Evaluation of Elemental Sulphur Fertilizer Efficiency in Potato Production

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Abstract

Sulfur (S) is essential for plant growth because it is a key component of amino acids, proteins, and enzymes, playing a vital role in chlorophyll production and nitrogen metabolism. However, its availability in agricultural soils is often limited due to leaching, particularly in sandy soils. This study evaluated the effectiveness of elemental sulfur (ES) compared to ammonium sulfate (AS) in potato production across two grower fields, Sulphur Fields B and C (SFB and SFC), in Manitoba. The objective was to assess the impact of ES on soil sulfur availability, nitrogen dynamics, and potato yield and quality under conventional sulfur management practices. Results showed that ES-treated zones had significantly lower pre-season sulfur levels than AS-only zones, but sulfur levels gradually increased over time due to microbial oxidation. In SFB, ES-treated zones eventually reached sulfur levels comparable to AS-only zones, while in SFC, ES-treated zones exhibited significantly higher sulfur concentrations at later growth stages. Despite this increase in sulfur availability, no significant differences in yield, tuber size, or specific gravity were observed between treatments, suggesting that baseline fertility was sufficient for yield optimization. However, tuber defect rates were lower in ES-treated zones, particularly in SFC, indicating a potential benefit of ES in improving tuber quality. Additionally, nitrogen efficiency appeared to improve in ES-treated zones, as indicated by significantly higher nitrogen levels at row closure in SFC, despite ES containing no nitrogen. This suggests that ES may enhance nitrogen use efficiency by facilitating protein synthesis and enzymatic processes. No significant changes were observed in phosphorus (P) or potassium (K) levels, reinforcing that existing soil fertility conditions were non-limiting for these nutrients. While ES demonstrated its ability to provide a sustained sulfur supply over time, its advantages over AS were limited under non-deficient conditions. To improve treatment comparisons, the trial should have included zones treated with elemental sulfur alone, allowing for a clearer evaluation of its standalone effects. Future research should explore ES effectiveness under diverse environmental conditions, particularly in sulfur-deficient soils, to determine its long-term benefits in sustainable potato production.

Keywords

Elemental Sulphur, Ammonium Sulphate, Slow Release, Potato Yield, Soil Fertility

Introduction

Potatoes, as a short-duration crop, have unique sulfur requirements due to their growth cycle and high nutrient demand. Research has shown that sulfur loss can be substantial in sandy soils, with studies in Florida demonstrating that most applied sulfate was leached within 45 days of application. However, due to cold temperatures at planting, potato emergence can be delayed by 15 to 20 days, limiting the early-season uptake of sulfate fertilizers (Sharma et al., 2023). Plants primarily absorb sulfur in the form of sulfate (SO_4^{2-}), which must be continuously replenished in agricultural soils due to its high susceptibility to leaching (Riley et al., 2002). Conventional sulfur fertilizers, such as ammonium sulfate (AS), supply sulfur in the readily available sulfate form, but their efficiency is often compromised by nutrient loss, particularly in sandy soils with heavy rainfall (Wei et al., 2011). In contrast, elemental sulfur (S_0) undergoes microbial oxidation to convert into sulfate, providing a slower, more sustained sulfur release over time. The oxidation process is influenced by environmental factors such as temperature, microbial activity, and soil conditions, making it a potentially valuable long-term sulfur source in crop production systems (Rhue & Kamprath, 1973). Elemental sulfur offers a potential advantage by remaining in the soil longer and gradually releasing sulfate, ensuring availability to the plant during later growth stages when nutrient demand is higher. Field trials comparing different sulfur sources have shown that ammonium sulfate had the highest sulfur loss (72%), followed by micronized sulfur (26%) and bentonite clay sulfur (6%) (Riley et al., 2002).

Beyond sulfur availability, the interaction between sulfur and other macronutrients is crucial for optimizing crop growth. Leaching of sulfate can contribute to environmental concerns by allowing nitrogen (N) and phosphorus (P) to enter water systems, leading to eutrophication in lakes, rivers, and groundwater (Wei et al., 2011). Studies have also indicated that elemental sulfur applications can enhance nitrogen use efficiency by supporting protein synthesis and enzymatic activity in plants. Furthermore, magnesium sulfate ($MgSO_4$) has been found to improve potato yields more effectively than ammonium sulfate and calcium sulfate ($CaSO_4 \cdot 2H_2O$), while ammonium sulfate has been associated with increased tuber specific gravity, making it a preferred option for processing potatoes (Scherer, 2001; Sharma et al., 2023).

Given the potential agronomic and environmental benefits of elemental sulfur, this study aims to evaluate its efficiency in comparison to conventional sulfur fertilizers in potato production systems. The primary objectives are to assess the impact of elemental sulfur on soil sulfur availability over time, its interaction with nitrogen and other nutrients, and its overall effect on potato yield and quality. The study was conducted at two grower fields using Tiger XP (elemental sulfur) alongside conventional sulfur management practices. By analyzing soil nutrient dynamics and plant responses, this research seeks to determine whether elemental sulfur can provide a more sustainable and efficient sulfur source for potato cultivation.

Materials and Methods

Location: The trial was conducted in Manitoba.

Variety: Russet Burbank

Study Design:

- Two grower fields (SFB and SFC) were selected for the trial.
- Two treatments were applied: Treatment A, which consisted of elemental sulfur combined with conventional sulfur management, and Treatment B, which followed conventional sulfur management using ammonium sulfate.
- Sulphur (S), Nitrogen (N), Phosphorus (P), and Potassium (K) levels were measured at the pre-season stage.

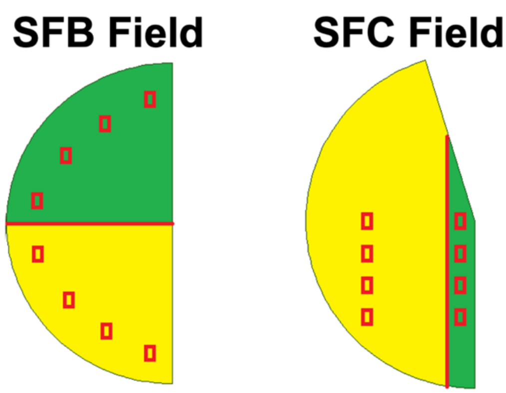


Figure 1. Experimental field layout for sulfur fertilizer treatments at two grower fields (SFB and SFC). The green sections represent Treatment A**,** which includes Tiger XP (elemental sulfur) in addition to conventional sulfur management (Ammonium Sulphate), while the yellow sections represent Treatment B**,** which follows conventional sulfur management alone. Red squares indicate sampling locations within each treatment zone. The diagram highlights differences in treatment distribution between the two fields, with SFB having a more balanced division and SFC showing a smaller portion allocated to Treatment A.

Data Collection

- Soil Tests: Sulphur (S), Nitrogen (N), Phosphorus (P), and Potassium (K) levels were analyzed across different growth stages.
- Petiole Nitrate Tests: Evaluated plant nitrogen uptake.
- Yield and Tuber Quality: Potato size (length and width), specific gravity, defects, and disease incidence were recorded.

Statistical Analysis

Statistical comparisons were performed using IBM SPSS Statistics Version 30.0.0.0 (172) to determine significant differences between treatment zones.

Results and Discussion

Tuber Yield, Quality, and Defects

There was no significant impact on potato yields, tuber size, or specific gravity between treatments, suggesting that sulfur and nitrogen were non-limiting for yield optimization and that baseline fertility was already sufficient (Fig. 1 and 2). The zones treated with Elemental Sulphur (ES) and Ammonium Sulphate (AS) had a lower percentage of defects compared to AS-only zones (Fig. 1B and 2B), with a more pronounced difference in the SFC field (Fig. 2B), suggesting that the combination of ES and AS likely improves tuber quality and reduces defects by providing a more balanced and sustained sulfur supply.

