

Original Research Article

Productivity and profitability of sunflower (*Helianthus annuus* L.) under different straw management options in rice fallows

ABSTRACT

A fixed field plot experiment was carried out for two consecutive *rabiseasons* of 2022-23 and 2023-24 at Agriculture Research Station, Tornala, Telangana, India to evaluate various rice residue management options on the performance and economic of sunflower grown after dry direct sown rice. Plant height and dry matter production at different growth stages and yield attributes and yield per hectare were consistently and significantly superior in the treatments where incorporation of rice straw was done 15 days prior to planting duly adjusting C: N and C:N:P ratio of straw by adding part of recommended nitrogen and phosphorus, and both of which were on par with each other. The performance of zero till sunflower along with straw retention and application recommended doses of fertilizers after dry direct sown rice was also on par with the C: N and C:N:P adjusted straw incorporation treatments during the second year of study. Mean seed and stalk yield, harvest index, net returns and B: C ratio were superior with incorporation of C: N: P and C: N ratio adjusted straw treatments and zero till sunflower treatments when compared to straw burning, straw incorporation as such, straw removal and incorporation of C: P ratio adjusted straw treatments.

Key words: Sunflower, Rice fallows, straw management, C:N:P ratio, Yield, Economics

1. INTRODUCTION

Rice is the most important staple food crop grown in all regions of India. Rice area, production and productivity in India are approximately 44.79 million hectares, 112.41 million tonnes (mt), and 2,578 kg ha⁻¹, respectively. The area under rice during both *khari* and *rabiseasons* together has gone up to 42.95 lakh hectares during 2020-21 in Telangana and in Siddipet district to 2.04 lakh hectares during 2020-21 recording a threefold increase over 2017-18. While this expanded area of the crop contributes to making the state the rice bowl of India, it also brings in its wake potential environmental threats from burning of the huge quantities of residues.

In India about 500 mt of crop residues are generated annually, in that rice crop alone contributes 34% to the crop residues [1]. In Siddipet district alone nearly 8 to 12 lakh tonnes of rice residue per annum are being produced from the current level of area and production. The use of combined harvesters resulted in bigger volumes of straw being dispersed across the field. Managing post-harvest rice straw constitutes a crucial element within the rice production cycle. Rice residue have been regarded as a waste material and therefore are either removed or burned *in situ*. Farmers resort to burning to dispose the residue quickly so as to enable land preparation for the next crop due to little turnaround time between crops. Burning results in release of gases, mainly CO₂, into the atmosphere. Amongst the different crops according to FAO (2019) globally, maize (45%) contributes the highest emissions (CO₂ equivalent–gigagram) through burning of crop–residues, followed by wheat (26%), rice (25%) and sugarcane (4%). In India, annually 140 mt of rice straw is being burnt[2].

Crop straw is increasingly regarded as an essential natural organic fertilizer that might take the place of chemical fertilizers due to numerous studies showing that it is rich in organic components and soil nutrients. An average rice straw contains 0.5-0.8% nitrogen, 0.16-0.27% phosphorus, 1.4-2.0% potassium, 0.05-0.10% sulphur and 4-7% silicon (Si) on dry matter basis [3]. Burning results in a nearly full loss of N, around 25% loss of P, 20% loss of K, and 5-60% loss of S [2]. Incorporating rice straw into the soil has been demonstrated to enhance nutrient recycling, boost soil organic carbon levels, and improve yields of subsequent crops [4]. Residue incorporation or retention instead of burning, would help reduce CO₂ and other GHGs since burning of 1 Mg rice straw emits 280 kg CO₂-C, 3 kg CH₄-C, 0.07 kg N₂O-N, with global warming potential (GWP) of 1,118 kg CO₂-equivalents per hectare [5]. On the other hand, incorporation of residues leads to short-term immobilization of N due to high C: N ratio (80:1) [6]. Straw of the crops, especially of rice, has high silicon content (4-7%) and decomposition of crop–residues is slow due to either lack of optimum moisture and temperature [7] or high lignin content [8]. As incorporation leads to temporary immobilization of nitrate-N, extra N fertilizer needs to be added to correct the high C: N ratio at the time of residue incorporation [9]. The returning of rice straw not only enhances the physical characteristics of the soil but also decreases nitrogen loss through immobilization and increases nitrogen availability, which assists in synchronizing the

release of N with crop demands. The use of rice straw as an organic fertilizer to soils has gained popularity due to these benefits [10].

