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Conservation agriculture practices and sulphur fertilization effects on productivity and resource-use efficiency of rainfed mustard (*Brassica juncea*)

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ABSTRACT

Moisture and sulphur deficiency in soil are major reasons for low productivity of mustard [*Brassica juncea* (L.) Czern.] in rainfed semi-arid areas. To overcome this problem a field experiment was conducted during 2013–15 to find out the effect of conservation agriculture and sulphur fertilization on productivity and resource-use efficiency of mustard under rainfed conditions. Five tillage and residue management practices, i.e. conventional tillage with 0, 2 and 4 t/ha crop residue; zero tillage with 2 and 4 t/ha crop residue were allocated to main plots and four sulphur levels (0, 15, 30 and 45 kg S/ha) in sub-plots. Result showed that zero tillage with 4 t/ha crop residue produced 24.6% higher mustard seed yield than conventional tillage without residue resulted maximum net returns (44.7×10^3 ₹/ha). Similarly, highest water use efficiency (12.7 kg/ha mm) and total nutrient uptake were also recorded in the same treatment. Increasing levels of sulphur (S) up to 45 kg/ha significantly increased seed and oil yield (37.5%). However, sulphur use efficiency was decreased with graded levels of sulphur. Conversely, higher net returns (47.6×10^3 ₹/ha) and benefit-cost ratio (1.89) were fetched with 45 kg S/ha.

Key words: Crop residue, Nutrient balance, oil, Sulphur, Tillage

Rapeseed-mustard is the third important oilseed crop in the world after soybean and palm oil. In India, it accounts for 23% of the total oilseeds area and 27% of the total oilseeds production. Mostly they are cultivated for edible oils but used as condiments, spices, leafy vegetable and as fodder for livestock. However, its productivity is far below than the other countries. Of the several reasons moisture stress is the most important one because it is generally grown in rainfed semi-arid regions. Conservation agriculture (CA) is becoming popular globally because of its potential to increase productivity, profitability, resource-use efficiency and soil quality, besides many environmental benefits (Friedrich *et al*. 2017, Jat *et al.* 2020). Many studies have been conducted on CA in rice-wheat rotation in irrigated Indo-Gangetic Plains of South Asia, but very few studies conducted in rainfed areas. Soil cover or residues have important role in the success of CA. However, the major constraint in adoption of CA in dry areas is non-availability of crop residues due to competing demands of residue for livestock fodder (Valbuena *et al.* 2012). Further, costs are also involved in their application. Therefore, it is necessary that a suitable amount should be applied to enhance crop productivity in a cost-effective manner.

Widespread sulphur (S) deficiency in soils is another reason for low productivity of mustard in rainfed areas (Rego *et al*. 2007). Asia has the largest S deficient soil with India (40%) and China (30%) in the lead (Messick 2014). Its deficiency occurs mainly due to leaching, shift towards S-free fertilizers and removal of more amounts of S from the field by high-yielding varieties. Sulphur application in deficient soils significantly increased crop yield in the on-farm studies (Gupta and Jain 2008). However, for sustained increase in productivity of rainfed areas, soil and water conservation measures need to be integrated with plant nutrition, and choice of crops and their management. These evidences suggest that optimization of tillage with residue and sulphur fertilization could be a key factor for achieving more remuneration and maintaining soil health. Considering these facts, a field experiment was conducted to assess the effects conservation agriculture practices, and S fertilization on productivity, and resource use efficiency of mustard under rainfed semi-arid environment.

MATERIALS AND METHODS

A field experiment was conducted at the Research Farm of Indian Agricultural Research Institute, New Delhi, India during *rabi* 2013–14 and 2014–15. The experimental site was situated at $28^0 38'23''$ N latitude and $77^0 09'27''$ E longitude and at an altitude of 228.6 m above mean sea level in a semi-arid sub-tropical climatic belt. It was characterized by extreme temperatures, the annual maximum

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temperature goes up to as high as 45°C in summer, whereas the minimum temperature dips to as low as 1°C in winter. The total rainfall received during crop growing season was 128 and 242 mm in first and second year, respectively. The soil of experimental site was sandy loam in texture, slightly alkaline in reaction (pH 7.8), low in organic carbon (4.5 g/kg soil) and available nitrogen (139.7 kg/ha) and medium in available P (15.2 kg/ha) and K (178.8 kg/ha) and deficient in available S (8.8 mg/kg soil).