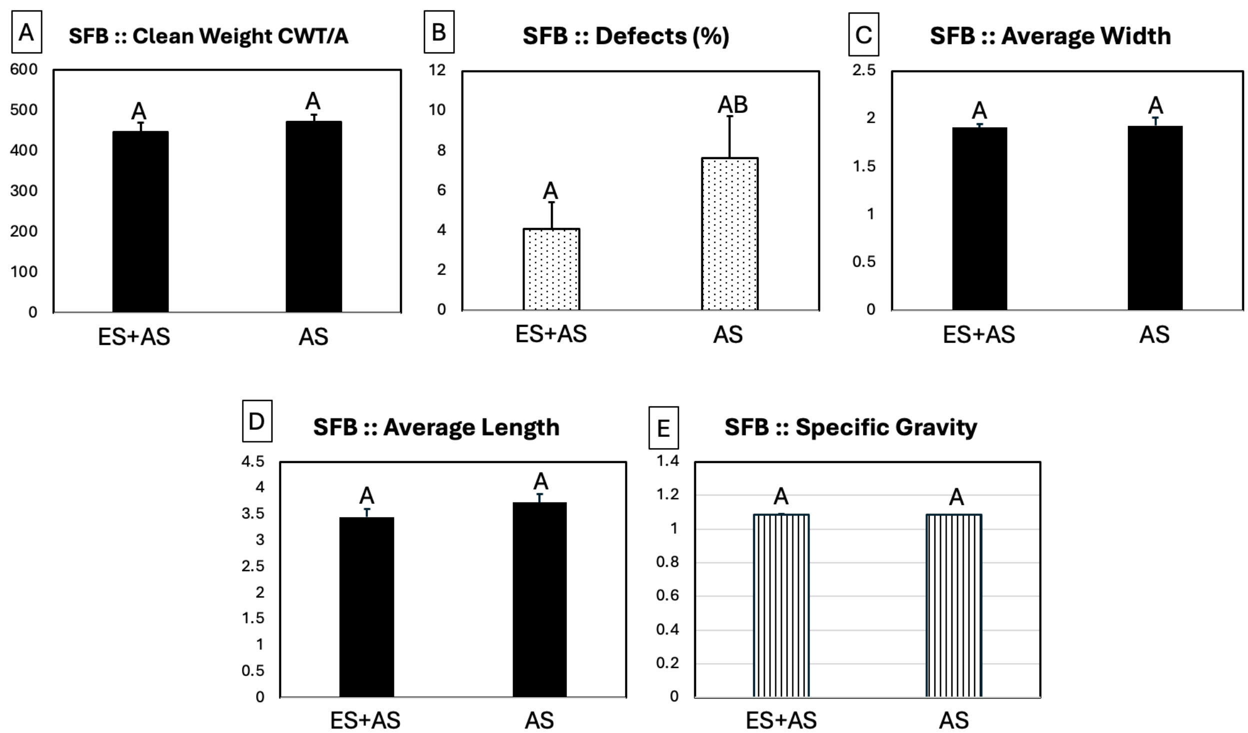


Figure 2. Yield and quality parameters of potatoes grown in Sulphur Field B (SFB) under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A) Clean weight (CWT/A), (B) Defects (%) including Rot %, Mechanical Damage %, Sun/Green %, Frost %, Foreign Material %, Net Necrosis %, Internal Defects %, Hollow Heart %, Trace Hollow Heart %, Wireworm %, and Scab %, (C) Average width, (D) Average length, and (E) Specific gravity. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

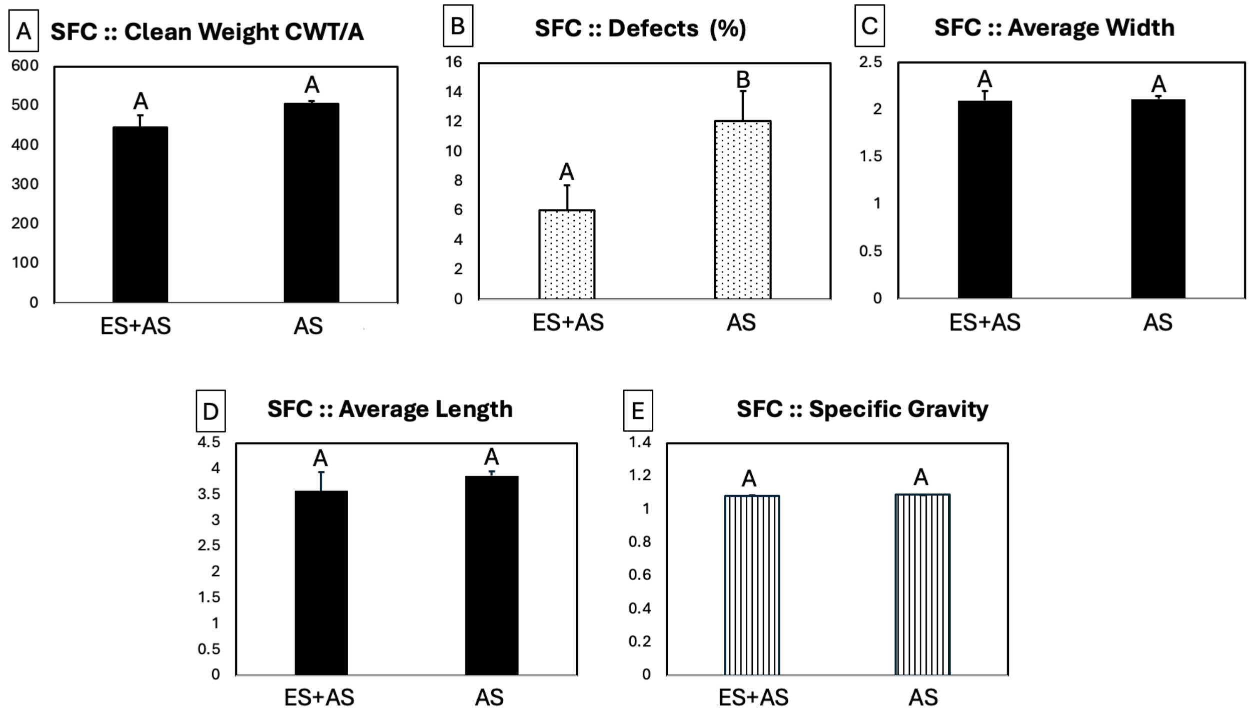


Figure 3. Yield and quality parameters of potatoes grown in Sulphur Field C (SFC) under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A) Clean weight (CWT/A), (B) Defects (%) including Rot %, Mechanical Damage %, Sun/Green %, Frost %, Foreign Material %, Net Necrosis %, Internal Defects %, Hollow Heart %, Trace Hollow Heart %, Wireworm %, and Scab %, (C) Average width, (D) Average length, and (E) Specific gravity. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

Sulphur Availability in Soil

Elemental sulphur-treated zones had significantly lower sulphur levels at the pre-season stage compared to conventional zones in both fields (Figs. 4D, 4G, 5D, and 5G). In SFB, no significant differences in sulphur levels were observed at row closure and late bulk stages; however, elemental sulphur-treated zones showed an increase over time, eventually reaching levels similar to conventional treatments (Figs. 4B, 4C, 4E, 4F, 4H, and 4I). In SFC, elemental sulphur-treated zones showed significantly elevated sulphur levels compared to conventional treatment zones (Figs. 5B, 5C, 5E, 5F, 5H, and 5I). These results confirm that elemental sulphur undergoes gradual oxidation, leading to a delayed but sustained sulphur supply. Figure 6A-C showed that elemental S compensated the low levels of sulphur at the pre-season stage in the treated zones in SFB (Field 1) to catch up with conventional zones, and the significant increase in sulphur levels in SFC (Field 2). In general, sulphur levels increased at the row closure and late bulking stages.