The variations in C and N dynamics are mainly depending on the straw C: N ratio. Rice straw have low N and high cellulose content, and high C: N ratio results in low N mineralization because of N immobilization in soil, with a negative influence on the amount of the available N for crops in soil [11]. Application of inorganic fertilizers along with straw provides available nutrients at initial stage of crop growth and has a priming effect on native soil C, thereby reducing C accumulation.

Expanding the cultivation of sunflower in rice fallows (11.65m ha) areas holds great promise, leveraging residual soil moisture and nutrients. Sunflower emerges as an optimal catch crop after *kharif* rice cultivation. With its seeds comprising 28-35% oil and 14-19% protein, sunflower contributes significantly to the oilseed crop production, constituting about 14% of the total yield [12]. However, despite its potential, sunflower productivity in India has remained relatively low at 0.6 t ha⁻¹ compared to the global average of 1.3 t ha⁻¹[13], indicating a need for improved management techniques. In the state of Telangana, sunflower cultivation covered 17,776.22 ha during the *kharif* and *rabi* seasons in 2021-2022. Notably, Siddipet (2,738 ha) and Nizamabad (2,574 ha) are the primary districts where sunflowers are grown. However, despite these efforts, sunflower production in the state stands at only 0.19 lakh tonnes, with a productivity of 2671 kg/ha [14]. This production meets merely 1.85% of Telangana's annual consumption requirement, estimated at 10.22 lakh metric tonnes, indicating opportunity for expanding sunflower cultivation in the region.

Since, sunflower is an exhaustive crop, plant nutrients, particularly N and P, play a crucial role in low production, and this is one of the many causes. In the majority of situations, the two main limiting nutrients are nitrogen and phosphorus [13]. Therefore, there is a lot of opportunity to grow production with the application of appropriate fertility control and effective agronomic methods.

Several studies reported that increase in growth and yield of sunflower crops is dependent upon the adequate supply of nitrogen and phosphorus and their ratio as these nutrients regulate growth and photosynthesis [15]. Keeping this in view, it is carried out an investigation entitled “effect of rice residue management options on growth and productivity of sunflower in rice-sunflower cropping system in an Alfisol”.

2. MATERIALS AND METHODS

A field experiment was carried out during *rabi*, 2022-23 and 2023-24 at Agricultural Research station, Tornala in Siddipet district, Telangana, India, situated at 18°06'35" North latitude and 78°44'27" East longitude and falls in semi-arid zone with a hot and humid climate. Experimental soil is sandy clay loam in texture with 66.40% sand, 8.30% silt and 25.30% clay, neutral in soil reaction with pH 6.5, non-saline (EC 0.16 dS m⁻¹), low in organic carbon (0.44%) and available nitrogen (209.6 kg/ha), high in available phosphorus (39.21 kg/ha) and available potassium (237.33 kg/ha).

For studying the impact of different options of straw management in rice fallows, sunflower crop was taken as test crop during *rabi* season. *Kharif* season's rice was cultivated as dry direct sown rice with all the recommended package of practices outlined by Professor Jayashankar Telangana State Agricultural University (PJTSAU). During *rabi* season, rice residue management treatments were imposed and the recommended dose of fertilizers (RDF) for sunflower is 75-90-30 kg NPK ha⁻¹ with application of N in 3 splits - 50% basal; remaining in 2 splits at 30 day after sowing (DAS) and 55 DAS; P & K basal. The study was conducted in randomized block design (RBD) with seven treatments viz., T₁: Burning of rice residue 2 weeks after harvesting + RDF, T₂: Rice residue removal + RDF, T₃: Rice residue retention and zero till sowing of sunflower + RDF, T₄: Incorporation of residue as such after harvest + RDF, T₅: Adjusting C: N ratio of residue to 30:1 by applying part of 1st dose of N through urea at the time of incorporation + remaining recommended dose of nitrogen (RDN) in 3 splits and P, K as recommended, T₆: Adjusting the C: P ratio of residue to 30:0.3 by applying part of recommended dose of P through SSP at the time of incorporation + remaining recommended dose of phosphorus (RDP) as basal & N, K as recommended and T₇: Adjusting C: N: P ratio of residue to 30:1:0.3 by applying part of 1st dose of N through urea and part of recommended dose of P through SSP at the time of incorporation + remaining RDN in 3 splits and P, K as recommended. All the treatments were replicated in thrice during both years. The plan of layout for sunflower was made exactly same for both seasons. So, the same treatments will come on the same plots. The net plot size was 8.0 X 7.2 m and gross plot size was 57.6 m². Urea and SSP were used to supply N and P to sunflower as per the treatments. Muriate of potash was applied as a source of potassium.

