}) being at par statistically but higher significantly than rest. The use of 60 kg ha^{-1} K gave highest mean allicin (11.80 mg g^{-1})

among potassium treatments followed by 20 kg ha⁻¹ K (11.79 mg g⁻¹) and 40 kg ha⁻¹ K (11.65 mg g⁻¹) being at par statistically but higher significantly than control.

During year 2020-21, highest allicin content with 30 kg ha⁻¹ S (12.10 mg g⁻¹) followed by 20 kg ha⁻¹ S (11.88 mg g⁻¹) being at par statistically with each other but higher significantly than rest. Use of 40 kg ha⁻¹ K gave greatest mean allicin content (12.22 mg g⁻¹) among potassium treatments followed by 60 kg ha⁻¹ K (12.19 mg g⁻¹) and 20 kg ha⁻¹ K (12.12 mg g⁻¹) being at par statistically but higher significantly than control.

During year 2021-22, allicin content with 30 kg ha⁻¹ S (13.19 mg g⁻¹) followed by 20 kg ha⁻¹ S (13.0 mg g⁻¹) being at par statistically but higher significantly than rest. The use of 40 kg ha⁻¹ K gave highest mean allicin content (12.80 mg g⁻¹) among potassium treatments followed by 60 kg ha⁻¹ K (12.58 mg g⁻¹) and 20 kg ha⁻¹ K (12.46 mg g⁻¹) being at par statistically with each other but higher significantly than control.

Results found were in conformity with Bloem *et al* (2010) who used 45 kg ha⁻¹ S to get maximum of 15.7 mg per g allicin.

4.2.2 TSS

The total soluble solids of garlic bulb are an important parameter from an industrial point of view. The bulbs containing higher TSS will be better suitable for processing of garlic bulbs to form pastes, powders, and spices. The data pertaining to the TSS influenced by various doses of potassium and sulphur is shown in Table 4.14.

Table 4.14: Influence of various levels of potassium and sulphur applications on TSS (%)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	39.7	39.9	39.8
K₂₀	K @20 kg ha ⁻¹	40.3	40.3	40.3
K₄₀	K @40 kg ha ⁻¹	40.5	40.7	40.6
K₆₀	K @60 kg ha ⁻¹	41.2	41.5	41.3
LSD (<i>p</i><0.05) K		0.5	0.8	0.5
S₀	S @0 kg ha ⁻¹	39.3	39.6	39.4
S₁₀	S @10 kg ha ⁻¹	40.4	40.2	40.3
S₂₀	S @20 kg ha ⁻¹	40.5	41.0	40.7
S₃₀	S @30 kg ha ⁻¹	41.4	41.5	41.5
LSD (<i>p</i><0.05) S		0.4	0.7	0.4
LSD (<i>p</i><0.05) K×S		NS	NS	NS

Pooled data of both seasons showed maximum TSS using 30 kg ha⁻¹ S (41.5%) which was higher significantly than rest. Using 60 kg ha⁻¹ K showed greatest mean TSS (41.3%) among Potassium treatments which was significantly different from all other treatments.

During year 2020-21, highest TSS was obtained by using 30 kg S ha⁻¹ (41.4%) followed by 20 kg ha⁻¹ (40.5%) being significantly higher than all treatments. Use of K 60 kg ha⁻¹ (41.2%) gave highest TSS followed by K 40 kg ha⁻¹ (40.5%) being significantly different from all treatments.

During year 2021-22, 60 kg K ha⁻¹ (41.5%) followed by 40 kg ha⁻¹ (40.7%) gave the highest TSS being significantly different from all treatments. The use of S 30 kg ha⁻¹ (41.5%) gave highest TSS followed by S 20 kg ha⁻¹ (41.0%) among the sulphur treatments being at par statistically among each other but higher significantly in comparison to other treatments.

Results found were in conformity with Divyasree *et al* (2021) who used K₂SO₄ @ 60 kg ha⁻¹ to get highest TSS of 43.16°Brix. In an experiment conducted by El-Sayed *et al* (2018) maximum TSS of 39.83°Brix was observed by using 450 kg S fed⁻¹. Malik *et al* (2021) got highest TSS of 40.81°Brix by using 45 kg S ha⁻¹. While experimenting Zyada and Bardisi (2018), using 150 kg K fed⁻¹ got the highest TSS of 37.77°Brix. Arisha *et al* (2017) used 125 kg K₂O fed⁻¹ to get maximum TSS of 32.00°Brix. Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get maximum TSS of 11.54°Brix. In another experiment, Diriba-Sheferaw *et al* (2014) observed maximum (21.73°Brix) TSS by using 60 kg ha⁻¹ S. Singh *et al* (2018) observed a maximum TSS of 30.51°Brix using S @60kg ha⁻¹. Patidar *et al* (2017) used 75 kg S ha⁻¹ to get maximum TSS of 36.3°Brix.

4.2.3 Ascorbic acid

Ascorbic acid (Vitamin C) is an important quality aspect of garlic. Ascorbic acid helps to build up immunity in humans and is considered as an important supplement. The higher amounts of ascorbic acid in garlic will lead to better immunity and health of the consumers. The data pertaining to the ascorbic acid affected by potassium and sulphur is shown in Table 4.15.

Pool of both seasons showed maximum ascorbic acid using 30 kg ha⁻¹ S (21.8 mg per 100g dry weight) which was higher significantly than rest. Use of 60 kg ha⁻¹ K showed greatest mean ascorbic acid (21.6 mg per 100g dry weight) among potassium treatments which was significantly different from all other treatments.

During year 2020-21, highest ascorbic acid was obtained by using 30 kg ha⁻¹ S (21.9 mg per 100g dry weight) followed by 20 kg ha⁻¹ (20.7 mg per 100g dry weight) being significantly higher than all treatments. Use of K @60 kg ha⁻¹ (21.5 mg per 100g dry weight) gave highest ascorbic acid followed by K 40 kg ha⁻¹ (20.3 mg per 100g dry weight) being significantly different from all treatments.

Table 4.15: Influence of various levels of potassium and sulphur applications on Ascorbic acid (mg per 100g dry weight)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	19.8	19.9	19.8
K₂₀	K @20 kg ha ⁻¹	19.5	19.2	19.3
K₄₀	K @40 kg ha ⁻¹	20.3	20.4	20.3
K₆₀	K @60 kg ha ⁻¹	21.5	21.7	21.6
LSD (<i>p</i><0.05) K		0.8	0.8	0.6
S₀	S @0 kg ha ⁻¹	18.6	18.4	18.5
S₁₀	S @10 kg ha ⁻¹	20.0	20.4	20.2
S₂₀	S @20 kg ha ⁻¹	20.7	20.7	20.7
S₃₀	S @30 kg ha ⁻¹	21.9	21.7	21.8
LSD (<i>p</i><0.05) S		0.7	0.8	0.5
LSD (<i>p</i><0.05) K×S		NS	NS	NS

During year 2021-22, 60 kg ha⁻¹ K (21.7 mg per 100g dry weight) followed by 40 kg ha⁻¹ (20.4 mg per 100g dry weight) gave the highest ascorbic acid being significantly different from all treatments. The use of S 30 kg ha⁻¹ (21.7 mg per 100g dry weight) gave highest ascorbic acid followed by S 20 kg ha⁻¹ (20.7 mg per 100g dry weight) among the sulphur treatments being at par statistically among each other but higher significantly compared to other treatments.

Results found were in conformity with Divyasree *et al* (2021) who used potassium sulphate @ 60 kg ha⁻¹ to get maximum ascorbic acid (20.81 mg per 100g dry weight). In another experiment, Arisha *et al* (2017) used 125 kg K₂O fed⁻¹ to get maximum ascorbic acid (25 mg per 100g dry weight).

4.2.4 Total minerals

The total mineral present in a crop gives us an idea about the concentration of various nutrients in the crop. Crop with higher total minerals would be healthier and more vigorous and also give better yields. The data pertaining to the total minerals affected by potassium and sulphur is shown in Table 4.16.

Pool of both seasons showed maximum total minerals using 30 kg ha⁻¹ S (53.5 mg per 100g dry weight) which was higher significantly than rest. Using 60 kg ha⁻¹ K showed greatest mean total minerals (53.1 mg per 100g dry weight) among potassium treatments which was significantly different from all other treatments.