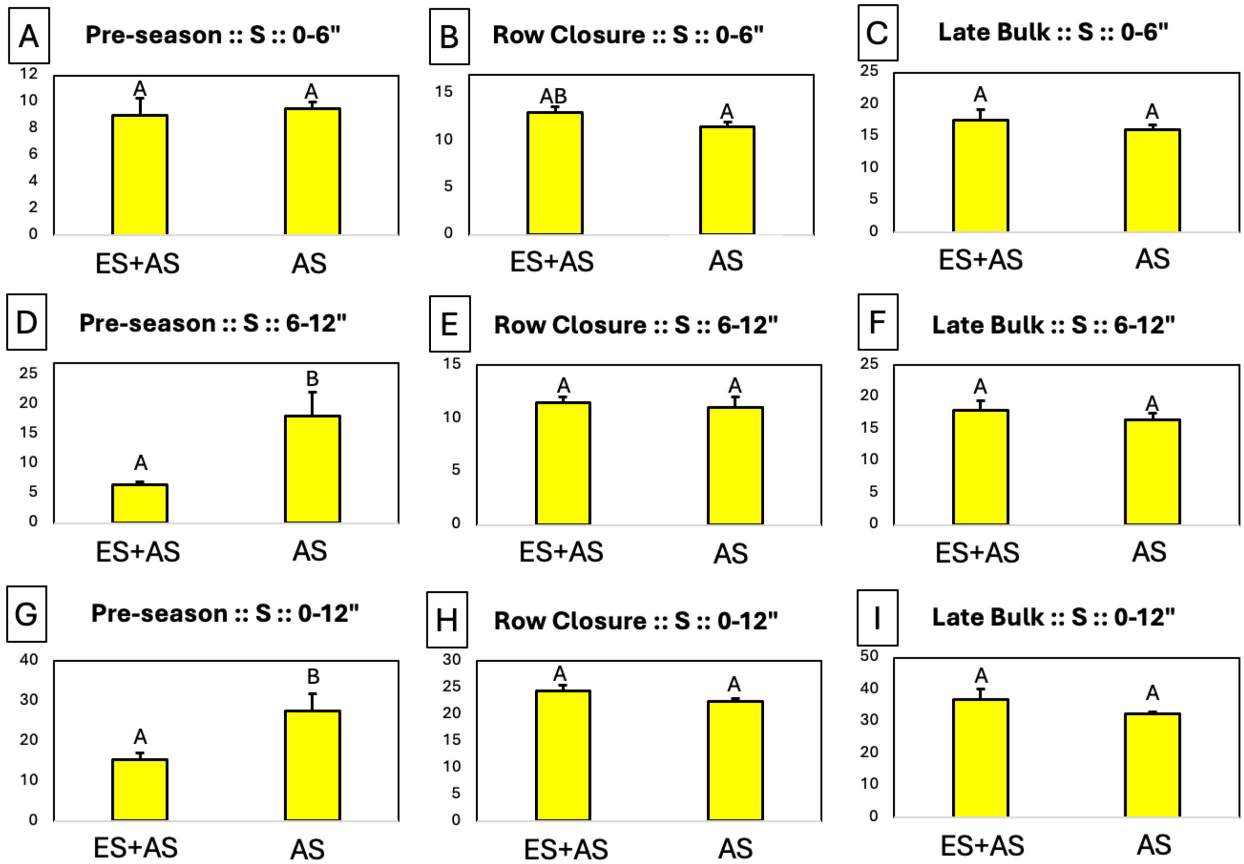


Figure 4. Sulphur (S) levels at different soil depths in Sulphur Field B (SFB) under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A) Sulphur levels (0–6 inches) during the pre-season, (B) Sulphur levels (0–6 inches) at row closure, (C) Sulphur levels (0–6 inches) during late bulking, (D) Sulphur levels (6–12 inches) during the pre-season, (E) Sulphur levels (6–12 inches) at row closure, (F) Sulphur levels (6–12 inches) during late bulking, (G) Sulphur levels (0–12 inches) during the pre-season, (H) Sulphur levels (0–12 inches) at row closure, (I) Sulphur levels (0–12 inches) during late bulking. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