Treatment imposition was done by quantifying the rice residue after harvesting of *kharif* crop. The yield of straw during the years 2022–2023 and 2023–2024 was 3, 5.186 t/ha. It contains 0.65, 0.71% nitrogen, 0.28, 0.22% phosphorus and 35.75, 36.75% carbon respectively. From this calculated the straw C: N (55:1, 51.76:1), C: P (126:1, 167.05:1) and C:N:P (55:126:1, 51.76:167.05:1) ratios for the years 2022–2024. According to the findings, the straw's C:N ratio was adjusted to 30: 1 prior to incorporation by applying a portion of the first dose of nitrogen (284, 338g urea/plot), its C:P ratio was adjusted to 30: 0.3 by applying a portion of the first dose of phosphorus (111.5, 275g SSP/plot), and its C:N:P ratio was adjusted to 30: 1: 0.3 by applying a portion of the first dose of applying part of the first dose of nitrogen and phosphorus through urea and SSP (284g, 111.5g/plot) at the time of incorporation. In all the residue incorporation treatments (T₄ to T₇), rotary mulcher was run to slash down the straw and then incorporated the straw in to soil by following standard tillage operations like running cultivator twice followed by rotavation. In case of the treatments with burning/residue removal (T₁ and T₂), cultivator twice followed by rotavator was adopted. In case of T₃, control of rejuvenation of rice stubbles was done by spraying of paraquat @5 ml/l, rice residue was retained and zero till sowing of sunflower was taken up along with applying of the RDF as recommended.

Sunflower hybrid DRSH-1, which matures in 90 to 95 days was sown at the rate of 2kg/ha. Two seeds per each hill were manually dibbled into the ground at recommended 45cm × 20cm spacing.

The biometric observations like plant height (cm) at different crop growth stages and yield attributes like head diameter (cm), seeds head⁻¹, and test weight (g) were recorded in each treatment duly tagging the plants. The plants were intended to be harvested at the physiological maturity stage, which was indicated by the change in colour of the bracts (to brown) and the back of the head (from green to yellow). Plants were taken from one square meter of each treatment to evaluate the seed and stalk yield. The seeds were then separated, weighed and the yield ha⁻¹ was calculated after sun drying.

3. RESULTS AND DISCUSSION

3.1 Plant height

Irrespective of the treatments, as the crop grew older, plant height increased, reaching peak at maturity. The pooled data of two years (Table 1) indicated that, significantly highest plant height at vegetative stage (94.42 cm), flowering (122.21 cm) and harvest (151.75 cm) was recorded with residue retention + zero tillage of sunflower + RDF, *i.e.*, T₃ treatment and was superior over all other treatments. While lowest plant height at all the stages was recorded in T₄ treatment where residue was incorporated as such (65.42, 110.52 and 132.78 cm at vegetative, flowering and harvest stages respectively). Plant height at different crop growth stages in other treatments *viz.*, residue removal, residue burning, incorporation of straw with C:N ratio adjusted to 30:1, straw C:P ratio adjusted to 30: 0.3, straw C:N:P ratio adjusted to 30:1: 0.3 was at par and significantly higher than the plant height recorded in treatment where straw was incorporated as such. This may be attributed to rapid mobilization of N, P, K from inorganic fertilizers and steady supply of N and P from straw decomposition which might have met N and P requirement for cell elongation and cell division at early growing period [16]. Babuet *al.* [13] also reported that plant height was significantly impacted by the residual effect of incorporating rice residue at all growth stages. Plants that receive a sufficient supply of mineralized nutrients from well-decomposed rice straw may experience increased photosynthetic activity and strong development. These results concerned with other studies by [16, 17]. In this study, the application of organic nutrient sources like rice straw incorporation led to enhanced plant response, as evidenced by improved growth parameters. This improvement can be attributed to increased mineralization and nutrient absorption, ultimately resulting in superior plant growth compared to control plants. Organic fertilizers have the potential to boost the agronomic characteristics of sunflower by augmenting nutrient accessibility, particularly in the form of nitrogen (N), phosphorus (P), and potassium (K) within the soil environment.