Table 4.16: Influence of various levels of potassium and sulphur applications on total minerals (mg per 100g dry weight)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	51.2	50.9	51.1
K₂₀	K @20 kg ha ⁻¹	51.4	51.9	51.6
K₄₀	K @40 kg ha ⁻¹	52.2	52.4	52.3
K₆₀	K @60 kg ha ⁻¹	53.1	53.2	53.1
LSD (<i>p</i><0.05) K		1.1	1.2	0.8
S₀	S @0 kg ha ⁻¹	50.4	50.1	50.2
S₁₀	S @10 kg ha ⁻¹	51.8	52.2	52.0
S₂₀	S @20 kg ha ⁻¹	52.3	52.5	52.4
S₃₀	S @30 kg ha ⁻¹	53.4	53.6	53.5
LSD (<i>p</i><0.05) S		1.0	1.1	0.7
LSD (<i>p</i><0.05) K×S		NS	NS	NS

During year 2020-21, highest total minerals was obtained by using 30 kg ha⁻¹ S (53.4 mg per 100g dry weight) followed by 20 kg ha⁻¹ (52.3 mg per 100g dry weight) being significantly higher than all treatments. Use of K 60 kg ha⁻¹ (53.1 mg per 100g dry weight) gave highest total minerals followed by K 40 kg ha⁻¹ (52.2 mg per 100g dry weight) being at par statistically with each other but different significantly in comparison to other treatments.

In season 2021-22, S 30 kg ha⁻¹ (53.6 mg per 100g dry weight) gave highest total minerals followed by S 20 kg ha⁻¹ (52.5 mg per 100g dry weight) among the sulphur treatments being at par statistically with each other but different significantly in comparison to other treatments. The use of 60 kg K ha⁻¹ (53.2 mg per 100g dry weight) followed by 40 kg ha⁻¹ (52.4 mg per 100g dry weight) gave the highest total minerals among potassium treatments being at par statistically with each other but different significantly in comparison to other treatments.

4.2.5 Dry matter

It is one of the most important quality aspects of the garlic crop. Crop with higher dry matter would be better suited to industrial processing. Dry matter content is directly related to weight of crop and also increases the post-harvest life of the crop. The data regarding dry matter influenced by various doses of potassium and sulphur is shown in Table 4.17 and Fig. 4.6.

Table 4.17: Influence of various levels of potassium and sulphur applications on dry matter content (%)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	39.7	39.3	39.5
K₂₀	K @20 kg ha ⁻¹	40.4	40.9	40.7
K₄₀	K @40 kg ha ⁻¹	41.6	42.4	42.0
K₆₀	K @60 kg ha ⁻¹	42.5	42.3	42.4
LSD (<i>p</i><0.05) K		1.6	1.1	1.0
S₀	S @0 kg ha ⁻¹	38.9	39.5	39.2
S₁₀	S @10 kg ha ⁻¹	40.4	41.1	40.7
S₂₀	S @20 kg ha ⁻¹	41.3	42.0	41.6
S₃₀	S @30 kg ha ⁻¹	43.5	42.4	42.9
LSD (<i>p</i><0.05) S		1.5	1.0	0.9
LSD (<i>p</i><0.05) K×S		NS	NS	NS

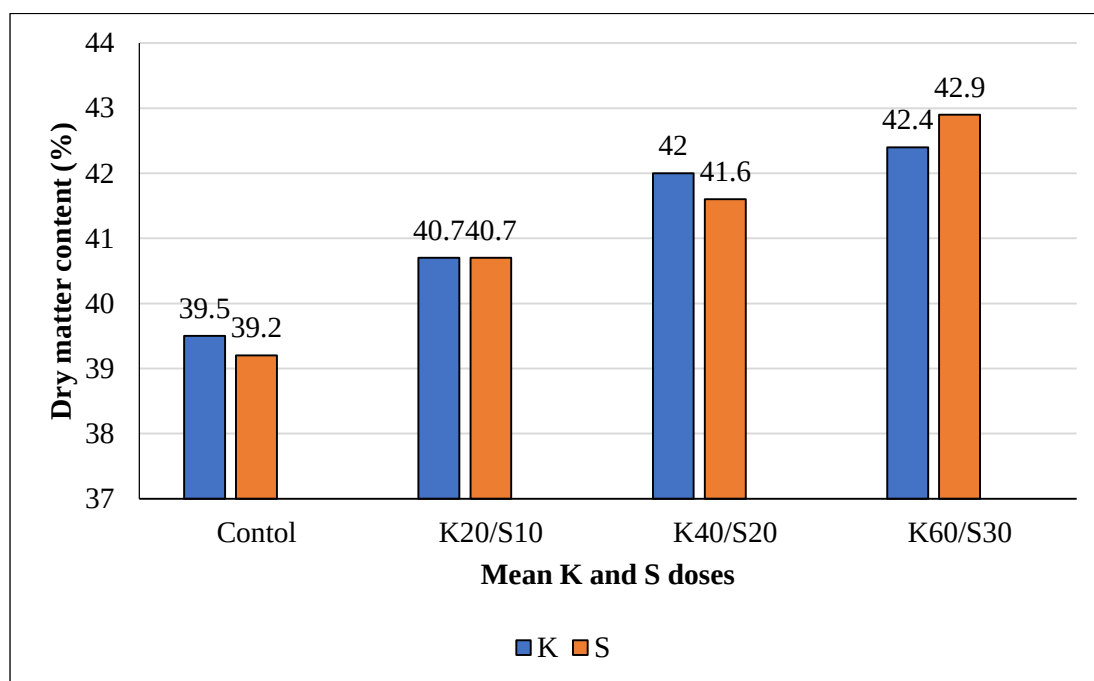


Fig. 4.6: Influence of various levels of potassium and sulphur applications on dry matter content (%)

Pool of both seasons showed maximum dry matter content using 30 kg ha⁻¹ S (42.9%) which was higher significantly than rest. Using 60 kg ha⁻¹ S gave highest mean dry matter

content (42.4%) followed by 40 kg ha⁻¹ K (42.0%) being at par statistically among each other but different significantly compared to other treatments.

In season 2020-21, highest dry matter content was obtained by using 30 kg ha⁻¹ S (43.5%) followed by 20 kg ha⁻¹ S (41.3%) being significantly higher than all treatments. Use of K 60 kg ha⁻¹ (42.5%) gave highest dry matter content followed by K 40 kg ha⁻¹ (41.6%) being at par statistically among each other but different significantly compared to other treatments.

In season 2021-22, S 30 kg ha⁻¹ (42.4%) gave highest dry matter content followed by S 20 kg ha⁻¹ (42.0%) among the sulphur treatments being at par statistically among each other but different significantly compared to other treatments. Use of 40 kg ha⁻¹ K (42.4%) followed by 60 kg K ha⁻¹ (42.3%) gave the highest dry matter content among potassium treatments being at par statistically among each other but different significantly compared to other treatments.

The results found were in conformity with Bloem *et al* (2010) who got maximum dry matter of 31.1 % by using 45 kg ha⁻¹ S. In another experiment, Diriba-Sheferaw *et al* (2014) observed highest (39.76%) dry matter by using 60 kg ha⁻¹ S.

4.2.6 Total protein

The protein content of garlic is dependent upon K and S. The crop with higher protein content will have higher allicin and dry matter will be increased. The data pertaining to the total protein influenced by potassium and sulphur is shown in Table 4.18.

Table 4.18: Influence of various levels of potassium and sulphur applications on total protein (mg g⁻¹)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	93.2	94.3	93.7
K₂₀	K @20 kg ha ⁻¹	100.7	103.5	102.1
K₄₀	K @40 kg ha ⁻¹	106.6	104.6	105.6
K₆₀	K @60 kg ha ⁻¹	122.6	119.1	120.8
LSD (<i>p</i><0.05) K		5.1	6.2	3.9
S₀	S @0 kg ha ⁻¹	95.9	95.3	95.6
S₁₀	S @10 kg ha ⁻¹	107.9	105.9	106.9
S₂₀	S @20 kg ha ⁻¹	108.2	107.4	107.7
S₃₀	S @30 kg ha ⁻¹	111.3	113.0	112.1
LSD (<i>p</i><0.05) S		5.2	6.3	3.8
LSD (<i>p</i><0.05) K×S		NS	NS	7.81

Pooled data of both seasons showed maximum total protein with 60 kg ha⁻¹ K (120.8 mg g⁻¹) being higher significantly than rest. Use of 30 kg ha⁻¹ S gave the highest mean total protein (112.1 mg g⁻¹) among sulphur treatments which was significantly higher from all other treatments.

