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Conservation agriculture, nitrogen and residual sulphur effects on maize (*Zea mays*) growth and yield in a long-term maize-Indian mustard (*Brassica juncea*) system

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of 2020–21 and 2021–22 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi to assess the effects of nitrogen and residual sulphur (S) on maize crop in the 11th year of a long-term conservation agriculture (CA)-based maize (*Zea mays* L.)-Indian mustard [*Brassica juncea* (L.) Czern.] cropping system. The CA-based practice CA₃ [ZT maize (ZTMz) + mustard residue (MsR) + brown manuring (BM) – ZT mustard (ZTMs) + maize residue (MzR)] resulted in greater maize plant height and dry weight than other CA and CT systems except CA₄ [ZTMz + mungbean residue (MbR) – ZTMs + MzR – ZTMb + MsR], which had comparable plant height and dry weight. The CA₃ increased maize dry weight by 9% and 11.7% over CT in 2020–21 and 2021–22, respectively. On the contrary, CA₄ exhibited highest root length, root mass, and root volume densities in both years, and CA₃ was comparable. It gave significantly higher grain yield than other treatments except CA₃ and CA₂ (ZTMz + MsR- ZTMs + MzR), which were comparable. The 100% and 75% recommended dose of N gave comparable grain yield under all CA-based treatments, indicating a saving of 25% N (~37.5 kg N/ha), mainly under CA practices. This highlights N economization over times in CA system. The 100% and 50% S applied to mustard could not show any significant residual effect on maize grain, stover and biological yields. Interactions between CA practices and N treatments for grain yield was significant but between CA and residual S, treatments were statistically similar. Thus, this study underscores the importance of CA framework for enhancing yield and income through better N and S management/savings in maize-mustard system.

Keywords: Conventional tillage, Crop residue retention, Nitrogen, Sulphur, Yield, Zero tillage

Agriculture faces dual challenges of meeting the increasing global demand for food while minimizing environmental degradation and resource depletion. Conservation agriculture (CA) is a promising sustainable farming approach that aims to enhance crop productivity while preserving natural resources (Kassam *et al.* 2009, Das *et al.* 2021, Kadam *et al.* 2022). Maize (*Zea mays* L.) and Indian mustard [*Brassica juncea* (L.) Czern.] are essential cereal and oilseed crops, respectively and are cultivated worldwide across agro-ecosystems. Maize is a viable alternative to rice and a potential driver for diversification of rice-wheat system in the Indo-Gangetic Plains (IGP) of India (Das *et al.* 2013, 2018, Meena *et al.* 2021) that can ensure food and nutritional security. Mustard having short

growing cycle and grown during *rabi* (winter) season under both rainfed and irrigated conditions is ideal for diversifying rice-wheat system as well as rice-fallow areas. Both maize and mustard being exhaustive feeders of nutrients, their continuous adoption may deplete nutrients from soil in substantial amounts, which may exceed the replenishments through fertilizers and manures. This would ultimately lead to depleting soil fertility, limiting crop productivity and fertilizer-use efficiency (Sinha 2018, Singh *et al.* 2022). The inadequacy in existing fertilizer recommendation and ignorance of nutrient balance also poses serious threat (Panwar 2008). Thus, nutrient management in this cropping system appears to be most crucial. Appropriate N application can significantly boost up crop yield and overall agricultural production (Mosier *et al.* 2013, Yadav *et al.* 2021). However, excessive N use can lead to environmental issues like nitrate leaching that may threaten water quality, and greenhouse gases emission that may contribute to climate change (Pathak *et al.* 2011). Sulphur (S) is often overlooked as a secondary