3.2 Dry matter production

The combined data over two years regarding dry matter production in *rabi* sunflower, as presented in Table 2, reveals significant impacts from both rice straw and nutrient management strategies. At vegetative stage, treatment involved adjusting the straw C:N:P ratio to 30:1:0.3 prior to incorporation (T₇), exhibited the highest dry matter accumulation (2523 kg/ha), and closely followed by residue retention + zero tillage

sowing of sunflower + RDF as recommended (T₃- 2365kg/ha) and adjusting the straw C:N ratio to 30:1 prior to incorporation treatment (T₅-2240kg/ha) are at par with treatment recorded higher dry matter production and superior over the rest of the treatments. The straw C:P ratio to 30:0.3 prior to incorporation treatment (T₆-2108kg/ha) and residue incorporation as such+ RDF as recommended (T₄-1982kg/ha) are on par at each other and significantly lowest dry matter was recorded in residue burning + RDF (T₁-1518kg/ha) followed by residue removal+ RDF (T₂-1577kg/ha) treatment are on par at each other. At flowering stage, highest dry matter production was recorded in residue retention + zero tillage sowing of sunflower + RDF as recommended (T₃- 3706kg/ha), followed by adjusting the straw C:N:P ratio to 30:1:0.3 prior to incorporation (T₇) with 3531kg/ha and adjusting the straw C:N ratio to 30:1 prior to incorporation treatment (T₅) with 3397kg/ha are significantly on par with higher dry matter production and superior over the rest of the treatments. Followed by straw C:P ratio to 30:0.3 prior to incorporation treatment (T₆) with 3092kg/ha. Residue burning + RDF (T₁) with 2670kg/ha are on par with residue removal + RDF (T₂) with 2721kg/ha and residue incorporation as such+ RDF as recommended (T₄-2588kg/ha). At harvest, adjusting the straw C:N:P ratio to 30:1:0.3 prior to incorporation (T₇) recorded highest dry matter production (8028kg/ha), followed by adjusting the straw C:N ratio to 30:1 prior to incorporation treatment (T₅) with 7662kg/ha and residue retention + zero tillage sowing of sunflower + RDF as recommended (T₃) with 7646 kg/ha are on par with each other and significantly superior over other treatments. Residue incorporation as such+ RDF as recommended (T₄-6203 kg/ha), residue removal + RDF (T₂- 6198 kg/ha) and residue burning +RDF (5998kg/ha) are significantly on par. Similar results are reported by [18, 19, 20]. Dry matter accumulation is more important because all other vegetative characters contained it. Dry matter production related to grain productivity contributes an important factor in source-sink relationship [12]. The dry matter production per plant was increased linearly and reaching maximum at harvest under this study due to the fact that nitrogen, promoted the vegetative growth and increased carbohydrate in leaves, which resulted in more dry matter accumulation [13]. Naveed *et al.* [21] reported that incorporating organic waste into agriculture serves as both a soil enhancer and bio stimulant, fostering crop growth while concurrently reducing agricultural waste accumulation.

3.3 Yield attributes

3.3.1 Head Diameter

The data pertaining to the head diameter during both the seasons and pooled over years is presented in Table 3 and mean higher head diameter (11.75cm) was recorded under residue retention + zero tillage + RDF (T₃), followed by straw C:N ratio adjustment to 30: 1 (T₅) treatment (11.50cm). The lowest head diameter (10.98cm) was recorded in straw C: P ratio adjustment to 30:0.3 treatment (T₆). However, the variations were statistically non-significant.