The experiment was laid out in split-plot design with three replications in a fixed lay out. The main plot treatments consisted of five tillage and residue management (CA) practices, viz. conventional tillage without crop residue; conventional tillage with 2 and 4 t/ha crop residue; zero tillage with 2 and 4 t/ha crop residue while four S levels (0, 15, 30 and 45 kg S/ha) were assigned in sub-plots. In conventional tillage, field was prepared with a disc plough followed by two pass of a disc harrow and planking in the last to have a uniform seed bed of fine tilth. No tillage operation was carried out in zero- tilled plot. Crop residues of previous season pearl millet were applied by spreading the material uniformly on the field just after sowing. Sulphur was applied through agriculture grade gypsum ($CaSO_4.2H_2O$) containing 13% S at the time of field preparation as per treatment. Mustard (Pusa mustard 28) was sown on 18th and 30th of October 2013 and 2014, respectively with a spacing of 45 cm. Uniform dose of N, P_2O_5 and K_2O at 80:40:30 kg/ha were applied. Entire P and K were applied as basal through di-ammonium phosphate (DAP) and muriate of potash, respectively at the time of sowing, whereas N was applied in two equal split through urea. In zero-tilled (ZT) plots weeds were managed by glyphosate 41 SL at 2 litres/ha ten days before sowing and pendimethalin 30 EC at 0.75 kg a.i./ha as pre-emergence. Plant population was maintained by thinning at 15-20 days after emergence. Crop was grown on residual soil moisture and only one pre-sowing irrigation was given in second year. Aphids were controlled by spraying of dimethoate 30EC at 0.03%.

At maturity, seed and stalk yield of mustard was recorded from the net plot and was expressed at 8 and 15% moisture level, respectively. Grain analyzer (FOSS Infratec^{TM} 1241) based on near infrared transmittance technology was employed for non-destructive method of oil estimation to determine oil content in the whole seed. Oil yield was determined by multiplying the oil content with seed yield. Water-use efficiency was calculated by dividing seed yield with consumptive use (~ET) of water. The evapotranspiration (ET) from each treatment plot was calculated from the soil moisture difference between beginning and end of the cropping season to which the effective rainfall of the period was added. Effective rainfall was calculated by USDA Soil Conservation Service method in CROPWAT 8.0 (model developed by FAO). The N, P, K and S content in plant samples were analysed by Kjeldahl, Vanado-molybdate yellow color, Flame-photometric and Turbidimetric method, respectively as per procedure described by Jackson (1973). Thereafter, the uptake of nutrient was calculated by multiplying concentration with their respective yield. Apparent nutrient balance was calculated by differences between the inputs (from fertilizer and crop residue) and outputs. Partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) of applied S were computed as suggested by Baligar *et al*. (2001).

The economics of the treatment was calculated based on prevailing prices of inputs and output. Benefit: cost ratio was calculated by dividing net return with cost of cultivation. Data were analysed by two-way Analysis of Variance (ANOVA) with Tukey's multiple comparison at $P<0.05$ using Genstat 18th edition (VSN International Ltd., Hemel Hempstead, UK).

RESULTS AND DISCUSSION

Crop productivity: Significant difference ($P<0.05$) in seed and stalk yield of mustard were recorded in CA practices (Table 1). On an average, marginally higher, the seed and stalk yield of mustard were recorded under ZT than CT at corresponding residue level. Zero tillage with 4 t/ha crop residue showed 24.5 and 25.4% higher seed and stalk yield over CT without residue, respectively. High residue load (4 t/ha) on an average gave 9.6% increased seed yield over low residue load (2 t/ha) irrespective of tillage. At same residue level both the tillage produced on par seed and stalk yield of mustard. This could be attributed to residue effect on soil surface characteristics. It is likely that applying the same amount of residue in both tillage regimes have assisted the soil with the same benefits in terms of developing favorable soil surface. This experiment was conducted in rainfed conditions on conserved soil moisture. In that situation, the role of residue in conserving soil moisture coupled with enhanced the nutrient supply through decomposition created conducive environment for plant growth and development (Choudhary *et al*. 2019).