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nutrient in crop production, but when sulphur is appropriately provided in the field, it can enhance both crop yield and quality (Dwivedi *et al.* 2002). To optimize the potential benefits of CA, appropriate nutrient management identifying optimal nitrogen (N) dose, which balances yield output and environmental concerns is crucial (Oyeogbe *et al.* 2017). Therefore, this study was designed to evaluate the impact of N application and residual S on the growth and yield of maize in a long-term CA-based maize-mustard system.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*kharif*) seasons of 2020–21 and 2021–22 at the research farm of ICAR-Indian Agricultural Research Institute, New Delhi (28°38'38" N and 77°09'08" E; 228 m msl). Study was carried out in the 11th year of a CA-based diversified cropping system in which rice-maize (initial 3 years), rice-mustard (then 5 years), and maize-mustard (next 3 years) systems were adopted in fixed layout with similar treatments. Soil (order Inceptisol, typic Haplustept) was clayey loam in texture. The design in maize crop was split plot for first year experiment, while split-split plot for second year experiment as S was applied only in mustard. Four CA practices, viz. CA₁ [zero till maize (ZTMz)- zero till mustard (ZTMs)]; CA₂ [ZTMz + mustard residue (MsR)- ZTMs + maize residue (MzR)]; CA₃ [ZTMz + MsR + brown manuring (BM) – ZTMs + MzR]; and CA₄ [ZTMz + mungbean residue (MbR)- ZTMs + MzR – ZTMb + MsR] and a conventional tillage (CT) practice (CTMz- CTMs) were adopted in the main plots. The respective 75% and 100% recommended doses of N (RDN) of maize and mustard crops were included as subplot treatments and control (0%), 50% and 100% recommended dose of S (RDS) of mustard crop were adopted as sub-sub plot treatments. In this study, the RDN (maize) was 150 kg N/ha and the RDS (mustard) was 40 kg S/ha. One commercial sulphur fertilizer named 'Shri Uttam (Sulphur WDG 80%)', product of Karnataka crop science (India) used as sulphur source for this experiment.

Maize (Mz) and mustard (Ms) were sown under ZT without crop residue (R) in CA₁ treatment and with 40%

residue of maize (3.30 t/ha) and mustard (3.10 t/ha) in CA₂ treatment. Maize residue (MzR) was retained in ZTMs, and mustard residue (MsR) was retained in ZTMz. The CA₃ treatment was CA₂ plus brown manuring (BM) done additionally with maize (Das *et al.* 2019). Unlike double cropping CA₁, CA₂ and CA₃ systems, CA₄ was a triple cropping system with retention of three crops residue [i.e. 40% Mz (3.42 t/ha), 40% Ms (3.15 t/ha), 100% mungbean (Mb) residue (2.95 t/ha)]. The conventional tillage (CTMz-CTMs) system served as control. Maize 'PMH 1' was sown with a seed rate of 20 kg/ha at 60 cm row-spacing by using a turbo seeder for CA and a seed-cum-fertilizer drill for CT treatments. Recommended dose of 150 kg and 112.5 kg N (for 100% and 75% N, respectively), and 60 kg P₂O₅ and 40 kg K₂O per ha was applied to maize. The 50% N and full dose of P and K were applied as basal and remaining N in two equal splits at 30 and 60 days after sowing (DAS) of maize.

At 60 DAS, maize roots were collected from three consecutive rows in each plot using root auger (7 cm diameter) up to a soil depth of 15 cm, washed and dried in air. Total root length, surface area, volume, and average diameter were determined using WinRHIZO software (Himmelbauer 2004). Root dry weight was estimated after oven-drying at 65°C for 24 hours. Maize cobs were collected from net plots, sun-dried, and cob yield recorded. Maize grains were separated from the cobs and dried to about 12% moisture for grain yield. The net benefit:cost was the ratio of net returns to cost of cultivation. Data were subjected to analysis of variance in split plot design (first year data) and split-split plot design (second year data) using R software (version 4.0.5). The Tukey Multiple Comparison Test was used to determine differences between treatments at 5% level of significance.

RESULTS AND DISCUSSION

Maize plant height and dry matter accumulation: At 60 DAS in both years, maize plant height and dry matter accumulation differed significantly between the CA and CT practices (Table 1). In first year (2020–21), CA₃ had

Table 1 Effect of CA and N management on maize growth and root parameters at 60 DAS