3.3.2 Number of seeds per head

The impact of residue management treatments during both the years of study was found to be significant on the number of seeds per head. During first year (2022-23) of study significantly higher number of seeds per head were observed in the treatment where C: N ratio of the straw was adjusted to 30: 1 prior to incorporation by adding part of the first dose of recommended nitrogen (601.2) and it was closely followed by residue removal treatment (596.3) and straw incorporation with adjustment of C: N: P ratio to 30: 1 :0.3 (591.3) and these treatments were at par with other and superior over rest of the treatments. The residue burning (T₁-573.3), residue retention + zero till sunflower cultivation (569.6) and straw incorporation with adjustment of C: P ratio to 30:0.3 (563.9) treatments was at par with each other. Significantly lowest number of seeds was recorded in T₄ treatment where straw was incorporated as such (542.1).

During second year (2023-24), the performance of residue retention + zero till sunflower cultivation (755.47) was significantly superior over rest of the treatments and it was followed by incorporation of C: N ratio (706.73) and C:N: P ratio adjusted straw (695.60). Both these treatments were at par with each other. While the treatments, residue burning (T₁- 651.33), straw incorporation with adjustment of C: P ratio to 30:0.3 (T₆-668.40) and residue removal (T₂-647.53) recorded on par number of seeds per head. Significantly lowest number of seeds per head were observed in straw incorporation as such (627.67) treatment.

Pooled data of two (Table 3) years indicated an on par performance of residue retention + zero tillage + RDF (T₃-662.54), straw C:N ratio adjustment to 30: 1 (T₅) treatment (653.97) and straw C: N: P ratio adjustment to 30: 1 :0.3 treatment (T₇-644.45) and superior over other treatments. While significantly lowest number of seeds per head

was recorded with treatment T₄ where straw incorporation was done as such along with application of RDF (584.89).

3.3.3 Test weight

The test weight (100 seeds) of sunflower seed was not significantly affected by treatments. The highest test weight of seed (4.25g) was recorded in straw C: N ratio adjustment to 30: 1 (T₅), followed by (4.23g) straw C: N: P ratio adjustment to 30: 1: 0.3 (T₇). The least test weight of seed (3.84g) was recorded in straw incorporation without adjustment of C: N or C: P ratio (T₄).

These findings are in line with those of scientists [17, 22], who found a positive impact of combined use of NPK along with organic manures on sunflower yield. Mallick and Majumder [16] reported that highest yield attributing characters might be due to higher availability of P, N and simultaneously better nutrition since early stage of growth.

3.4 Yield

The seed yield (Table 4), during first year of study, among the residue options tested, adjusting C-N ratio of residue to 30:1 by applying part of 1st dose of N through urea before incorporation + remaining RDN in 3 splits and P, K as recommended treatment (T₅) recorded maximum sunflower seed yield (1879 kg/ha) and it was on par with treatment T₇ (1854 kg/ha) where C-N-P ratio of residue to 30 :1 : 0.3 by applying part of 1st dose of N through urea and part of recommended dose of P through SSP at the time of incorporation + Remaining RDN in 3 splits and P, K as recommended. While the treatments T₂ (Rice residue removal + RDF -1704 kg/ha) and T₃ (Rice residue retention and zero till sowing of sunflower + RDF-1675 kg/ha) recorded on par yield, however yield under these treatments was significantly lower than T₅ and T₇ but superior over T₁, T₄ and T₆. Lowest yield was recorded with residue burning (T₁-1500 kg/ha) and the yield under the treatments T₄ (Incorporation of residue as such after harvest + RDF -1525 kg/ha) and T₆ (Adjusting the C-P ratio of residue to 30: 0.3 by applying part of recommended dose of P through SSP at the time of incorporation + remaining RDP as basal & N, K as recommended -1538 kg/ha) were found to be on par.

During second year also the seed yield of sunflower after dry direct sown rice was superior with incorporation of rice residue with adjustment C: N: P ratio to 30:1: 0.3 by applying part of 1st dose of N and phosphorus before incorporation (T₇-2305 kg/ha),

closely followed by incorporation of straw by adjusting the C:N ratio to 30:1 (T₅-2278 kg/ha) both of which were on par with each other and with Zero till sunflower (T₃-2040 kg/ha) and superior over residue burning (T₁-1519 kg/ha) or residue incorporation as such (T₄-1685 kg/ha). However, zero till sunflower (T₃-2040 kg/ha) and residue removal (T₂-1850 kg/ha) treatments were on par with each other in terms of productivity.