During year 2020-21, highest total protein was obtained by using 60 kg ha⁻¹ K (122.6 mg g⁻¹) followed by 40 kg ha⁻¹ (106.6 mg g⁻¹) being significantly higher than other treatments. Use of S 30 kg ha⁻¹ (111.3 mg g⁻¹) gave highest total protein followed by S 20 kg ha⁻¹ (108.2 mg g⁻¹) and S 10 kg ha⁻¹ (107.9 mg g⁻¹) being at par statistically among each other but higher significantly when compared to control.

During year 2021-22, 60 kg ha⁻¹ K (119.1 mg g⁻¹) followed by 40 kg ha⁻¹ (104.6 mg g⁻¹) gave the highest total protein being significantly different from other treatments. The use of S 30 kg ha⁻¹ (113.0 mg g⁻¹) gave highest total protein followed by S 20 kg ha⁻¹ (107.4 mg g⁻¹) among the sulphur treatments being at par statistically among each other but higher significantly when compared to other treatments.

Results found were in conformity with Diriba-Sheferaw *et al* (2014) who got maximum protein (12.17%) using 60 kg ha⁻¹ S.

4.2.7 Phenols

The phenol content of plant is directly related to its tolerance against various diseases and pests and hence plays a vital role in plant health and is also important to get a good crop. The data pertaining to the phenols influenced by various doses of potassium and sulphur is shown in Table 4.19.

Pooled data of both seasons showed maximum phenols content using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (0.54 mg g⁻¹) followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (0.51 mg g⁻¹) being at par among each other and significantly different than rest.

During year 2020-21, maximum phenols content was observed using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (0.53 mg g⁻¹) followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (0.51 mg g⁻¹) and 60 kg ha⁻¹ K and 10 kg ha⁻¹ S (0.45 mg g⁻¹) being at par among each other and significantly different than rest.

In year 2021-22, maximum phenols content was observed using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (0.54 mg g⁻¹) followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (0.51 mg g⁻¹) being at par among each other and significantly different than rest.

Results found were in conformity with Divyasree *et al* (2021) who used potassium sulphate @ 60 kg ha⁻¹ to get maximum phenols (0.49 mg g⁻¹).

Table 4.19: Influence of various levels of potassium and sulphur applications on phenols in (mg g⁻¹)

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K ₀	0.36	0.39	0.45	0.45	0.41
K ₂₀	0.33	0.36	0.42	0.45	0.39
K ₄₀	0.42	0.42	0.48	0.37	0.42
K ₆₀	0.45	0.45	0.51	0.53	0.48
Mean	0.39	0.41	0.47	0.45	
LSD (<i>p</i> <0.05)	0.06 (K)	0.08 (S)	0.10 (K×S)		
2021-22					
K ₀	0.37	0.39	0.42	0.47	0.41
K ₂₀	0.33	0.39	0.43	0.45	0.40
K ₄₀	0.41	0.41	0.45	0.39	0.41
K ₆₀	0.42	0.43	0.51	0.54	0.47
Mean	0.38	0.41	0.45	0.46	
LSD (<i>p</i> <0.05)	0.09 (K)	0.07 (S)	0.11 (K×S)		
Pooled data					
K ₀	0.37	0.40	0.44	0.46	0.41
K ₂₀	0.34	0.38	0.43	0.46	0.39
K ₄₀	0.42	0.42	0.47	0.38	0.42
K ₆₀	0.44	0.44	0.51	0.54	0.48
Mean	0.39	0.40	0.46	0.46	
LSD (<i>p</i> <0.05)	0.08 (K)	0.05 (S)	0.09 (K×S)		

4.2.8 Total sugars

The total sugars content in garlic is an important quality parameter that has industrial importance. The data pertaining to the total sugars influenced by various doses of potassium and sulphur is shown in Table 4.20.

Pooled data of both seasons showed maximum phenols content using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (182.2 mg g⁻¹) followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (175.5 mg g⁻¹) and 60 kg ha⁻¹ K and 10 kg ha⁻¹ S (174.8 mg g⁻¹) being at par among each other and significantly different than rest.

Table 4.20: Influence of various levels of potassium and sulphur applications on total sugars (mg g⁻¹)

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K₀	73.0	154.3	147.0	137.6	128.0
K₂₀	93.3	107.6	129.3	110.0	110.0
K₄₀	105.6	122.6	143.0	154.3	131.4
K₆₀	160.3	173.3	177.3	180.6	172.9
Mean	108.1	139.5	149.1	145.6	
LSD (<i>p</i><0.05)	7.6 (K)	7.7 (S)	15.4 (K×S)		
2021-22					
K₀	77.3	157.3	150.0	142.3	131.7
K₂₀	96.6	105.0	126.0	112.0	109.9
K₄₀	106.6	128.0	146.3	151.6	133.1
K₆₀	158.0	176.3	173.6	183.6	172.9
Mean	109.6	141.6	149.0	147.4	
LSD (<i>p</i><0.05)	7.3 (K)	7.4 (S)	14.8 (K×S)		
Pooled data					
K₀	75.2	155.8	148.5	140.0	129.8
K₂₀	95.0	106.3	127.7	111.0	110.0
K₄₀	106.2	125.3	144.7	153.0	132.2
K₆₀	159.2	174.8	175.5	182.2	172.9
Mean	108.8	140.5	149.1	146.5	
LSD (<i>p</i><0.05)	5.2 (K)	5.1 (S)	10.3 (K×S)		

During year 2020-21, maximum phenols content was observed using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (180.6 mg g⁻¹) followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (177.3 mg g⁻¹) and 60 kg ha⁻¹ K and 10 kg ha⁻¹ S (173.3 mg g⁻¹) being at par among each other and significantly different than rest.

In year 2021-22, maximum phenols content was observed using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (183.6 mg g⁻¹) followed by 60 kg ha⁻¹ K and 10 kg ha⁻¹ S (176.3 mg g⁻¹) and 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (173.6 mg g⁻¹) being at par among each other and significantly different than rest.

4.2.9 Reducing sugars

The total sugars content in garlic is an important quality parameter that has industrial importance. The data pertaining to the reducing sugars influenced by various doses of potassium and sulphur is shown in Table 4.21.

Table 4.21: Influence of various levels of potassium and sulphur applications on reducing sugars (mg g^{-1})

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	2.44	2.43	2.43
K₂₀	K @20 kg ha ⁻¹	2.43	2.46	2.45
K₄₀	K @40 kg ha ⁻¹	2.49	2.51	2.50
K₆₀	K @60 kg ha ⁻¹	2.56	2.57	2.57
LSD ($p<0.05$) K		NS	NS	NS
S₀	S @0 kg ha ⁻¹	2.46	2.30	2.38
S₁₀	S @10 kg ha ⁻¹	2.48	2.47	2.47
S₂₀	S @20 kg ha ⁻¹	2.43	2.55	2.49
S₃₀	S @30 kg ha ⁻¹	2.55	2.65	2.60
LSD ($p<0.05$) S		NS	0.23	NS
LSD ($p<0.05$) K×S		NS	NS	NS

Pool of both seasons failed to show any significant difference in reducing sugars with use of potassium and sulphur treatments.

During year 2020-21, the use of potassium and sulphur treatments didn't lead to any significant difference in reducing sugars.

During year 2021-22, potassium treatments failed to show any significant result in reducing sugars, whereas, the sulphur treatments showed significant difference in reducing sugars. S @30 kg ha⁻¹ gave highest reducing sugars followed by S 20kg ha⁻¹ and S 10kg ha⁻¹. They were observed to at par statistically among each other but higher significantly than control.

4.3 Nutrient Uptake

4.3.1 Nitrogen uptake

Uptake of a nutrient by crop is calculated to check the requirement of that nutrient by the crop. The N uptake will depict the need of N as a nutrient and can be correlated with the quality, growth and yield of crop at the same treatment. It will give us information about the

amount of nutrient absorbed to give a particular response. The data regarding N uptake as influenced by various doses of potassium and sulphur is shown in Table 4.22 and Fig. 4.7.