| Treatment | Plant height (cm) | | Plant dry matter (g/m ²) | | Root length density (cm/cm ³) | | Root mass density (mg/cm ³) | | Root volume density (×10 ⁻² cm ³ /cm ³) | |
|----------------------------|---------------------|---------------------|--------------------------------------|--------------------|-------------------------------------------|-------------------|-----------------------------------------|--------------------|---------------------------------------------------------------------------|--------------------|
| | 2020–21 | 2021–22 | 2020–21 | 2021–22 | 2020–21 | 2021–22 | 2020–21 | 2021–22 | 2020–21 | 2021–22 |
| <i>CA practices</i> | | | | | | | | | | |
| CA ₁ | 191.8 ^b | 189.3 ^c | 778.2 ^d | 778.9 ^c | 3.33 ^c | 3.28 ^c | 10.96 ^c | 10.80 ^c | 5.89 ^c | 5.81 ^c |
| CA ₂ | 199.2 ^{ab} | 202.9 ^{ab} | 834.3 ^b | 806.1 ^b | 3.74 ^b | 3.80 ^b | 11.92 ^b | 12.10 ^b | 6.51 ^b | 6.61 ^b |
| CA ₃ | 203.8 ^a | 208.3 ^a | 871.9 ^a | 883.7 ^a | 4.14 ^a | 4.23 ^a | 12.62 ^a | 12.90 ^a | 6.71 ^b | 6.86 ^{ab} |
| CA ₄ | 202.3 ^a | 206.2 ^a | 870.2 ^a | 882.5 ^a | 4.18 ^a | 4.30 ^a | 12.99 ^a | 13.36 ^a | 7.02 ^a | 7.22 ^a |
| CT | 193.2 ^b | 193.0 ^{bc} | 808.8 ^c | 790.0 ^c | 3.08 ^d | 3.11 ^c | 10.18 ^d | 10.28 ^c | 6.10 ^c | 6.16 ^c |
| <i>Nitrogen management</i> | | | | | | | | | | |
| 75% RDN | 196.3 ^a | 198.0 ^a | 816.2 ^a | 814.5 ^a | 3.67 ^a | 3.72 ^a | 11.58 ^a | 11.74 ^a | 6.4 ^a | 6.48 ^a |
| 100% RDN | 199.8 ^a | 201.9 ^a | 849.1 ^a | 842.0 ^a | 3.71 ^a | 3.76 ^a | 11.88 ^a | 12.04 ^a | 6.5 ^a | 6.59 ^a |

*Treatments with the same letter are not significantly different. Treatment details are given under Materials and Methods.

the greatest maize plant height (203.8 cm), which was similar to that in CA₄ (202.3 cm). These plant heights were significantly greater than in other CA and CT treatments. The trend was consistent in second year (2021–22). Again, in both years, CA₃ exhibited highest dry matter accumulation in maize plants (871.9 g/m²), which was significantly higher than in other CA and CT treatments except CA₄, which was comparable (Table 1). The CA₃ increased maize plant dry matter by 8% and 11.9% over CT in 2020–21 and 2021–22, respectively. Competition between maize and brown manure crop during initial 25–30 DAS might have led to slight increase in maize plant height in CA₃ plots, otherwise, both CA₄ and CA₃ had similar plant height (Das *et al.* 2019). Both these treatments (CA₄, CA₃) having triple and double ZT plus three crops residue (100% MbR + 40% MzR + 40% MsR in CA₄; 40% MsR + 100%BM + 40% MzR in CA₃) contributed equally towards improved soil health and nutrients retention, leading to better dry matter accumulation, root growth and plant height (Saad *et al.* 2015). *Sesbania* brown manuring not only added plant nutrients in soil but also reduced inadvertent weed growth (although common weed control measures adopted), which might enhance maize crop growth (Das *et al.* 2019). This effect was further reflected under the 100% and 75% RDN (Table 1), which had statistically similar maize plant height and dry matter accumulation, although 100% RDN exhibited slightly greater plant height (199.8 and 201.9 cm) and dry weight (849.1 and 842.0 g/m²) than 75% RDN (196.3 and 198.0 cm; 816.2 and 814.5 g/m²). Crop residue decomposition for last 10 years might have accumulated sufficient N in soil and improved the capacity of soil to supply adequate N to maize crop under 75% RDN. Similarly, the S applied to mustard (100%, 50% and control/no S) had no significant effect on maize plant height and dry weight (Table 2), although 100% S application plots gave numerically greater plant height and dry matter accumulation. This indicated sufficiency of S in soil under the CA-based practices having crop residue retention over times, which nullified the residual effect of applied S to mustard.