Pooled data of two years (table 4) showed that incorporation of rice straw along with inorganic fertilizers to adjustment of straw C:N:P ratio to 30:1:0.3 (T₇) recorded the highest seed yield (2080kg/ha), it was statistically on par with adjustment of straw C:N ratio to 30:1 (T₅) treatment (2079kg/ha), which are significantly superior over the retest of the treatments, followed by residue retention + zero tillage + RDF(T₃) treatment (1858 kg/ha), which was on par with residue removal+RDF treatment (1777kg/ha). This was probably due to the adequate N and P availability at initial stages, which helped to acquire a definite advantage in respect of growth [13]. The least seed yield (1510kg/ha) was observed under straw burning (T₁) treatment. These findings are confirmed with [23]. Different straw management practices did not influence the stalk yields of *rabi* sunflower significantly during the first season after residue addition and their effect was observed only from the second season. Stalk yield of *rabi* sunflower was presented in Table 4. It showed that, the maximum stalk yield was obtained in T₇ (5948kg/ha) treatment, which was on par with T₃(5738kg/ha) and T₅(5583kg/ha) and T₆ (5529 kg/ha). Lowest stalk yield was recorded in T₂ (4421kg/ha). The other treatments could be ranked as T₇>T₃>T₅>T₆>T₄>T₁>T₂. Similar findings were also stated by [24].

The treatments comprising of straw retention and incorporation along with inorganic fertilizers to adjust straw C: N and C: P ratio to 30:1 and 30: 0.3 contributes to 23.04% to 37.77% increase of seed yield over T₁ treatment that is burning of straw. Higher seed yield ha⁻¹ of sunflower was mainly associated with the greater head diameter and more number of seeds head⁻¹ [22]. This might be due to the positive effect of rice straw incorporation on soil fertility. Favourable effects of rice straw incorporation in combination with inorganic nutrient sources could be attributed to the better nutrient availability in these treatments, as explained by [25]. Alzamel *et al.* [26] found that robust seed and stalk yield of sunflower crops may be attributed to enhanced nutrient availability resulting from the decomposition of organic compost. The release of weak

acids, along with CO₂ released during decomposition, contributes significantly to lowering pH levels, facilitating greater nutrient absorption by plants. Moreover, the activity of indigenous soil microorganisms further augments nutrient availability. However, certain soils may lack adequate nutrients for optimal sunflower growth and yield. To address this issue, the application of organic compound fertilizers is recommended.

3.5 Economics

Cost of cultivation, gross returns, net returns and benefit cost ratios were worked out for different straw and nutrient management options of this experiment (Table 5). Cost of cultivation of *rab*sunflower varied from Rs. 49511 to 57386/ha during 2022-23 and from Rs. 54898 to 61271/ha during 2023-24 in different treatments. Mean data of two years on cost of cultivation showed that highest cost of cultivation (Rs.59328/ha) was in residue removal + RDF (T₂) treatment, because it required additional labour for removal of straw.

Gross returns were product of seed yield and market price of seed and the pooled data obtained on gross returns from *rab*sunflower varied among different treatments. Significantly higher (Rs. 137214/ha) gross returns were obtained in adjustment of straw C:N: P ratio to 30: 1: 0.3 (T₇) treatment followed by Rs. 137113/ha in adjustment of straw C:N ratio to 30:1 (T₅) and Rs. 122552/ha in residue retention + zero tillage + RDF (T₃) compared with Rs. 99334 ha⁻¹ in residue burning (T₁) treatment. Similar trend was also observed in net returns. However, B:C ratio of irrigated *rab*sunflower was similar in residue retention + zero tillage + RDF (T₃-2.34) and with incorporation of the straw with adjustment of C: N ratio to 30: 1 (T₅) (2.34) and adjustment of straw C:N:P ratio to 30:1:0.3 (T₇-2.34) treatments. Residue burning (T₁) recorded lowest B:C ratio (1.75). These findings are similar with Mallick and Majumder (2023).

3.6 CONCLUSION

The results recorded in the present experiment revealed appreciable and significant variation in different growth parameters, yield attributing characters and yield of sunflower due to different options of management of rice straw along with inorganic fertilizers in light textured soils of Siddipet district, Telangana. The basic

objectives of the study were to effectively manage agricultural residue while ensuring the sustainable productivity of the subsequent crop and promoting ecological sustainability.