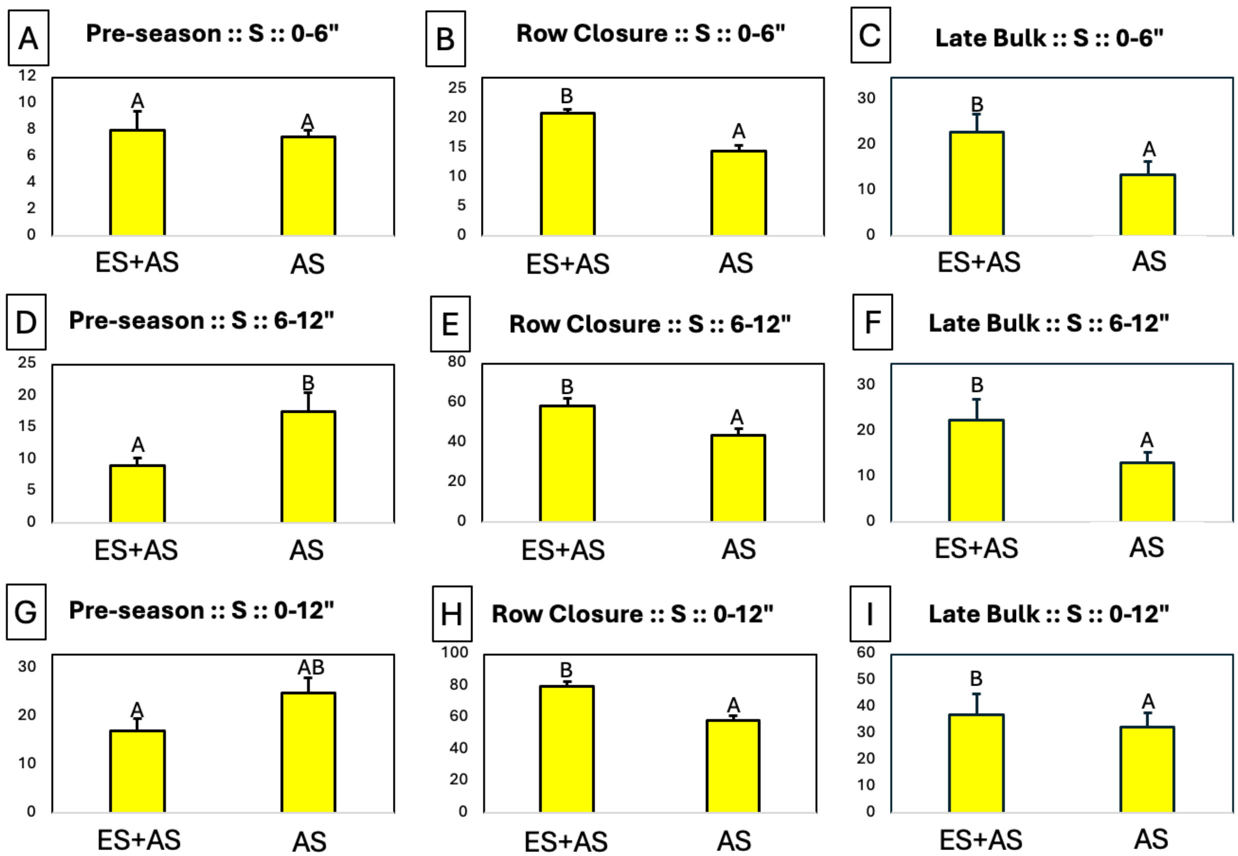


Figure 5. Sulphur (S) levels at different soil depths in Sulphur Field C (SFC) under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A) Sulphur levels (0–6 inches) during the pre-season, (B) Sulphur levels (0–6 inches) at row closure, (C) Sulphur levels (0–6 inches) during late bulking, (D) Sulphur levels (6–12 inches) during the pre-season, (E) Sulphur levels (6–12 inches) at row closure, (F) Sulphur levels (6–12 inches) during late bulking, (G) Sulphur levels (0–12 inches) during the pre-season, (H) Sulphur levels (0–12 inches) at row closure, (I) Sulphur levels (0–12 inches) during late bulking. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

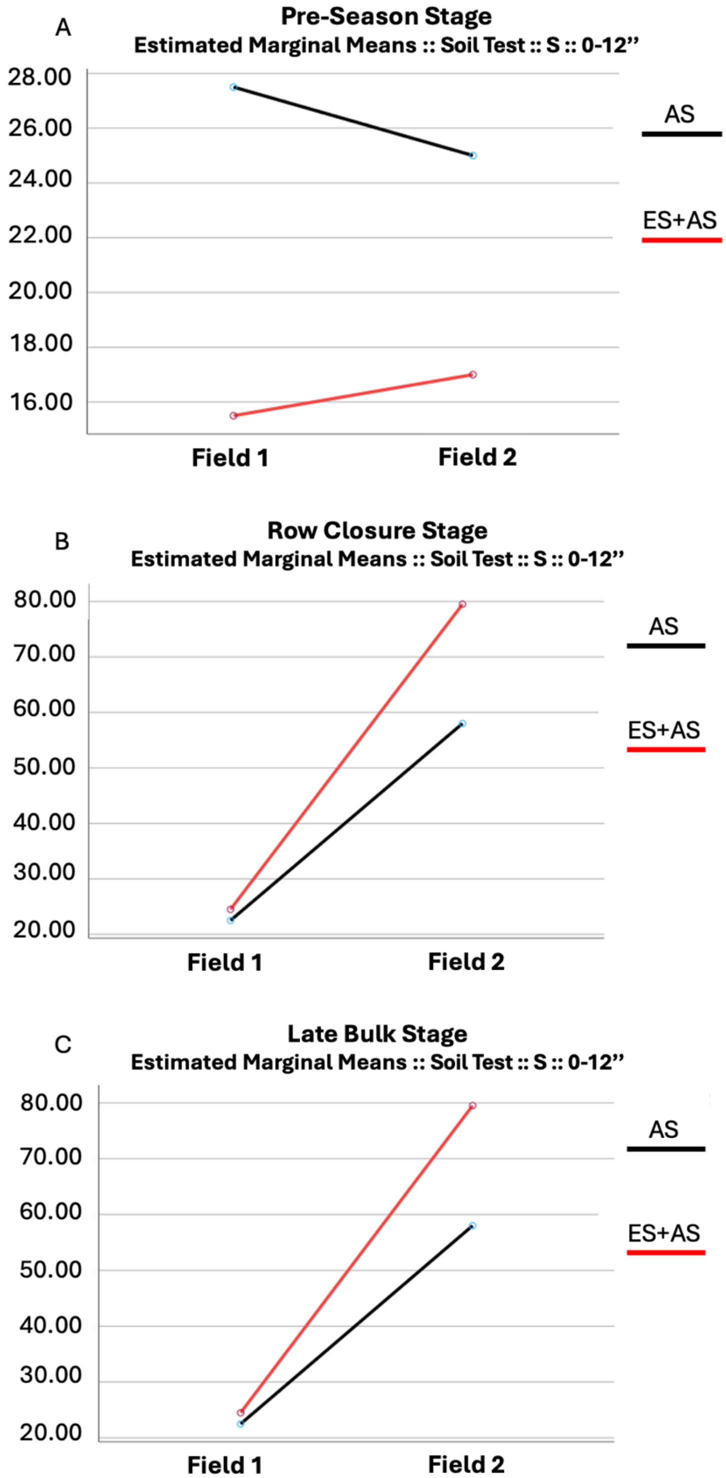


Figure 6. Sulphur (S) content in Sulphur Field B (SFB) and Sulphur Field C (SFC) at different growth stages under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. Estimated marginal means of soil sulphur levels (0–12 inches depth) are shown for each field. Black lines represent AS alone, while red lines represent ES+AS. (A) Sulphur content at the pre-season stage, (B) Sulphur content at the row closure stage, (C) Sulphur content at the late bulking stage. Statistical analysis was conducted using two-way ANOVA with a post hoc least significant difference test (LSD) test at $P < 0.05$.

Nitrogen Content in Soil and Petioles

In SFB, there was no significant difference in soil nitrogen (Fig. 7A–I, Fig. 10A-C) or petiole nitrate levels (Fig. 9A, B). In SFC, nitrogen levels were significantly higher at row closure in soil and petioles of elemental sulfur-treated zones (Figs. 8B, 8E, 8H, 9C, and 10B). Since elemental sulphur does not contain nitrogen, this increase suggests improved nitrogen use efficiency, likely due to sulphur's availability and its role in protein synthesis and enzyme activation.