With regards to S fertilization, increasing levels of S significantly increased the seed and stalk yield of mustard (Table 1). Application of S at 45 kg/ha significantly improved the seed and stalk yield of mustard by 28.2 and 26.2% over control, respectively. However, this treatment was found comparable with 30 kg S/ha. Sulphur plays a vital role in improving vegetative structure for nutrient absorption, strong sink strength through development of reproductive structures and production of assimilates to fill economically important sink (Prasad and Shivay 2018). Since the experimental soil was deficient in available S (8.8 mg/kg), so application of S to soil increased the availability of SO_4-S in soil, which might have helped the crop to achieve better growth and yield. Seed yield is a product of yield attributing characters.

Oil content and oil yield: Mustard crop planted under ZT with 4 t/ha crop residue produced significantly higher oil content (40.5%) in seeds (Table 1). However, this treatment was on par with all other treatments except CT without residue. Similarly, the highest mustard oil yield was observed in ZT–CR4 with an increase of 28.9% over

Table 1 Effect of conservation agriculture practices and sulphur fertilization on productivity and oil yield of mustard (pooled over two years)

Treatment	Seed yield (t/ha)	Stalk yield (t/ha)	Oil content (%)	Oil yield (kg/ha)	Water-use efficiency (kg/ha- mm)	Total cost (×10^3 ₹/ha)	Net returns (×10^3 ₹/ha)	B:C ratio
CA practices								
CT–CR0	1.75 c	5.50 c	39.0 b	687 d	9.4 d	18.9	40.5 ab	2.14 a
CT–CR2	1.89 bc	5.92 bc	39.6 ab	751 cd	10.5 c	26.0	38.1 b	1.47 b
CT–CR4	2.06 ab	6.63 ab	40.1 ab	827 ab	12.0 ab	32.6	37.2 b	1.14 c
ZT–CR2	1.98 b	6.22 b	39.9 ab	794 bc	11.1 bc	22.8	44.4 a	1.95 a
ZT–CR4	2.18 a	6.90 a	40.5 a	886 a	12.7 a	29.4	44.7 a	1.52 b
Sulphur level (kg/ha)								
0	1.70 c	5.41 c	38.3 d	653 d	9.7 c	25.3	32.4 c	1.32 c
15	1.93 b	6.00 b	39.5 c	765 c	10.9 b	25.9	39.6 b	1.58 b
30	2.08 a	6.49 a	40.4 b	841 b	11.7 a	26.2	44.3 a	1.77 a
45	2.18 a	6.83 a	41.1 a	898 a	12.3 a	26.5	47.6 a	1.89 a

Means followed by the same letter within a column are not significantly different at 0.05 level of probability by Tukey's HST test.

CT without residue. Residue application increased seed oil content for two possible reasons. The first reason could be nutrient content of crop residue particularly nitrogen (N) which converted into an available form of N. The second reason for the greater seed oil content with residue incorporation could be related to soil moisture availability. Higher residue (4 t/ha) level increased soil water capture as is decreased water loss through evaporation and improved soil water infiltration. The high soil water availability once again expands crop maturation period. This provides a greater period for oil accumulation by stimulating leaf cellular activities towards oil production pathways (Omidi *et al*. 2010).

Oil content in mustard seed increased with graded application of S and highest oil content was recorded under 45 kg S/ha. Likewise, oil yield also was improved with S fertilization. Progressive increase in S levels up to 45 kg S/ha increased oil yield. Crop fertilized with 45 kg S/ha produced 37.5% higher oil yield over control. The increase in oil concentration due to role of S in oil synthesis, as S is a constituent of glutathione, a compound that play a vital role in oil synthesis (Prasad and Shivay 2018). Oil yield is a function of oil content and seed yield, both the components increased with increasing level of S resulting in a significant increase in oil yield.