Table 4.22: Influence of different levels of potassium and sulphur applications on nitrogen uptake (kg ha^{-1})

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K ₀	34.8	42.9	53.5	60.8	48.0
K ₂₀	43.9	52.7	60.1	63.6	55.1
K ₄₀	55.9	71.1	77.6	84.1	72.2
K ₆₀	60.2	82.5	87.7	96.2	81.6
Mean	48.7	62.3	69.7	76.2	
LSD ($p<0.05$)	2.8 (K)	NS (S)	5.7 (K×S)		
2021-22					
K ₀	35.3	41.6	54.0	59.1	47.5
K ₂₀	43.7	52.5	59.2	63.0	54.6
K ₄₀	55.1	71.6	81.5	84.9	73.2
K ₆₀	59.4	82.9	85.5	94.4	80.5
Mean	48.4	62.1	70.1	75.3	
LSD ($p<0.05$)	3.0 (K)	NS (S)	6.1 (K×S)		
Pooled data					
K ₀	35.1	42.3	53.8	60.0	47.7
K ₂₀	43.8	52.7	59.7	63.4	54.8
K ₄₀	55.5	71.4	79.6	84.5	72.7
K ₆₀	59.9	82.7	86.7	95.3	81.1
Mean	48.6	62.3	69.9	75.8	
LSD ($p<0.05$)	2.0 (K)	NS (S)	4.1 (K×S)		

Pooled data of both seasons showed maximum nitrogen uptake using 60 kg ha^{-1} K and 30 kg ha^{-1} S (95.3 kg ha^{-1}) which was higher significantly than rest followed by 60 kg ha^{-1} K and 20 kg ha^{-1} S (86.7 kg ha^{-1}) being second best treatment.

During year 2020-21, maximum nitrogen uptake was obtained by using 60 kg ha^{-1} K and 30 kg ha^{-1} S (96.2 kg ha^{-1}) which was higher significantly than rest followed by 60 kg ha^{-1} K and 20 kg ha^{-1} S (87.7 kg ha^{-1}) being second best treatment.

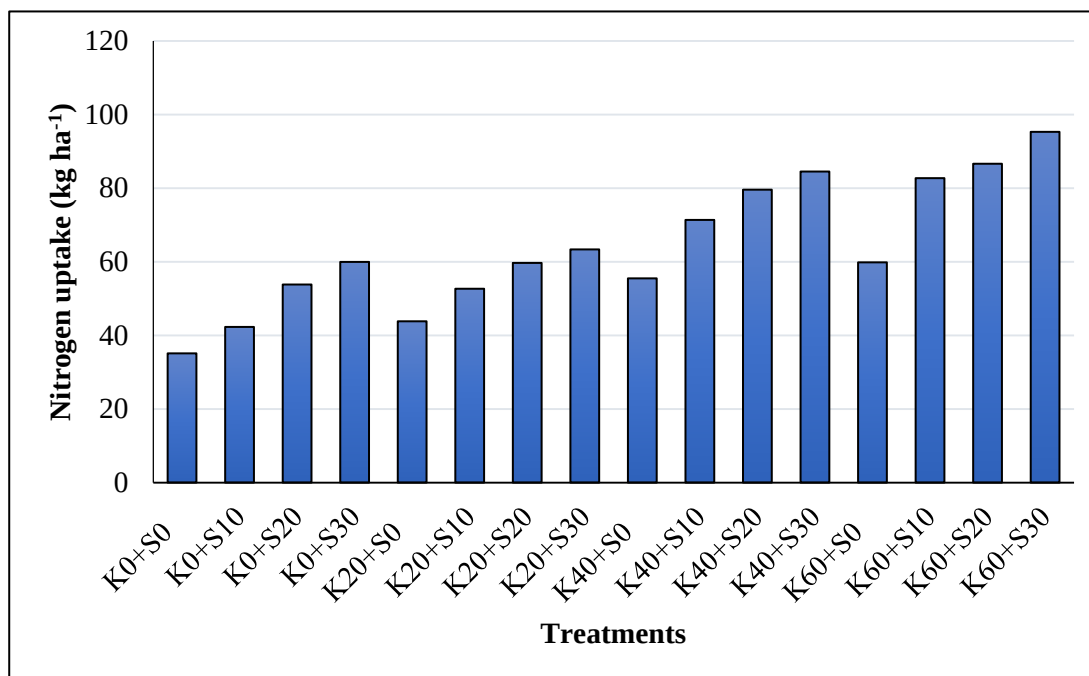


Fig. 4.7: Influence of different levels of potassium and sulphur applications on nitrogen uptake (kg ha⁻¹)

In year 2021-22, maximum nitrogen uptake was obtained by using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (94.4 kg ha⁻¹) which was higher significantly than rest followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (85.5 kg ha⁻¹) being second best treatment.

The results found were in conformity with Malik *et al* (2021) who got maximum N uptake of 153.21 kg ha⁻¹ by using 45 kg S ha⁻¹. In another experiment, Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get maximum N uptake of 94.44 kg ha⁻¹. Magray *et al* (2017) applied 100 kg K and 45 kg S ha⁻¹ to observe highest N uptake of 105.29 kg ha⁻¹.

4.3.2 Phosphorus uptake

The uptake of a nutrient by crop is calculated to check the requirement of that nutrient by the crop. The P uptake will depict the need of P as a nutrient and can be correlated with the quality, growth and yield of crop at the same treatment. It will give us information about the amount of nutrient absorbed to get a particular response. Results showing P uptake as influenced by various doses of potassium and sulphur is shown in Table 4.23 and Fig. 4.8.

Pooled data of both seasons showed maximum phosphorus uptake using 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (34.3 kg ha⁻¹) followed by 60 kg ha⁻¹ K + 30 kg ha⁻¹ S (32.9 kg ha⁻¹) being at par statistically but higher significantly than rest.

During year 2020-21, maximum phosphorus uptake was obtained by using 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (33.9 kg ha⁻¹) followed by 60 kg ha⁻¹ K + 30 kg ha⁻¹ S (32.6 kg ha⁻¹) being at par statistically but higher significantly than rest.

Table 4.23: Influence of various levels of potassium and sulphur applications on phosphorus uptake (kg ha⁻¹)

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K ₀	17.5	24.0	24.4	23.8	22.4
K ₂₀	18.0	21.3	27.1	24.2	22.6
K ₄₀	23.8	25.0	33.5	33.5	29.0
K ₆₀	26.5	30.8	33.9	32.6	30.9
Mean	21.4	25.3	29.7	28.5	
LSD (<i>p</i> <0.05)	1.6 (K)	NS (S)	3.1 (K×S)		
2021-22					
K ₀	17.7	24.1	24.2	23.9	22.5
K ₂₀	18.3	21.4	27.2	24.4	22.8
K ₄₀	23.8	25.3	33.4	33.8	29.0
K ₆₀	26.6	31.3	34.7	33.1	31.4
Mean	21.6	25.5	29.9	28.8	
LSD (<i>p</i> <0.05)	1.4 (K)	NS (S)	2.7 (K×S)		
Pooled data					
K ₀	17.6	24.1	24.3	23.9	22.4
K ₂₀	18.2	21.4	27.2	24.3	22.7
K ₄₀	23.8	25.2	33.5	33.7	29.0
K ₆₀	26.6	31.1	34.3	32.9	31.2
Mean	21.5	25.4	29.8	28.7	
LSD (<i>p</i> <0.05)	1.0 (K)	NS (S)	2.0 (K×S)		

In year 2021-22, maximum phosphorus uptake was obtained by using 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (34.7 kg ha⁻¹) followed by 60 kg ha⁻¹ K + 30 kg ha⁻¹ S (33.1 kg ha⁻¹) being at par statistically but higher significantly than rest.

The results found were in conformity with Malik *et al* (2021) who observed highest P uptake of 20.06 kg ha⁻¹ using 45 kg S ha⁻¹. In another experiment, Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get highest P uptake of 23.89 kg ha⁻¹. Magray *et al* (2017) applied 100 kg K and 45 kg ha⁻¹ S to get highest P uptake of 30.84 kg ha⁻¹.