The yield of T₇ and T₅ treatments of present field experiment clearly stated that the incorporation of straw by adjusting straw C: N and C:N: P ratios to 30:1 and 30:1: 0.3 by applying part of recommended N and P fertilizers at the time of incorporation resulted in appreciable increase of growth and yield of sunflower crop in an alfisols. This approach exhibited superior performance compared to straw burning and removal treatments concerning the growth, yield, and yield attributes of sunflower.

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Table 1. Effect of rice straw and nutrient management options on plant height (cm) of sunflower (*Helianthus annuus*).

| Treatment | At vegetative stage | | | At flowering | | | At harvest | | |
|---|---------------------|---------|--------|--------------|---------|--------|------------|---------|--------|
| | 2022-23 | 2023-24 | Pooled | 2022-23 | 2023-24 | Pooled | 2022-23 | 2023-24 | Pooled |
| T ₁ : Residue Burning+ RDF | 78.38 | 63.92 | 71.15 | 114.50 | 103.32 | 108.91 | 155.6 | 135.45 | 145.53 |
| T ₂ : Residue Removal+ RDF | 76.02 | 65.57 | 70.79 | 116.63 | 105.10 | 110.86 | 155.6 | 135.32 | 145.46 |
| T ₃ : Residue Retention + ZT SF +RDF | 97.38 | 91.47 | 94.42 | 116.87 | 127.56 | 122.21 | 152.7 | 150.79 | 151.75 |
| T ₄ : Residue incorporation as such+ RDF | 71.25 | 59.60 | 65.42 | 108.17 | 112.87 | 110.52 | 131.7 | 133.85 | 132.78 |
| T ₅ : Adjustment of C:N of residue to 30: 1 before incorporation | 80.83 | 58.69 | 69.76 | 122.90 | 115.05 | 118.98 | 162.2 | 132.63 | 147.42 |
| T ₆ : Adjustment of C:P of residue to 30: 0.3 before incorporation | 87.85 | 63.30 | 75.57 | 121.27 | 115.22 | 118.25 | 160.5 | 132.80 | 146.65 |
| T ₇ : Adjustment of C:N:P of residue to 30:1: 0.3 before incorporation | 87.23 | 63.00 | 75.12 | 123.57 | 115.17 | 119.37 | 160.7 | 134.35 | 147.53 |
| SE(m)± for years | | | 1.63 | | | 0.89 | | | 1.31 |
| SE(m)±for treatments | 4.38 | 4.27 | 3.05 | 2.10 | 2.53 | 2.30 | 4.51 | 1.96 | 4.15 |
| SE(m)±for years X treatments | | | 4.32 | | | 2.33 | | | 3.47 |
| CD (P=0.05) for years | | | 4.76 | | | 2.57 | | | 3.83 |
| CD (P=0.05) for treatments | 13.49 | 13.15 | 8.92 | 6.48 | 7.81 | 9.92 | 14.04 | 6.03 | 17.89 |
| CD (P=0.05) for years × treatments | | | NS | | | 6.80 | | | 10.14 |
| CV(%) | 9.16 | 11.11 | 10.03 | 3.09 | 4.10 | 3.59 | 5.06 | 2.49 | 4.14 |

Note: RDF = 75-90-30kg NPK ha⁻¹, ZT SF = Zero tillage sunflower sowing

Table 2. Effect of rice straw and nutrient management options on dry matter production (kg/ha)