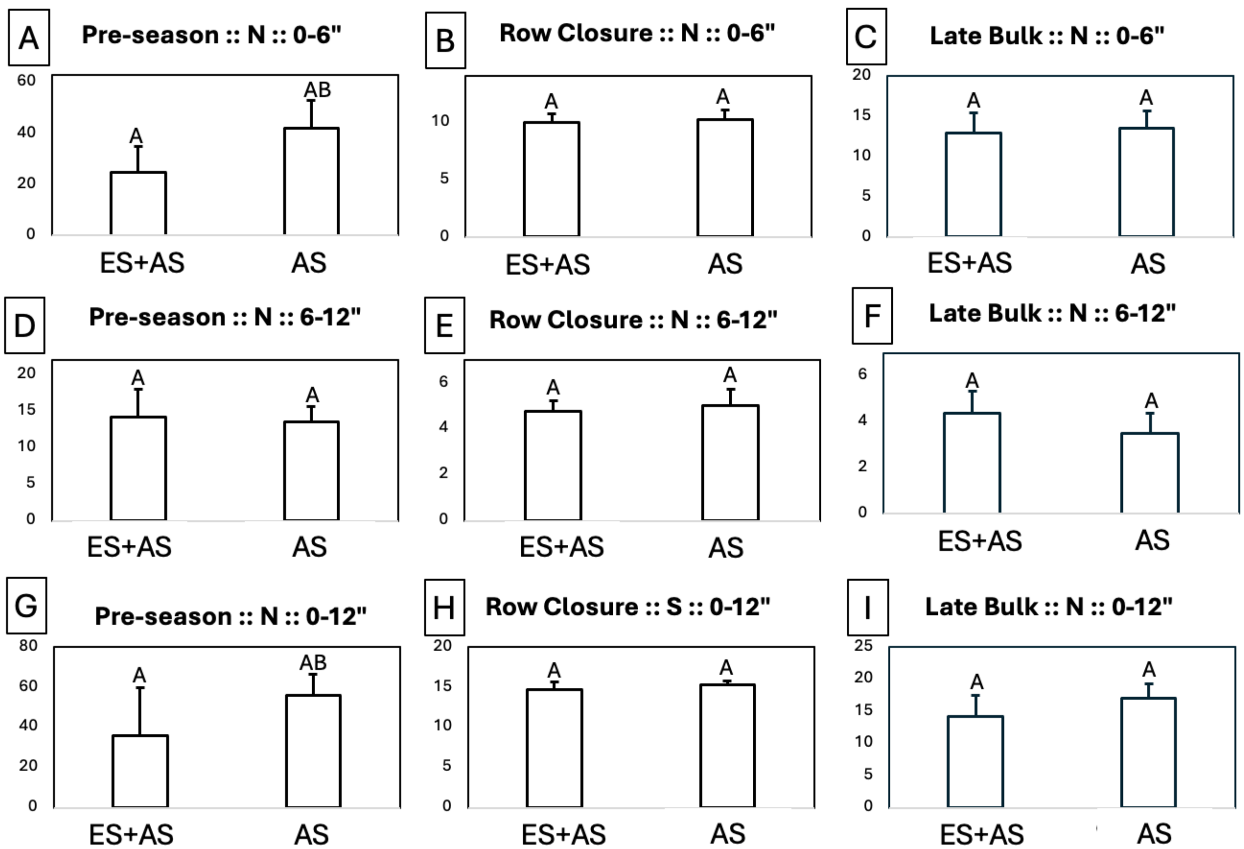


Figure 7. Nitrogen (N) levels at different soil depths in Sulphur Field B (SFB) under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A) Nitrogen levels (0–6 inches) during the pre-season, (B) Nitrogen levels (0–6 inches) at row closure, (C) Nitrogen levels (0–6 inches) during late bulking, (D) Nitrogen levels (6–12 inches) during the pre-season, (E) Nitrogen levels (6–12 inches) at row closure, (F) Nitrogen levels (6–12 inches) during late bulking, (G) Nitrogen levels (0–12 inches) during the pre-season, (H) Nitrogen levels (0–12 inches) at row closure, (I) Nitrogen levels (0–12 inches) during late bulking. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

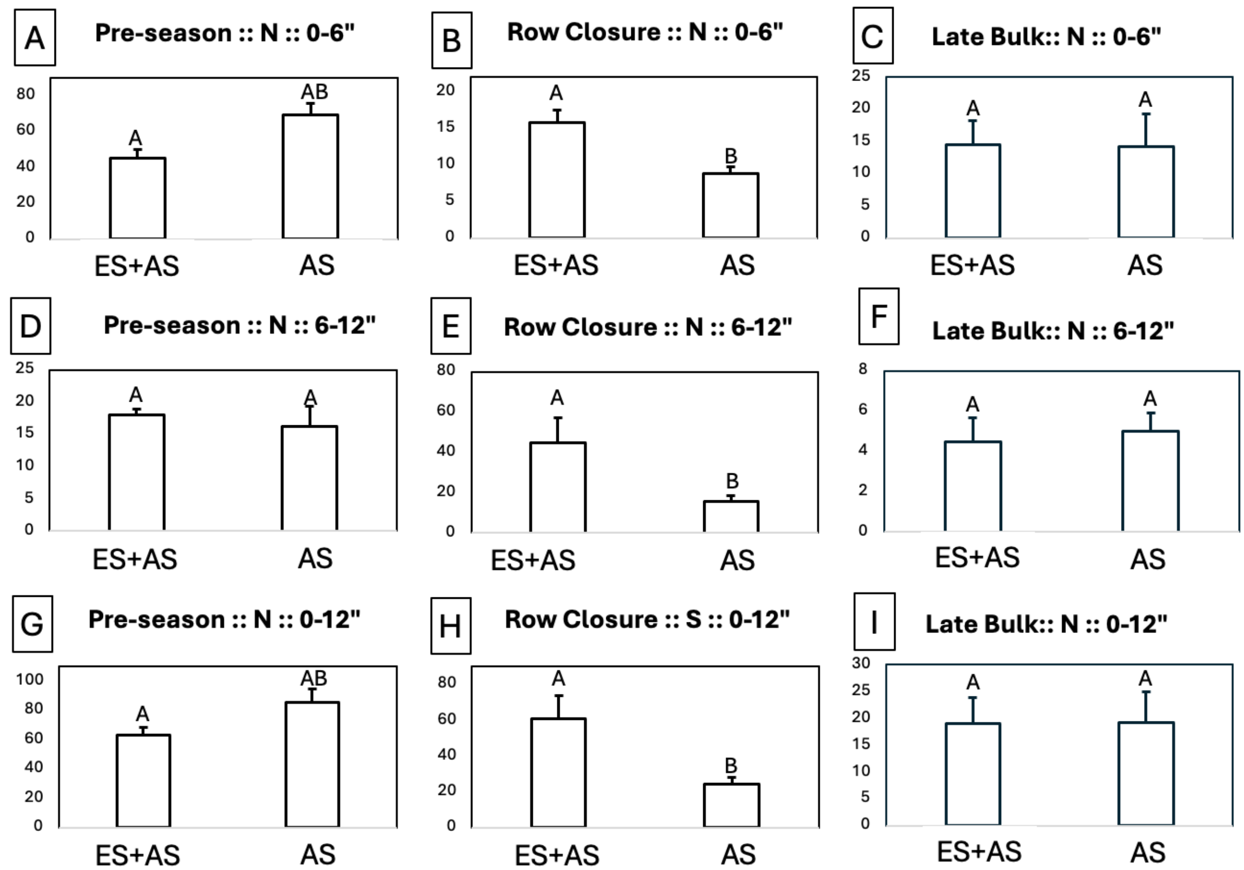


Figure 8. Nitrogen (N) levels at different soil depths in Sulphur Field C (SFC) under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A) Nitrogen levels (0–6 inches) during the pre-season, (B) Nitrogen levels (0–6 inches) at row closure, (C) Nitrogen levels (0–6 inches) during late bulking, (D) Nitrogen levels (6–12 inches) during the pre-season, (E) Nitrogen levels (6–12 inches) at row closure, (F) Nitrogen levels (6–12 inches) during late bulking, (G) Nitrogen levels (0–12 inches) during the pre-season, (H) Nitrogen levels (0–12 inches) at row closure, (I) Nitrogen levels (0–12 inches) during late bulking. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