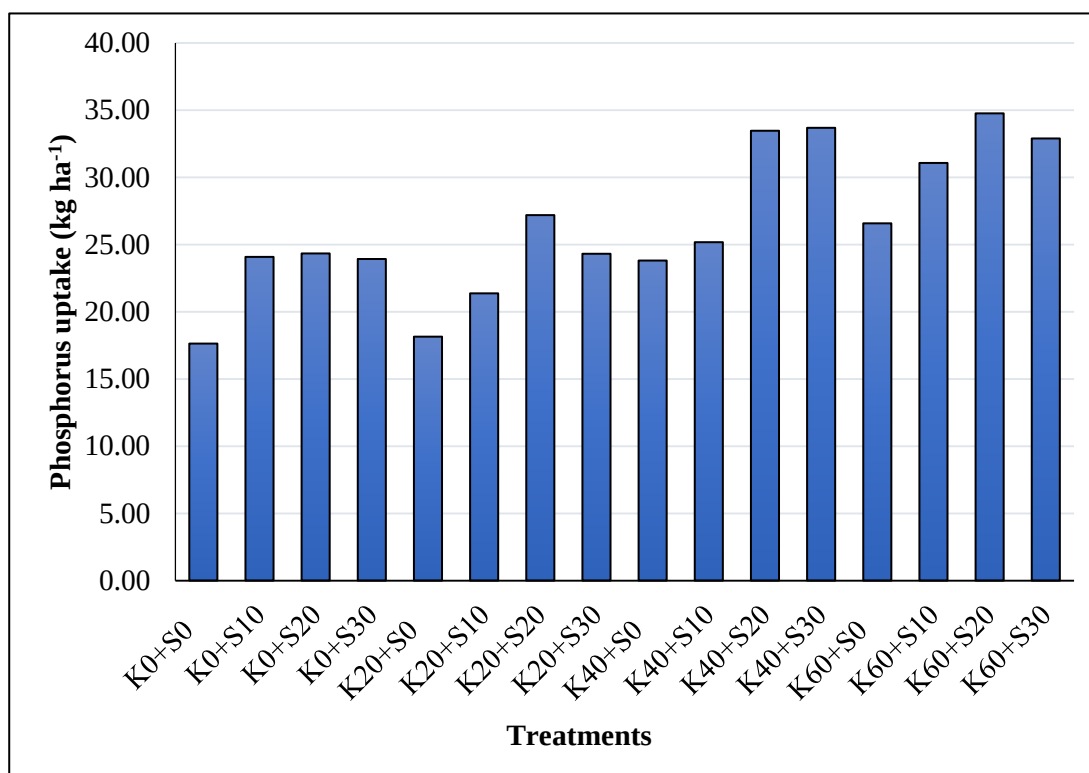


Fig. 4.8: Influence of various levels of potassium and sulphur applications on phosphorus uptake (kg ha⁻¹)

4.3.3 Potassium uptake

The uptake of a nutrient by crop is calculated to check the requirement of that nutrient by the crop. The K uptake will depict the need of K as a nutrient and can be correlated with the quality, growth and yield of crop at the same treatment. It will give us information about the amount of nutrient absorbed to give a particular response. Results showing potassium uptake as affected by various doses of potassium and sulphur is shown in Table 4.24 and Fig. 4.9.

Pooled data of both seasons showed maximum potassium uptake using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (148.8 kg ha⁻¹) which was higher significantly than rest followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (137.9 kg ha⁻¹) being second best treatment.

During year 2020-21, maximum potassium uptake was obtained by using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (148.2 kg ha⁻¹) which was higher significantly than rest followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (137.3 kg ha⁻¹) being second best treatment.

In year 2021-22, maximum potassium uptake was obtained by using 60 kg ha⁻¹ K and 30 kg ha⁻¹ S (149.3 kg ha⁻¹) which was higher significantly than rest followed by 60 kg ha⁻¹ K and 20 kg ha⁻¹ S (138.4 kg ha⁻¹) being second best treatment.

The results found were in conformity with Malik *et al* (2021) who observed highest K uptake of 163.15 kg ha⁻¹ by using 45 kg S ha⁻¹. While experimenting, Arisha *et al* (2017) used 125 kg K₂O to get 615.19 mg per plant of K uptake. Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get highest K uptake of 78.65 kg ha⁻¹. Magray *et al* (2017) applied 100 kg K and 45 kg ha⁻¹ S to get maximum K uptake of 83.90 kg ha⁻¹

Table 4.24: Influence of various levels of potassium and sulphur applications on potassium uptake (kg ha⁻¹)

Treatments	S ₀	S ₁₀	S ₂₀	S ₃₀	Mean
2020-21					
K ₀	75.1	80.4	85.3	89.3	82.5
K ₂₀	95.9	102.2	107.6	113.8	104.9
K ₄₀	108.7	109.0	121.7	126.9	116.6
K ₆₀	109.9	131.7	137.3	148.2	131.8
Mean	97.4	105.8	113.0	119.5	
LSD (<i>p</i> <0.05)	3.9 (K)	NS (S)	7.9 (K×S)		
2021-22					
K ₀	78.1	80.1	85.2	89.4	83.2
K ₂₀	93.3	102.8	108.9	113.7	104.7
K ₄₀	109.9	108.6	120.7	127.7	116.7
K ₆₀	110.1	132.1	138.4	149.3	132.4
Mean	97.8	105.9	113.3	120.0	
LSD (<i>p</i> <0.05)	5.2 (K)	NS (S)	10.4 (K×S)		
Pooled data					
K ₀	76.6	79.5	84.9	89.2	82.8
K ₂₀	94.6	102.5	109.7	114.2	104.8
K ₄₀	111.3	108.8	121.2	127.4	116.6
K ₆₀	112.4	130.7	137.9	148.8	132.1
Mean	97.6	105.8	113.1	119.8	
LSD (<i>p</i> <0.05)	3.2 (K)	NS (S)	6.3 (K×S)		

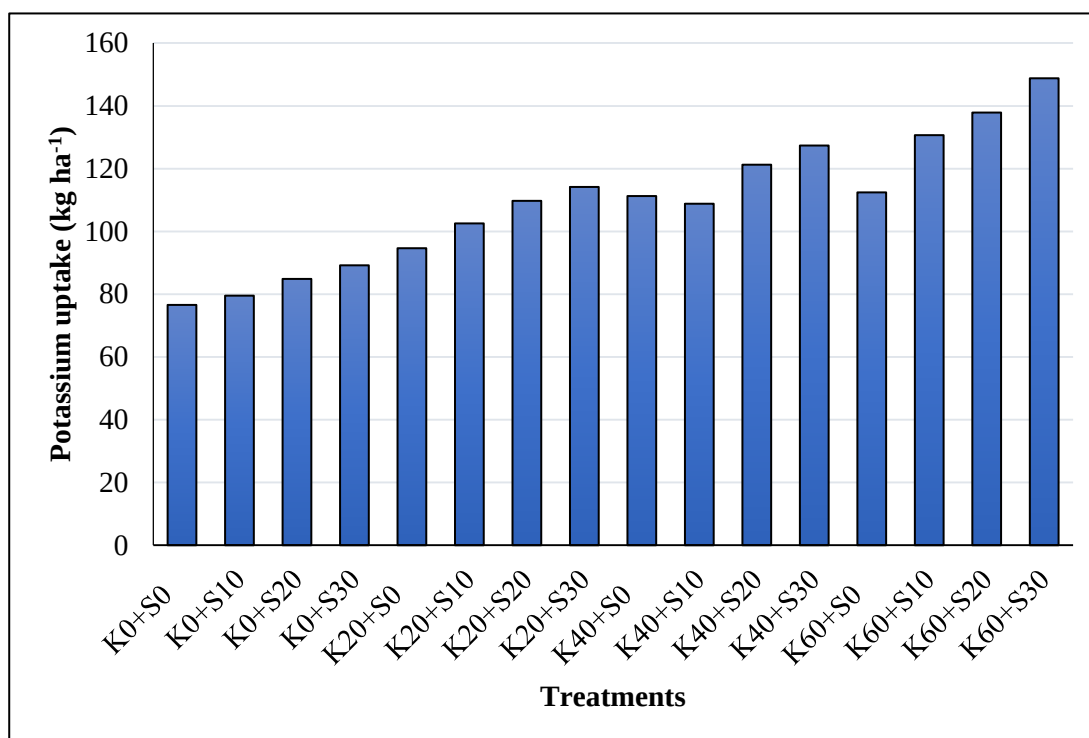


Fig. 4.9: Influence of various levels of potassium and sulphur applications on potassium uptake (kg ha⁻¹)

4.3.4 Sulphur uptake

The uptake of a nutrient by crop is calculated to check the requirement of that nutrient by the crop. The S uptake will depict the need of S as a nutrient and can be correlated with the quality, growth and yield of crop at the same treatment. It will give us information about the amount of nutrient absorbed to give a particular response. Results showing sulphur uptake as influenced by various doses of potassium and sulphur is shown in Table 4.25 and Fig. 4.10.