Water use efficiency: Water use efficiency of mustard differed significantly among treatments. Higher water use efficiency (12.7 kg/ha-mm) was recorded in ZT-CR4 while lowest in CT without residue (9.4 kg/ha-mm) (Table 1). At same residue cover, water use efficiency in CT and ZT was statistically on par. The spreading of residue at the soil surface in ZT system helped in reducing evaporation losses and hence conserving soil moisture (Ranaivoson *et al*. 2017). Higher soil moisture in the seed-zone not only gave better crop growth but also increased water-use efficiency. Greater soil moisture retention and moderated soil thermal regime under residue applied plots resulted in higher seed yield and lowering of water use, thus led to increased water use efficiency. The higher yield advantage in moisture deficit condition supports the concept of better soil moisture environment in CA based management practices (Pradhan *et al*. 2018). There was also increase in water use efficiency with increasing sulphur level up to 45 kg/ha mainly because of increased in the yield.

Nutrient uptake and apparent balance: In general, total N uptake (seed + stalk) was almost five times more than P and twice of S uptake (Table 2). However, K uptake was similar to N uptake. Maximum total uptake of N, P, K and S was recorded in ZT–CR4 which is 25.8, 5.6, 22.8 and 10.9 kg higher over CT–CR0, respectively. This might be due to improved physical environment under ZT–CR4 favorable for better microbial activity that might have favored mineralization resulting better availability of nutrients (macro and micro) to crops and thus increased the nutrients uptake. In most of the treatments, N and P apparent balance was positive however K and S was negative. The negative balance of K was reduced to minimum, while there was build-up of N and P in CT-CR4. This might be due to lower uptake of nutrients because of sub-optimal performance of crops under CT and also richer fertility due to addition of considerable amount of crop residue. Luxury uptake nature of crops for K was the cause for negative apparent balance in all the treatments.

As the dose of S increases, the uptake of nutrients increased but apparent nutrient balance in the soil decreased except S. Sulphur balance was increased from negative values of –29.8 kg/ha in control to a positive build-up of 3.4 kg/ha at 45 kg S/ha. The proportionate increase in S uptake was more than primary nutrients (N, P and K). Higher apparent balance of S is most likely because of less uptake of S in comparison to addition through S fertilization. The interaction between N and S is generally positive and occasionally additive in S deficient soil (Jamal *et al*. 2010). So, N content in plant increased with S fertilization.

Table 2 Effect of conservation agriculture practices and sulphur fertilization on apparent nutrient balance of mustard.

Treatment	Total nutrient uptake (kg/ha)				Apparent nutrient balance (kg/ha)			
	N	P	K	S	N	P	K	S
CA practices								
CT–CR0	80.2 d	15.7 d	71.0 d	34.5 d	-0.2	1.8	–46.1	–12.0
CT–CR2	87.9 c	17.5 c	78.4 c	38.2 c	5.9	3.7	–25.1	–12.6
CT–CR4	97.1 b	19.3 b	86.5 b	41.9 b	10.5	5.6	–4.8	–13.2
ZT–CR2	93.6 bc	18.5 bc	83.0 bc	40.3 bc	0.2	2.7	–29.7	–14.7
ZT–CR4	106.0 a	21.3 a	93.8 a	45.4 a	1.6	3.6	–12.1	–16.7
Sulphur level (kg/ha)								
0	78.6 d	15.7 d	71.1 c	33.5 d	17.9	6.2	–12.1	–29.8
15	90.3 c	17.9 c	80.3 b	38.7 c	6.3	4.0	–21.3	–20.0
30	98.5 b	19.5 b	87.5 a	42.6 b	–1.9	2.4	–28.5	–8.9
45	104.5 a	20.7 a	91.3 a	45.4 a	–7.9	1.2	–32.4	3.4

Means followed by the same letter within a column are not significantly different at 0.05 level of probability by Tukey's HST test.

Increasing S content in plant with S application might be due to increased availability of S in soil. Since, uptake of the nutrient is the function of nutrient content and biomass production, the significant increase in yield coupled with nutrient content enhanced the total uptake of nutrients.