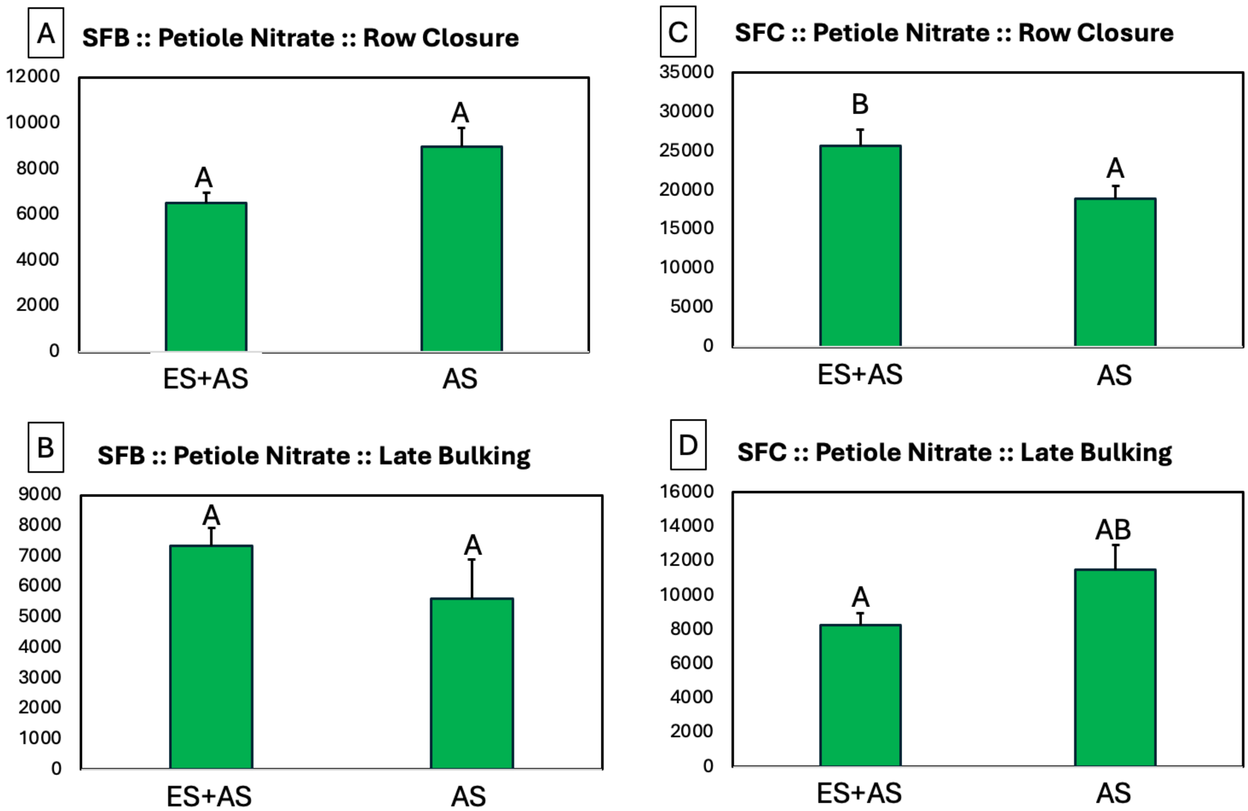


Figure 9. Petiole nitrate levels in Sulphur Field B (SFB) and Sulphur Field C (SFC) at different growth stages under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A–B) Petiole nitrate levels in SFB:(A) Row closure stage, (B) Late bulking stage. (C–D) Petiole nitrate levels in SFC: (C) Row closure stage, (D) Late bulking stage. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

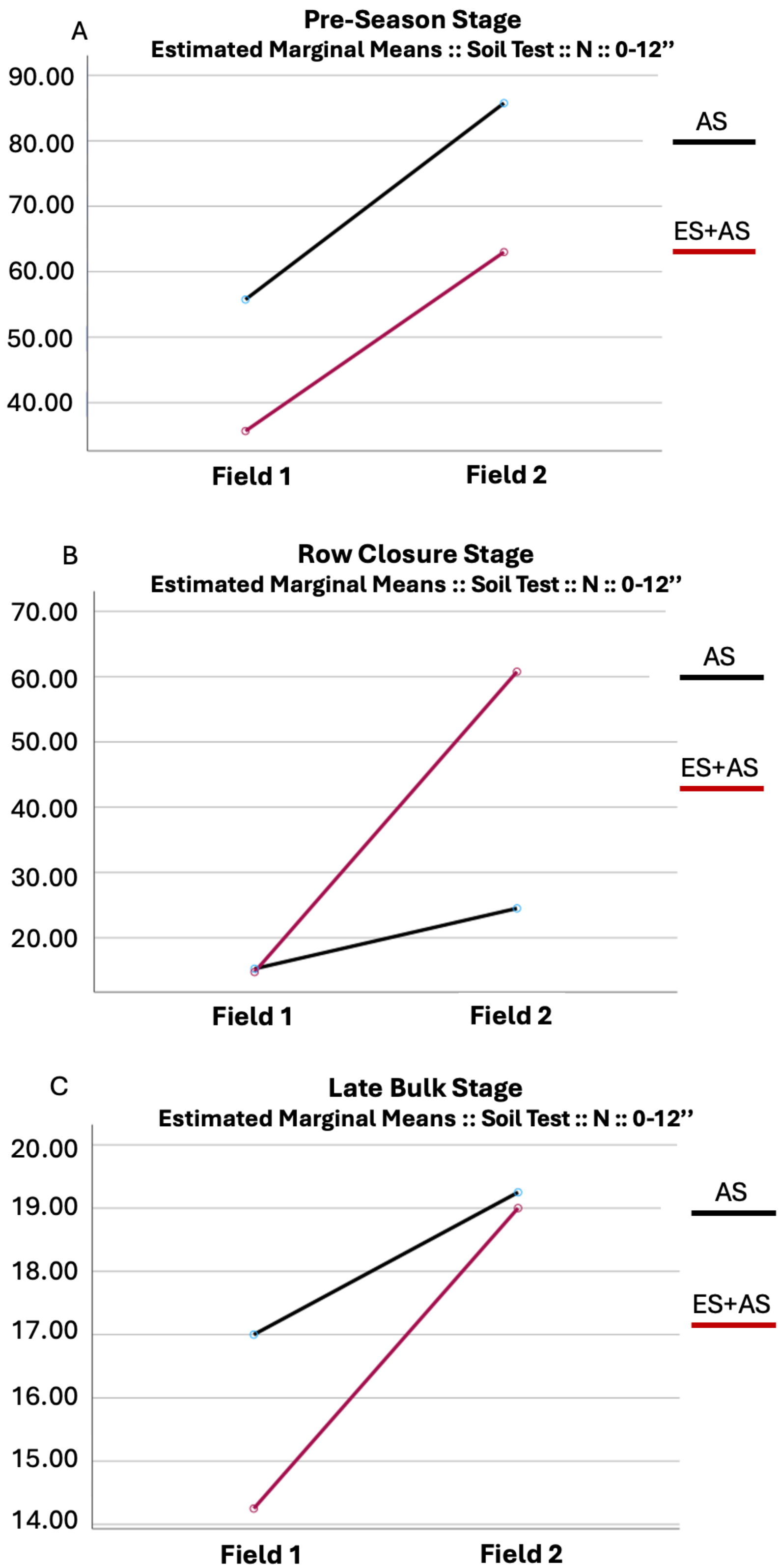
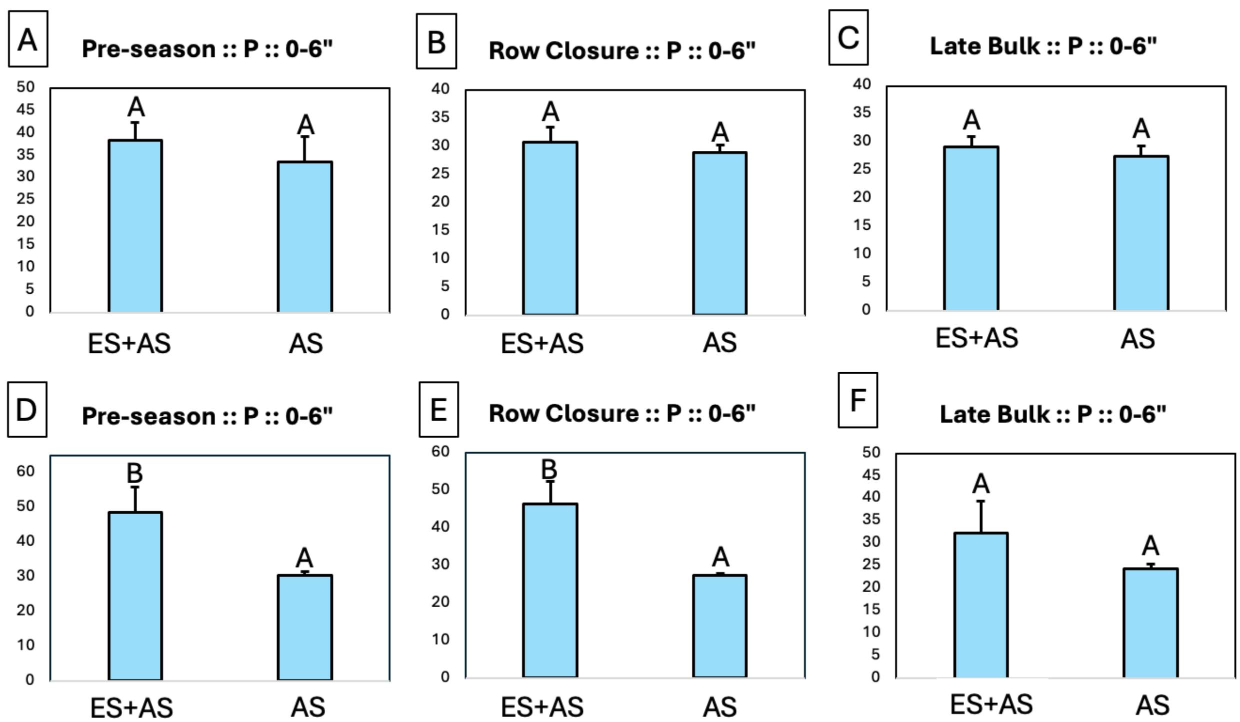