Pooled data of both seasons showed maximum sulphur uptake using 30 kg ha⁻¹ S (17.9 kg ha⁻¹) being higher significantly than rest. Application of potassium fertilizers did not cause any significant increase in sulphur uptake by crop.

During year 2020-21, maximum sulphur uptake was obtained by using 30 kg ha⁻¹ S (17.6 kg ha⁻¹) followed by 20 kg ha⁻¹ S (16.9 kg ha⁻¹) being at par statistically but higher significantly than rest. The application of potassium fertilizers did not cause any significant increase in sulphur uptake.

In year 2021-22, maximum sulphur uptake was obtained by using 30 kg ha⁻¹ S (18.1 kg ha⁻¹) followed by 20 kg ha⁻¹ S (16.6 kg ha⁻¹) being at par statistically but higher significantly than rest. The application of potassium fertilizers did not cause any significant increase in sulphur uptake by crop.

Table 4.25: Influence of various levels of potassium and sulphur applications on sulphur uptake (kg ha⁻¹)

Treatments		2020-21	2021-22	Pooled mean
K₀	K @0 kg ha ⁻¹	15.2	14.9	15.1
K₂₀	K @20 kg ha ⁻¹	16.3	15.6	16.0
K₄₀	K @40 kg ha ⁻¹	15.7	16.2	16.0
K₆₀	K @60 kg ha ⁻¹	15.3	15.8	15.6
LSD (<i>p</i><0.05) K		NS	NS	0.7
S₀	S @0 kg ha ⁻¹	13.0	12.7	12.9
S₁₀	S @10 kg ha ⁻¹	15.1	15.1	15.1
S₂₀	S @20 kg ha ⁻¹	16.9	16.6	16.8
S₃₀	S @30 kg ha ⁻¹	17.6	18.1	17.9
LSD (<i>p</i><0.05) S		1.02	1.00	0.8
LSD (<i>p</i><0.05) K×S		NS	NS	NS

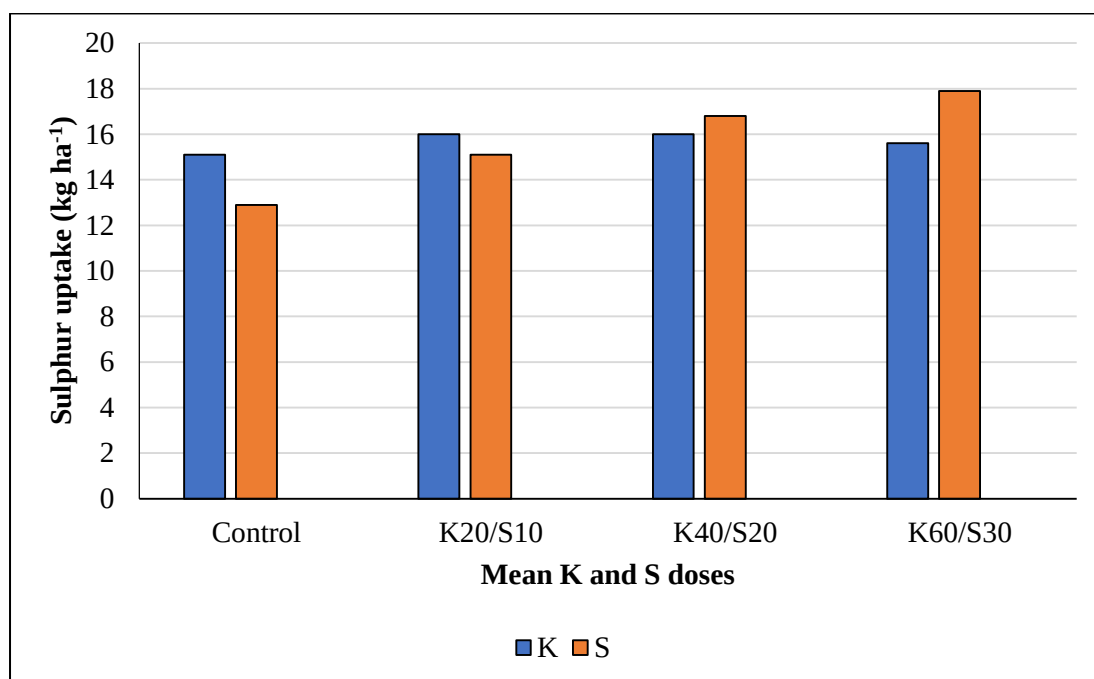


Fig. 4.10: Influence of various levels of potassium and sulphur applications on sulphur uptake (kg ha⁻¹)

The results found were in conformity with Malik *et al* (2021) who got highest S uptake of 17.74 kg ha⁻¹ using 60 kg S ha⁻¹. 16.6 mg per g of S uptake was observed by Bloem *et al* (2010) using 45 kg ha⁻¹ S. Chattoo *et al* (2019) used 45 kg ha⁻¹ of S to get highest S

uptake of 32.54 kg ha⁻¹. Magray *et al* (2017) applied 100 kg K and 45 kg ha⁻¹ S to get highest S uptake of 38.73 kg ha⁻¹.

4.4 Soil Status

4.4.1 Potassium status in soil

The soil status of potassium was checked before planting of the crop and came out be 62.4 mg kg⁻¹. The soil was checked after harvesting of crop to check the K content as affected by the addition of fertilizers into the soil. The data pertaining to the potassium status in soil influenced by potassium and sulphur is shown in Table 4.26.

Table 4.26: Influence of various levels of potassium and sulphur applications on potassium status in soil (mg kg⁻¹)

Treatments		2020-21	2021-22	Pooled mean
K₀	K 0 kg ha ⁻¹	62.8	62.8	62.8
K₂₀	K 20 kg ha ⁻¹	70.4	71.2	70.8
K₄₀	K 40 kg ha ⁻¹	74.9	74.8	74.8
K₆₀	K 60 kg ha ⁻¹	79.6	79.4	79.5
LSD (<i>p</i><0.05) K		2.0	1.6	1.7
S₀	S 0 kg ha ⁻¹	71.7	71.5	71.6
S₁₀	S 10 kg ha ⁻¹	72.0	72.5	72.25
S₂₀	S 20 kg ha ⁻¹	72.1	72.4	72.25
S₃₀	S 30 kg ha ⁻¹	71.8	71.8	71.8
LSD (<i>p</i><0.05) S		NS	NS	NS
LSD (<i>p</i><0.05) K×S		NS	NS	NS

Pooled data of both seasons showed maximum mean potassium soil content using 60 kg ha⁻¹ K (79.5 mg kg⁻¹) which was higher significantly than rest followed by 40 kg ha⁻¹ K (74.8 mg kg⁻¹). The application of sulphur fertilizers did not cause any significant increase in potassium uptake by crop.

During year 2020-21, maximum mean potassium soil content was obtained by using 60 kg ha⁻¹ K (79.6 mg kg⁻¹) followed by 40 kg ha⁻¹ K (74.9 mg kg⁻¹) being higher significantly than rest. The application of sulphur fertilizers failed to cause any significant increase in potassium uptake by crop.

In year 2021-22, maximum mean potassium soil content was obtained by using 60 kg ha⁻¹ K (79.4 mg kg⁻¹) followed by 40 kg ha⁻¹ K (74.8 mg kg⁻¹) being higher significantly than

rest. The application of sulphur fertilizers did not cause any significant increase in potassium uptake by crop.

4.4.2 Sulphur status in soil

The soil status of sulphur was checked before planting of the crop and came out be 13.2 mg kg⁻¹. The soil was checked after harvesting of crop to check the S content as affected by the addition of fertilizers into the soil. The data pertaining to the sulphur status in soil influenced by various doses of potassium and sulphur is shown in Table 4.27.