Maize root growth characteristics: The impact of different CA practices on maize root growth studied in 2020–21 and 2021–22 (Table 1) revealed that, among the CA treatments, CA₄ consistently exhibited highest root length density, root mass density, and root volume density in both years. In 2020–21, CA₄ resulted in root length density of

4.18 cm/cm³ of soil, root mass density of 12.99 mg/cm³ of soil, and root volume density of 7.02×10^{-2} cm³/cm³, all of which were significantly higher than those in CA₁, CA₂ and CT, but statistically similar with CA₃ practice. Similar root length, mass, and volume were recorded in second year too, of course, CA₄ proved superior to others. These root characteristics increased by 15.7–31.1% in CA₄ compared to CT. As already mentioned above, CA₄ system involving triple ZT system with three crops residue might have increased soil porosity and reduced soil bulk density, thereby promoting more extensive and denser root development of maize, which had positive implications on nutrient uptake, water absorption, and overall plant health (Nath *et al.* 2017). Maize root growth did not differ significantly between 100% and 75% RDN (Table 1), but differed significantly between the S levels applied to mustard crop (Table 2). Both 100% and 50% RDS applied to mustard significantly led to significant improvement in maize root growth (length, mass, and volume) over no S application (control).

Maize grain, stover, and biological yields and harvest index: The triple cropping ZT with residue, CA₄ resulted in significantly higher maize grain yield in both years (2020–21, 2021–22) than other treatments except CA₃ and CA₂, which were comparable with it (Table 3). In first year, this treatment led to an increase in grain yield by 23.5% and 18.5% compared to ZT without residue (CA₁) and CT treatments, respectively. Similarly, in second year too (Table 3), it gave highest grain yield (6.30 t/ha), which exceeded the grain yields in CA₁, CA₂, CA₃, and CT by 22.5%, 7.6%, 8.5%, and 21.1%, respectively. Contrary to grain yield, stover and biological yields were significantly higher in CA₃ treatment, and CA₄ was comparable in both years (Table 3). In first year, CA₃ showed an increase in stover yield by 15.3% and 11.9% over CA₁ and CT, respectively. It gave 14.0% higher biological yield than CT, which was significantly higher than in other treatments except CA₄. In second year too, CA₃ treatment led to highest biological yield, which was 17.0%, 8.5% and 15.8% higher than those in CA₁, CA₂ and CT, respectively. In both years, CA₄ gave higher harvest index (45.1%, 45%), implying that maize crop in this CA practice was more efficient in partitioning biomass to grain. Higher grain yield observed under CA₄ might be attributed to the practice of ZT with three crops (mungbean, maize, mustard) residue retention

Table 2 Effect of residual sulphur on the maize growth and root parameters, yields, harvest index and economics in second year (2021–22)

| Sulphur applied to mustard | Plant height (cm) | Dry matter (g/m ²) | Root length density (cm/cm ³) | Root mass density (mg/cm ³) | Root volume density ($\times 10^{-2}$ cm ³ /cm ³) | Grain yield (t/ha) | Stover yield (t/ha) | Biological yield (t/ha) | Harvest index (%) | Net B:C |
|----------------------------|--------------------|--------------------------------|-------------------------------------------|-----------------------------------------|---------------------------------------------------------------------------|--------------------|---------------------|-------------------------|-------------------|-------------------|
| Control | 198.0 ^a | 815.7 ^a | 3.62 ^b | 11.48 ^b | 6.31 ^b | 5.61 ^a | 7.32 ^a | 12.93 ^a | 43.1 ^a | 1.28 ^a |
| 50% RDS | 200.2 ^a | 827.9 ^a | 3.77 ^a | 12.01 ^a | 6.59 ^a | 5.70 ^a | 7.41 ^a | 13.11 ^a | 43.3 ^a | 1.32 ^a |
| 100% RDS | 201.7 ^a | 841.1 ^a | 3.84 ^a | 12.18 ^a | 6.70 ^a | 5.78 ^a | 7.51 ^a | 13.30 ^a | 43.4 ^a | 1.35 ^a |

*Treatments with the same letter are not significantly different.

Table 3 Effect of CA and N management on maize yield parameters, harvest index and economics