Figure 10. Nitrogen (N) content in Sulphur Field B (SFB) and Sulphur Field C (SFC) at different growth stages under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. Estimated marginal means of soil nitrogen levels (0–12 inches depth) are shown for each field. Black lines represent AS alone, while red lines represent ES+AS. (A) Nitrogen content at the pre-season stage, (B) Nitrogen content at the row closure stage, (C) Nitrogen content at the late bulking stage. Statistical analysis was conducted using two-way ANOVA with a post hoc least significant difference test (LSD) test at $P < 0.05$.

Phosphorus (P) and Potassium (K) Levels

No increase in phosphorus (P) and potassium (K) content was observed in either field, suggesting that baseline fertility was already sufficient, minimizing any additional impact from sulphur treatments (Figs. 11A-I, 12A-I).



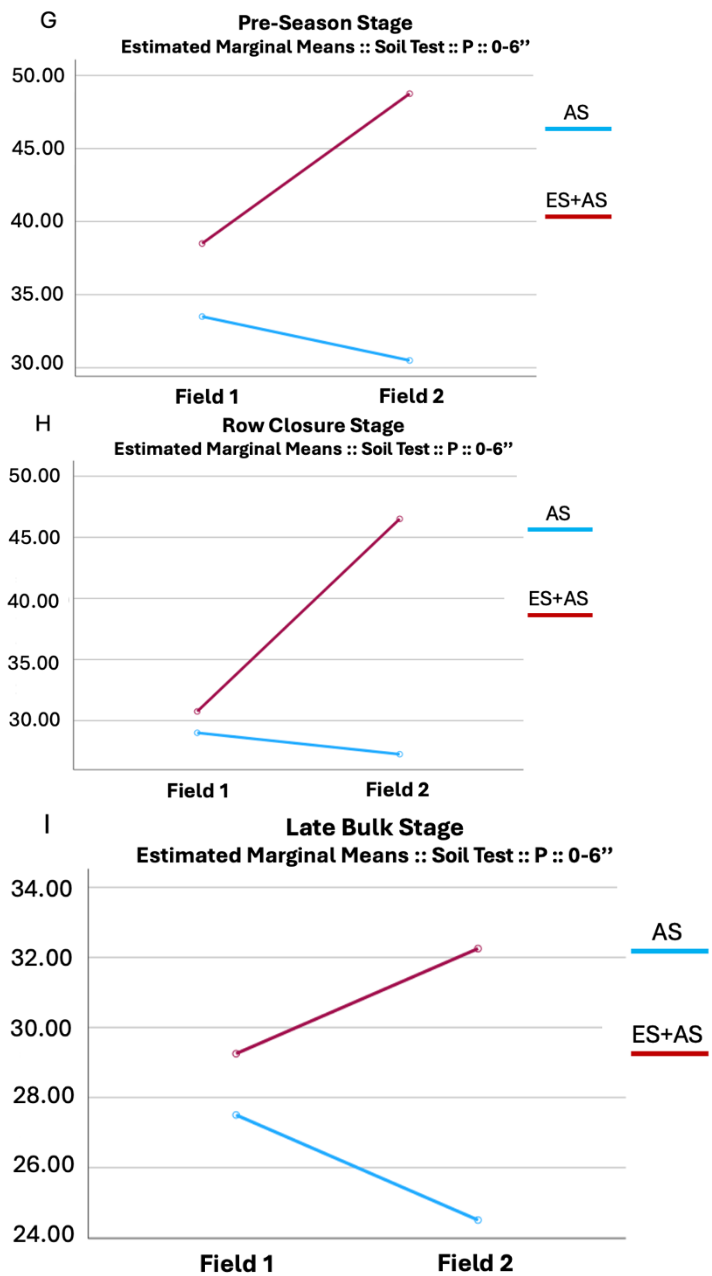
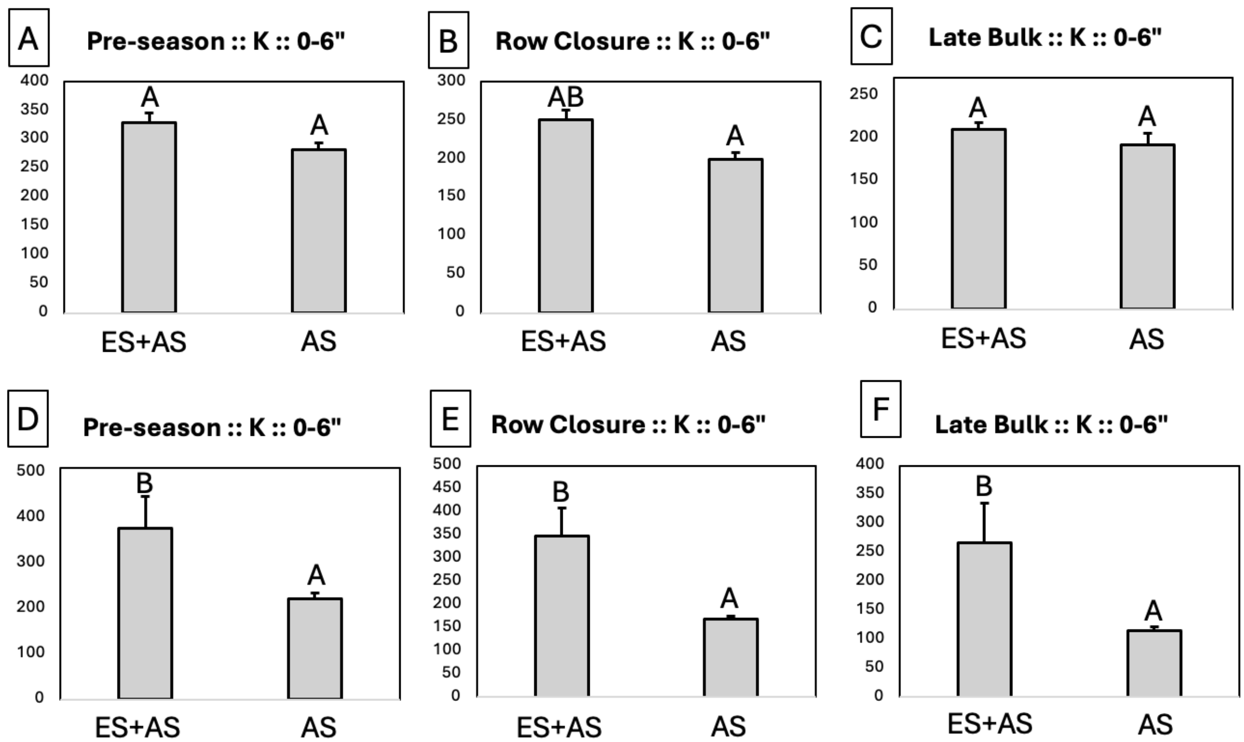