Table 4.27: Influence of various levels of potassium and sulphur applications on sulphur status in soil (mg kg⁻¹)

Treatments		2020-21	2021-22	Pooled mean
K₀	K 0 kg ha ⁻¹	16.2	16.3	16.1
K₂₀	K 20 kg ha ⁻¹	16.3	16.2	16.2
K₄₀	K 40 kg ha ⁻¹	16.1	16.1	16.2
K₆₀	K 60 kg ha ⁻¹	16.5	16.5	16.4
LSD (<i>p</i><0.05) K		NS	NS	NS
S₀	S 0 kg ha ⁻¹	13.8	13.6	13.7
S₁₀	S 10 kg ha ⁻¹	14.4	14.2	14.3
S₂₀	S 20 kg ha ⁻¹	17.1	17.2	17.2
S₃₀	S 30 kg ha ⁻¹	20.0	19.8	19.9
LSD (<i>p</i><0.05) S		0.3	0.4	0.4
LSD (<i>p</i><0.05) K×S		NS	NS	NS

Pooled data of both seasons showed maximum mean sulphur soil content using 30 kg ha⁻¹ S (19.9 mg kg⁻¹) which was higher significantly than rest followed by 20 kg ha⁻¹ S (19.9 mg kg⁻¹). The application of potassium fertilizers did not cause any significant increase in sulphur uptake by crop.

During year 2020-21, maximum mean sulphur soil content was obtained by using 30 kg ha⁻¹ S (20.0 mg kg⁻¹) followed by 20 kg ha⁻¹ S (17.1 mg kg⁻¹) being higher significantly than rest. The application of potassium fertilizers did not cause any significant increase in sulphur uptake.

In year 2021-22, maximum mean sulphur soil content was obtained by using 30 kg ha⁻¹ S (19.8 mg kg⁻¹) followed by 20 kg ha⁻¹ S (17.2 mg kg⁻¹) being higher significantly than rest. The application of potassium fertilizers did not cause any significant increase in sulphur uptake by crop.

4.5 Benefit-Cost ratio

Recommendation of technology cannot be given without evaluating its profit and loss; hence it becomes necessary to study the economics of experiment. The data pertaining to the B:C ratio influenced by various doses of potassium and sulphur is shown in Table 4.28.

Table 4.28: Influence of different levels of potassium and sulphur applications on Benefit-Cost ratio

Treatments	Fixed cost	Cost of treatment	Total cost of cultivation	Yield	Total returns	B:C
K ₀ +S ₀	187685	0	187685	9.10	318617	1.70
K ₀ +S ₁₀	187685	1870	189555	9.36	327658	1.73
K ₀ +S ₂₀	187685	3740	191425	9.92	347142	1.81
K ₀ +S ₃₀	187685	5610	193295	9.98	349242	1.81
K ₂₀ +S ₀	187685	320	188005	10.08	352858	1.88
K ₂₀ +S ₁₀	187685	2190	189875	10.36	362717	1.91
K ₂₀ +S ₂₀	187685	4060	191745	10.96	383483	2.00
K ₂₀ +S ₃₀	187685	5930	193615	10.62	371758	1.92
K ₄₀ +S ₀	187685	640	188325	10.80	377942	2.01
K ₄₀ +S ₁₀	187685	2510	190195	10.96	383658	2.02
K ₄₀ +S ₂₀	187685	4380	192065	11.28	394625	2.05
K ₄₀ +S ₃₀	187685	6250	193935	11.42	399583	2.06
K ₆₀ +S ₀	187685	960	188645	10.94	382783	2.03
K ₆₀ +S ₁₀	187685	2830	190515	11.47	401275	2.11
K ₆₀ +S ₂₀	187685	4700	192385	11.96	418483	2.18
K ₆₀ +S ₃₀	187685	6570	194255	12.76	446483	2.30

Data in Table 4.28 shows that greatest benefit cost ratio (2.30) was observed using 60 kg ha⁻¹ K + 30 kg ha⁻¹ S with Rs 4,46,483 as gross income which was higher than all other treatments. B:C obtained from K₆₀+S₃₀ ha⁻¹ treatment was 35.3% higher than control. Minimum B:C ratio of 1.70 was obtained by control being lower significantly than rest. Hence, 60 kg ha⁻¹ K + 30 kg ha⁻¹ S should be practiced to obtain maximum returns.

Research was in accordance with results of Diriba-Shiferaw *et al* (2015) while investigating optimum dose of NPS fertilizers for achieving optimum bulb yield of garlic in Andosols and use of 30 kg of S per ha gave the highest B:C ratio of 6.44 and highest net

returns. Hore *et al* (2014) also witnessed maximum B:C ratio of 1.92 and maximum net returns of Rs 1,48,038 by using 60 kg of S and 200 kg of N ha⁻¹.

Magray *et al* (2017) experimented upon economics of producing garlic and received highest B:C ratio of 5.67 and maximum net returns of Rs 7,42,272 by using 100 kg K + 45 kg S ha⁻¹. Malik *et al* (2021) checked the response of sulphur supplementation on economics of garlic and found that using 60 kg S ha⁻¹ gave highest B:C (2.61), and hence is the most profitable treatment. Zaman *et al* (2011) found that 43.6kg ha⁻¹ of S showed most economic yield in garlic.

CHAPTER V

SUMMARY

Garlic is the second most important bulb crop after onion. In China and India, it has been utilized for more than 5000 years (Kamenetsky and Rabinowitch 2001). It is used as a flavouring agent and spice worldwide in food industry (Tadese 2009). It is consumed raw as well as in processed forms like powder, extracts, paste, etc (Lanzotti *et al* 2014). China is the largest contributor of garlic with 75 per cent production followed by India contributing 9.5 per cent. Garlic covers an area of 349.39 thousand hectare with production of 2923.15 thousand metric tonnes in India (Anonymous 2021a). In India, Rajasthan has the highest garlic production, followed by Uttar Pradesh, Gujarat and Punjab. In Punjab, garlic is grown on an area of 8.87 thousand hectares with production of 109.10 thousand metric tonnes (Anonymous 2021b).

Productivity of garlic depends upon cultural practices followed during the cultivation, out of which nutrient management have a crucial role. For producing one ton of garlic bulbs, crop removes 9.49kg of N, 1.21kg of P, 3.8kg of K and 0.9kg of S (Thangasamy *et al* 2018). Among various nutrients potassium is one of the primary macro mineral nutrient which affect garlic plant growth, development, yield and quality. K helps in root development and essential for translocation of sugars and improving bulb diameter, weight and improve storage of garlic (Dorais *et al* 2001). Sulphur being a secondary macro nutrient is also consumed in high amounts right after N, P and K. Bulb crops including garlic are S loving crops and the requirement is high for its proper growth and yield. Role of S, in balanced fertilization and increasing yield and quality of garlic is well known. It is essential for the synthesis of amino acids like cystine (27 per cent), methionine (27 per cent) and cysteine (26 per cent) and is necessary for plant growth (Magray *et al* 2017). Considering these facts, the current experiment was exhibited with the following objectives:

- To determine response of potassium and sulphur on growth, yield and quality of garlic
- To work out the economics of garlic cultivation

The research investigation entitled “Response of sulphur and potassium applications on growth, yield and quality of garlic (*Allium sativum* L.)” was organized at research farm vegetable science, biochemistry laboratory and soil science laboratory, PAU, Ludhiana during rabi seasons of 2020-21 and 2021-22. The experiment was directed to standardise the dose of K and S in garlic to improve its growth, yield and quality. The experimental material comprises of garlic cultivar PG18. Soil samples were collected from the experimental site before bed preparation and after the crop harvesting for estimating the soil nutrient uptake.

Farmyard manure at the rate of 50 tonnes per ha was used for the experiment along with fertilization of N @125 kg per ha and P @67.5 kg per ha. Half dose of N and full dose of P was applied at time of field preparation and remaining half as top dressing 4 weeks after planting. The application of K and S were according to formulated treatments and applied as basal dose during bed preparation before planting. The crop was sown during first fortnight of October during the years 2020-21 and 2021-22. The data was recorded in respect to various parameters of growth, yield and quality i.e., leaf length (cm), plant height (cm), leaf number, LAI, neck thickness (mm), bulb diameter-radial (cm), bulb diameter-polar (cm), cloves per bulb, 50 clove weights (g), bulb weight (g), marketable yield (tonnes per ha), total yield (tonnes per ha), allicin (mg per g), TSS (per cent), ascorbic acid (mg per 100g dry weight), total minerals (mg per 100g dry weight), dry matter (per cent), total protein (mg per g), phenols (mg per g), total sugars (mg per g), reducing sugars (mg per g), N, P, K and S uptake by plants, K status in soil and S status in soil. The salient findings of the present investigation are as under:

- For both the seasons (2020-21 and 2021-22) the highest mean plant height (82.6cm and 83.0cm) was obtained using 60 kg ha⁻¹ K being higher significantly compared to other treatments along with highest pooled mean (82.8cm).
- Maximum mean leaf length (43.7 cm and 44.3 cm) was recorded with use of 60 kg of K ha⁻¹ during season 2020-21 and 2021-22 respectively along with highest pooled mean (44.1cm) which was significantly higher than all other treatments.
- Leaf number was highest in both seasons (2020-21 and 2021-22) with application of 60 kg K along with highest pooled mean (8.87) which were significantly higher from all other treatments. Use of 30 kg S gave the highest pooled mean (7.98) which was significantly different from all other treatments.
- The treatment with 60 kg K + 30 kg S gave maximum LAI in pooled mean, 2020-21 and 2021-22 (5.39, 5.59 and 5.19 respectively).
- Pooled data of two seasons showed minimum neck thickness (7.53mm) with use of K 20 kg which was significantly less from all other treatments.
- The highest bulb radial diameter (5.26cm, 5.21cm and 5.24cm) was achieved by use of 60 kg K and 30 kg S for seasons 2020-21, 2021-22 and pooled mean, respectively and were significantly higher than all other treatments.
- The highest bulb polar diameter (4.46cm, 4.43cm and 4.45cm) was achieved by use of 60 kg K and 30 kg S for seasons 2020-21, 2021-22 and pooled mean, respectively and were significantly higher than all other treatments for season 2020-21 and pooled mean.