Sulphur-use indices: Sulphur-use efficiency was quantified in terms of partial factor productivity (PFP), agronomic efficiency (AE), recovery efficiency (RE) and physiological efficiency (PE) of applied S through gypsum (Fig 1). As expected PFP, AE, RE and PE of S decreased as the level of S increased. On an average the highest PFP, AE, RE and PE of applied S was recorded with 15 kg S/ha and decreased substantially with increasing level of S.

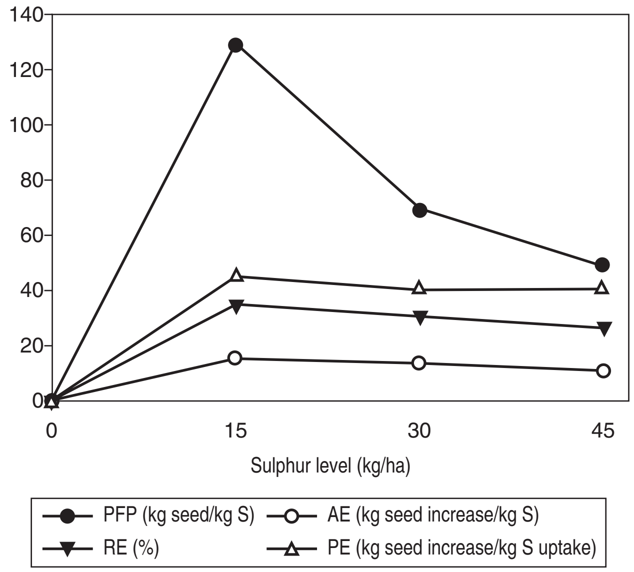

Fig 1 Relationship between sulphur fertilization and sulphur use indices in mustard. PFP, Partial factor productivity (kg seed/kg sulphur); AE, agronomic efficiency (kg seed increase/kg sulphur); RE, recovery efficiency (%); PE, physiological efficiency (kg seed increase/kg sulphur uptake).

Partial factor productivity was 128.9 kg seed/kg S for 15 kg S/ha and declined to 48.6 kg seed kg/S in 45 kg S/ha. Similarly, AE, RE and PE was declined with higher dose of S. The reduction in S use indices with successive increase in levels of S might be due to that the increase in levels of S did not bring corresponding increase in seed yield.

Economic analysis: Conservation agriculture practices and S fertilization had significant ($P<0.05$) effect on economics of mustard production (Table 1). Total cost of mustard cultivation under different CA practices varied from minimum under CT–CR0 (18.9×10^3 ₹/ha) to maximum under CT–CR4 (32.6×10^3 ₹/ha), While, maximum net returns were computed in ZT–CR4 (44.7×10^3 ₹/ha) and lowest under CT–CR4 (37.2×10^3 ₹/ha). Maximum B:C ratio (2.14) was found under CT without residue. Irrespective of residue, lower cost of cultivation in ZT treatment was attributed mainly to reduced cost of land preparation and weed control. Higher net returns in ZT–R4 due to more returns from higher yield as compared to cost involved under this treatment. However lower B:C ratio under residue applied plots mainly because of proportionate returns from residue was less in comparison to cost involved. Consistent to our results higher net returns and reduction in cost of cultivation with ZT practices was reported by many workers (Choudhary *et al*. 2017, Jakhar *et al*. 2018). Application of 45 kg S/ha fetched significantly higher net returns and B:C ratio. This might be due to the cost involved under treatment was comparatively lower than its additional income, which led to more returns. Since, gypsum is considered as a cheapest source of S (Choudhary *et al.* 2017).

From the present study it can be concluded that CA practice (zero-tillage with 4 t/ha crop residue) combined with application of S at 45 kg/ha through gypsum is a suitable option to enhance the productivity and profitability of mustard under rainfed ecosystem of semi-arid region. Furthermore, irrespective of tillage treatment, nutrients uptake and oil yield were higher in residue applied plots as compared to no residue. Being an oilseed crop, it's required high amount of S (45 kg/ha) for better growth and development.

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