Figure 11. (A-F) Phosphorus (P) content in Sulphur Field B (SFB) and Sulphur Field C (SFC) at different growth stages under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A–C) Phosphorus content in SFB: (A) Pre-season stage, (B) Row closure stage, (C) Late bulking stage. (D–F) Phosphorus content in SFC: (D) Pre-season stage, (E) Row closure stage, (F) Late bulking stage. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

(G-I) Phosphorus (P) content in Sulphur Field B (SFB) and Sulphur Field C (SFC) at different growth stages under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. Estimated marginal means of soil phosphorus levels (0–6 inches depth) are shown for each field. Black lines represent AS alone, while red lines represent ES+AS. (A) Phosphorus content at the pre-season stage, (B) Phosphorus content at the row closure stage, (C) Phosphorus content at the late bulking stage. Statistical analysis was conducted using two-way ANOVA with a post hoc least significant difference test (LSD) test at $P < 0.05$.


A
Pre-season :: K :: 0-6"
ES+AS
AS
B
Row Closure :: K :: 0-6"
ES+AS
AS
C
Late Bulk :: K :: 0-6"
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D
Pre-season :: K :: 0-6"
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AS

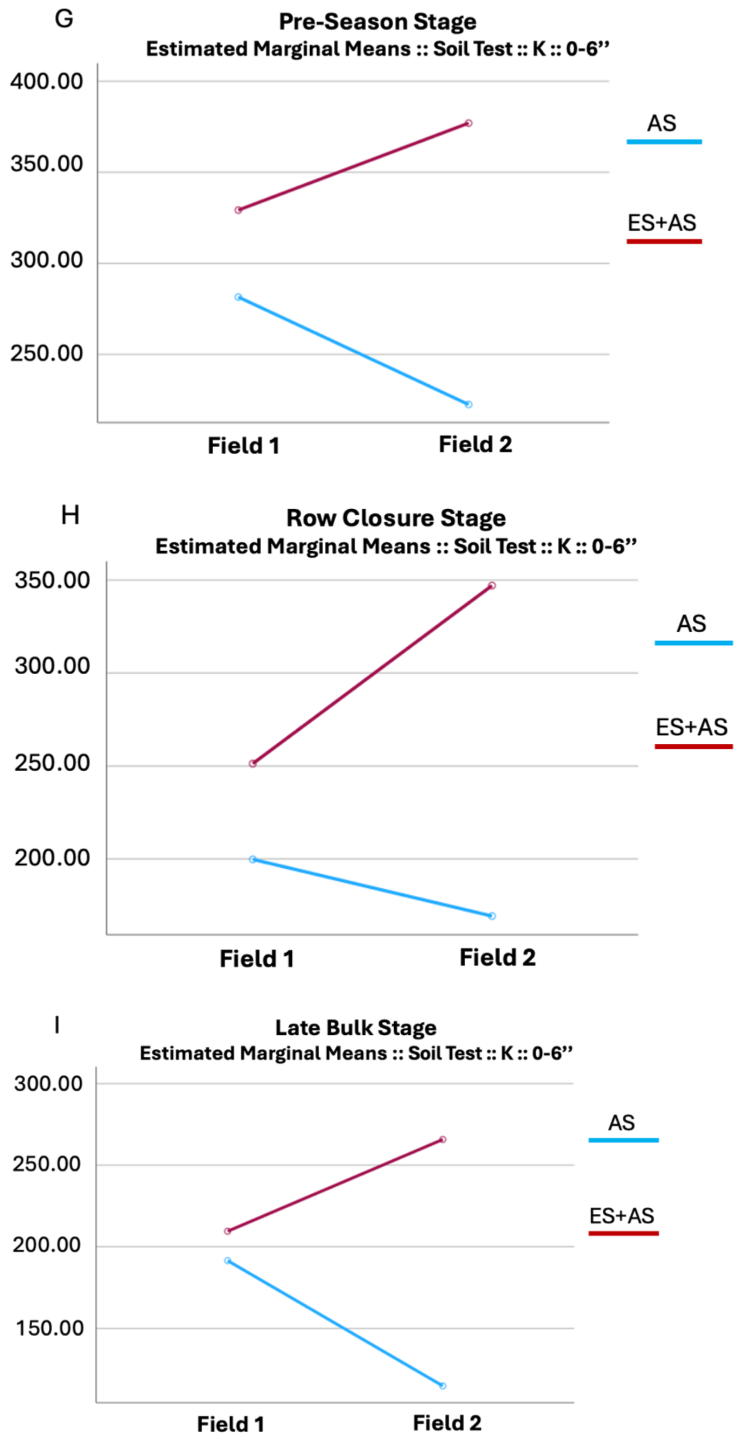

Figure 12. (A-F) Potassium (K) content in Sulphur Field B (SFB) and Sulphur Field C (SFC) at different growth stages under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. (A–C) Potassium content in SFB:(A) Pre-season stage, (B) Row closure stage, (C) Late bulking stage. (D–F) Potassium content in SFC: (D) Pre-season stage, (E) Row closure stage, (F) Late bulking stage. Letters on the bars indicate statistically significant differences based on one-way ANOVA with a post hoc least significant difference test ($P < 0.05$). Bars sharing the same letter are not significantly different from each other.

(G-I) Potassium (K) content in Sulphur Field B (SFB) and Sulphur Field C (SFC) at different growth stages under two treatments: Elemental Sulphur (ES) + Ammonium Sulphate (AS) and AS alone. Estimated marginal means of soil potassium levels (0–6 inches depth) are shown for each field. Black lines represent AS alone, while red lines represent ES+AS. (A) Potassium content at the pre-season stage, (B) Potassium content at the row closure stage, (C) Potassium content at the late bulking stage. Statistical analysis was conducted using two-way ANOVA with a post hoc least significant difference test (LSD) test at $P < 0.05$.

Conclusion

The trial demonstrated that elemental sulphur effectively increases sulphur availability over time, compensating for initially lower levels. However, under non-limiting fertility conditions, its impact on yield and tuber quality was negligible. While elemental sulphur may be beneficial in systems with sulphur deficiencies, it does not offer immediate advantages over conventional ammonium sulphate in already fertile soils. To improve the accuracy of comparisons between treatments, the trial should have included zones with elemental sulphur treatment alone, allowing for a clearer assessment of its standalone effects. Elemental sulphur should be considered in fields with known sulphur deficiencies or for long-term soil fertility management. Additionally, further research is needed to evaluate elemental sulphur's effectiveness under varying environmental conditions and soil microbial activity levels.

Acknowledgements

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