- Pooled data of both seasons showed maximum number of cloves per bulb with 60 kg K (27.47) which was significantly higher from all other treatments. The use of 20 kg S gave the highest mean cloves per bulb among sulphur treatments which was statistically at par with 30 and 10 kg S.
- Pooled data of both seasons showed maximum 50 cloves weight with 60 kg K (52.9g) which was significantly higher from all other treatments. The use of 30 kg S gave the highest mean 50 cloves weight (52.0g) among sulphur treatments which was significantly different from all other treatments.
- Use of 60 kg K gave the highest bulb weights (27.1g, 28.1g and 27.6g) for years 2020-21, 2021-22 and pooled means, respectively, being significantly different from all other treatments.
- Pooled data of both seasons showed maximum marketable yield with 60 kg K (11.76 t ha⁻¹) being higher significantly compared to other treatments. Use of 30 kg S gave the highest mean marketable yield (11.21 t ha⁻¹) among sulphur treatments which was significantly higher from all other treatments.
- Pooled data of both seasons showed maximum total yield with 60 kg K (14.17 t ha⁻¹) being higher significantly from rest. The use of 30 kg S gave the highest mean total yield (13.88 t ha⁻¹) among sulphur treatments which was significantly different from all other treatments.
- Pooled data of both seasons showed maximum allicin content with 30 kg S (12.64) followed by 20 kg S (12.44 mg g⁻¹) being at par statistically among each other but higher significantly from rest.
- Pooled data of two seasons showed maximum TSS with 30 kg S (41.5%) which was significantly higher from all other treatments. The use of 60 kg K gave the highest mean TSS (41.3%) among Potassium treatments which was significantly different from all other treatments.
- Pooled data of both seasons showed maximum ascorbic acid with 30 kg S (21.8 mg per 100g dry weight) which was significantly higher from all other treatments. The use of 60 kg K gave the highest mean ascorbic acid (21.6 mg per 100g dry weight) among potassium treatments which was significantly different from all other treatments.
- Pooled data of both seasons showed maximum total minerals with 30 kg S (53.5 mg per 100g dry weight) which was significantly higher from all other treatments. The use of 60 kg K gave the highest mean total minerals (53.1 mg per 100g dry weight) among potassium treatments which was significantly different from all other treatments.

- Pooled data of both seasons showed maximum dry matter content with 30 kg S (42.9%) being higher significantly from rest. Using 60 kg K gave the highest mean dry matter content (42.4%) followed by 40 kg K (42.0%) being at par statistically among each other but higher significantly from rest.
- Pooled data of two seasons showed maximum total protein with 60 kg K (120.8 mg g⁻¹) which was significantly higher from all other treatments. The use of 30 kg S gave the highest mean total protein (112.1) among sulphur treatments being higher significantly from rest.
- The highest phenols content (0.53, 0.54 and 0.54 mg g⁻¹) was achieved by use of 60 kg K and 30 kg S for seasons 2020-21, 2021-22 and pooled mean, respectively.
- The highest total sugars (180.6, 183.6 and 182.2 mg g⁻¹) were achieved by use of 60 kg K and 30 kg S for seasons 2020-21, 2021-22 and pooled mean, respectively and were statistically at par with 60 kg K and 20 kg S.
- Pooled data of both seasons failed to show any significant difference in reducing sugars with use of potassium and sulphur treatments.
- The treatment with 60 kg K + 30 kg S gave maximum nitrogen uptake in 2020-21, 2021-22 and pooled mean (96.2, 94.4 and 95.3 kg ha⁻¹ respectively). This treatment being significantly higher from all other treatments for 2020-21, 2021-22 and pooled mean.
- The treatment with 60 kg K and 20 kg S gave maximum phosphorus uptake in 2020-21, 2021-22 and pooled mean (33.9, 34.7 and 34.3 kg ha⁻¹ respectively).
- The treatment with 60 kg K and 30 kg S gave maximum potassium uptake in 2020-21, 2021-22 and pooled mean (148.2, 149.3 and 148.8 kg ha⁻¹ respectively). This treatment was significantly higher from all other treatments for 2020-21, 2021-22 and pooled mean.
- The highest mean sulphur uptake was achieved by using 30 kg S for years 2020-21, 2021-22 and pooled mean (17.6, 18.1 and 17.9 kg ha⁻¹, respectively) being significantly higher than the second-best treatment of 20 kg S (16.9, 16.6 and 16.8 kg ha⁻¹) for year 2021-22 and pooled mean whereas it was statistically at par during year 2020-21.
- The highest mean potassium soil content was achieved by using 60 kg K for years 2020-21, 2021-22 and pooled mean (79.6, 79.4 and 79.5 mg kg⁻¹, respectively) and was significantly higher than the second-best treatment of 20 kg S (74.9, 74.8 and 74.8 mg kg⁻¹) for year 2020-21, 2021-22 and pooled mean.
- The highest mean sulphur soil content was achieved by using 30 kg S for years 2020-21, 2021-22 and pooled mean (20.0, 19.8 and 19.9 mg kg⁻¹, respectively) and was

significantly higher than the second-best treatment of 20 kg S (17.1, 17.2 and 17.2 mg kg⁻¹) for year 2020-21, 2021-22 and pooled mean.

- Maximum benefit cost ratio (2.30) was obtained by using 60 kg K and 30 kg S with Rs 4,46,483 as gross income which was higher than all other treatments. B:C obtained from K60kg+S30kg ha⁻¹ treatment was 35.3% higher than control.

Conclusion

It is concluded from the present investigation that application with 60 kg of K ha⁻¹ along with 30 kg of S ha⁻¹ gave best overall B:C ratio and yield results in all parameters like plant height, number of leaves, LAI, bulb polar and radial diameters, bulb and clove weights, marketable and total yield and highest N and K uptakes. The quality characters like TSS, total protein, ascorbic acid, dry matter, total minerals and total sugars were highest with 60 kg K ha⁻¹ and 30 kg S ha⁻¹. So, recommendations can be made for use of 60 kg of K ha⁻¹ along with 30 kg of S ha⁻¹ in garlic for increasing yield and quality of garlic for the region.

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ANNEXURE 1

Meteorological details during the crop growth seasons 2020-21 and 2021-22

Month	Year	Temperature (°C)			Mean Relative Humidity (%)	Rainfall (mm)
		Maximum	Minimum	Mean		
October	2020	30.7	19.1	23.6	60.7	16.8
November	2020	25.3	9.8	17.5	62.3	15.6
December	2020	19.4	7.1	13.2	72.3	6.0
January	2021	23.8	7.1	12.0	79.0	11.0
February	2021	29.5	10.2	17.0	73.0	17.0
March	2021	34.2	14.9	22.2	59.0	5.0
April	2021	36.3	16.9	25.5	39.0	14.3
October	2021	31.3	19.5	25.4	65.0	16.2
November	2021	26.8	10.7	18.7	61.2	14.7
December	2021	20.7	6.7	13.7	72.3	6.4
January	2022	15.7	8.4	12.1	83.0	11.3
February	2022	21.1	8.5	14.8	71.4	16.8
March	2022	30.8	15.9	23.3	63.0	5.6
April	2022	39.0	20.5	29.7	36.1	14.1

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