| Treatment | Grain yield (t/ha) | | Stover yield (t/ha) | | Biological yield (t/ha) | | Harvest index (%) | | Net B:C | |
|----------------------------|-----------------------|-------------------|------------------------|--------------------|----------------------------|--------------------|----------------------|-------------------|-------------------|-------------------|
| | 2020–21 | 2021–22 | 2020–21 | 2021–22 | 2020–21 | 2021–22 | 2020–21 | 2021–22 | 2020–21 | 2021–22 |
| <i>CA practices</i> | | | | | | | | | | |
| CA ₁ | 5.09 ^c | 5.15 ^c | 6.86 ^c | 6.95 ^c | 11.95 ^c | 12.10 ^c | 42.7 ^a | 42.5 ^a | 1.21 ^c | 1.23 ^b |
| CA ₂ | 5.80 ^b | 5.61 ^b | 7.35 ^b | 7.44 ^b | 13.14 ^b | 13.05 ^b | 44.1 ^a | 42.9 ^a | 1.33 ^b | 1.25 ^b |
| CA ₃ | 6.17 ^a | 6.22 ^a | 7.91 ^a | 7.95 ^a | 14.08 ^a | 14.16 ^a | 43.9 ^a | 43.8 ^a | 1.45 ^a | 1.46 ^a |
| CA ₄ | 6.26 ^a | 6.30 ^a | 7.65 ^a | 7.71 ^{ab} | 13.90 ^a | 14.01 ^a | 45.1 ^a | 45.0 ^a | 1.52 ^a | 1.53 ^a |
| CT | 5.28 ^c | 5.20 ^c | 7.07 ^{bc} | 7.03 ^c | 12.35 ^c | 12.23 ^c | 42.7 ^a | 42.4 ^a | 1.15 ^c | 1.13 ^c |
| <i>Nitrogen management</i> | | | | | | | | | | |
| 75% RDN | 5.57 ^a | 5.60 ^a | 7.09 ^b | 7.32 ^a | 12.72 ^b | 12.93 ^a | 43.9 ^a | 43.2 ^a | 1.28 ^a | 1.29 ^a |
| 100% RDN | 5.87 ^a | 5.79 ^a | 7.65 ^a | 7.50 ^a | 13.51 ^a | 13.29 ^a | 43.5 ^a | 43.4 ^a | 1.39 ^a | 1.34 ^a |

*Treatments with the same letter are not significantly different. Treatment details are given under Materials and Methods.

in a system mode. Residues acted as a protective layer, reducing soil erosion, conserving moisture and organic matter, and fostering nutrient cycling and availability to crops, which are crucial for sustaining crop growth (Jat *et al.* 2019). The ZT without residue treatments having lower grain, stover and biological yields than ZT+ residue plots highlighted the role/need of residue for higher yield. The CT system that involves intensive tillage (without residue) results in loss of carbon and other nutrients (Nandan *et al.* 2019), and surface soil loses moisture rapidly through evaporation, resulting in poor crop germination/stands and lower crop yield (Das *et al.* 2018).

The mean effect of N exhibited that the 100% and 75% RDN were comparable on grain yield in both years, and on stover and biological yields in second year (Table 3). Further, the interaction effect between CA and N showed that these 100% and 75% RDN were comparable on maize grain yields only under the CA₄, CA₃ and CA₂ practices (Supplementary Table 1). The CT and CA₁ (ZT without residue) practices showed significant variation on grain yield between 100% and 75% RDN. This highlighted the superiority of CA practices over CT on N economization over times, which led to a saving of 25% N (~ 37.5 kg N/ha) in maize. Residual effect of 100% and 50% RDS (applied to mustard) on maize grain, stover, and biological yields was non-significant across CA and CT treatments (Table 2 and Supplementary Table 1). Probably, S was sufficient in soil for maize crop under both CA and CT plots, showing no significant variation in yields. Otherwise, significant variation in mustard yield was observed between S doses in both years under this maize-mustard system.

Benefit-cost analysis: Economic analysis is crucial for evaluating the profitability of agricultural practices. Net benefit: cost (~net B:C) calculated from the net benefit divided by cost of cultivation is an indicator of cost-effectiveness. The CA₄ with higher net B:C of 1.52 and 1.53 was superior to CA₁, CA₂, CA₃, and CT in both years. Higher net B:C of CA₄ could reveal its higher economic viability than other treatments.

This study showed that the ZT triple cropping with residue (CA₄, ZTMz + MbR- ZTMs + MzR- ZTMb + MsR) had higher maize root growth, grain yield, harvest index, and economic returns than CT and other ZT without residue. Another ZT double cropping with residue+ brown manuring (CA₃, ZTMz + MsR + BM- ZTMs + MzR) was comparable with it. The CA₄ through giving comparable maize grain yield between 100 and 75% N and between 100 and 50% residual S, could lead to savings of 25% N and 50% S. This CA-based maize-mustard system should be recommended for enhancing maize productivity and farm profitability in Indian IGP and in similar agro-ecologies of the tropics and sub-tropics.

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