| | At vegetative stage | | | At flowering | | | At harvest (Seed + stalk) | | |
|---|---------------------|---------|--------|--------------|---------|--------|------------------------------|---------|--------|
| | 2022-23 | 2023-24 | Pooled | 2022-23 | 2023-24 | Pooled | 2022-23 | 2023-24 | Pooled |
| T ₁ : Residue Burning+ RDF | 1583 | 1454 | 1518 | 2754 | 2586 | 2670 | 5881 | 6116 | 5998 |
| T ₂ : Residue Removal+ RDF | 1579 | 1576 | 1577 | 2817 | 2625 | 2721 | 6023 | 6373 | 6198 |
| T ₃ : Residue Retention + ZT SF +RDF | 2093 | 2638 | 2365 | 3548 | 3864 | 3706 | 7521 | 7771 | 7646 |
| T ₄ : Residue incorporation as such+ RDF | 1858 | 2106 | 1982 | 2374 | 2802 | 2588 | 5896 | 6510 | 6203 |
| T ₅ : Adjustment of C:N of residue to 30: 1 before incorporation | 2286 | 2194 | 2240 | 3290 | 3503 | 3397 | 7580 | 7743 | 7662 |
| T ₆ : Adjustment of C:P of residue to 30: 0.3 before incorporation | 2044 | 2172 | 2108 | 2936 | 3248 | 3092 | 7069 | 7306 | 7188 |
| T ₇ : Adjustment of C:N:P of residue to 30:1: 0.3 before incorporation | 2545 | 2501 | 2523 | 3578 | 3485 | 3531 | 7822 | 8233 | 8028 |
| SE(m)± for years | | | 33.97 | | | 66.70 | | | 78.99 |
| SE(m)± for treatments | 94.43 | 85.12 | 19.14 | 192.64 | 158.63 | 124.78 | 199.21 | 218.35 | 147.78 |
| SE(m)± for years X treatments | | | 89.90 | | | 176.46 | | | 208.99 |
| CD (P=0.05) for years | | | NS | | | NS | | | 230.57 |
| CD (P=0.05) for treatments | 290.97 | 262.28 | 412.27 | 593.59 | 488.79 | 364.19 | 613.83 | 672.80 | 431.54 |
| CD (P=0.05) for years × treatments | | | NS | | | NS | | | NS |
| CV (%) | 8.18 | 7.05 | 7.61 | 10.97 | 8.70 | 9.86 | 5.05 | 5.30 | 5.18 |

Table 3. Effect of rice straw and nutrient management options on yield attributes of sunflower

| Treatment | Head diameter (cm) | | | No of seeds per head | | | Test weight (g) (100 seed) | | |
|---|--------------------|---------|--------|----------------------|---------|--------|-------------------------------|---------|--------|
| | 2022-23 | 2023-24 | Pooled | 2022-23 | 2023-24 | Pooled | 2022-23 | 2023-24 | Pooled |
| T ₁ : Residue Burning+ RDF | 11.5 | 11.20 | 11.35 | 573.3 | 651.33 | 612.32 | 4.00 | 3.83 | 3.92 |
| T ₂ : Residue Removal+ RDF | 11.3 | 11.40 | 11.35 | 596.3 | 647.53 | 621.91 | 4.33 | 3.83 | 4.08 |
| T ₃ : Residue Retention + ZT SF +RDF | 11.5 | 12.06 | 11.75 | 569.6 | 755.47 | 662.54 | 4.33 | 4.03 | 4.18 |
| T ₄ : Residue incorporation as such+ RDF | 10.9 | 11.40 | 11.15 | 542.1 | 627.67 | 584.89 | 4.17 | 3.50 | 3.84 |
| T ₅ : Adjustment of C:N of residue to 30: 1 before incorporation | 11.6 | 11.50 | 11.50 | 601.2 | 706.73 | 653.97 | 4.37 | 4.13 | 4.25 |
| T ₆ : Adjustment of C:P of residue to 30: 0.3 before incorporation | 11.3 | 10.67 | 10.98 | 563.9 | 668.40 | 616.15 | 4.33 | 3.77 | 4.05 |
| T ₇ : Adjustment of C:N:P of residue to 30:1: 0.3 before incorporation | 11.6 | 11.04 | 11.32 | 591.3 | 695.60 | 644.45 | 4.33 | 4.13 | 4.23 |
| SE(m)± for years | | | 0.104 | | | 5.46 | | | 0.08 |
| SE(m)± for treatments | 0.20 | 0.25 | 0.19 | 10.87 | 23.17 | 21.08 | 0.15 | 0.20 | 0.16 |
| SE(m)±for years X treatments | | | 0.28 | | | 14.45 | | | 0.22 |
| CD (P=0.05) for years | | | NS | | | 15.94 | | | 0.24 |
| CD(P=0.05)for treatments | NS | NS | NS | 33.87 | 71.40 | 61.34 | NS | NS | NS |
| CD (P=0.05) for years × treatments | | | NS | | | 42.19 | | | NS |
| CV (%) | 3.03 | 3.88 | 4.21 | 3.27 | 5.91 | 3.99 | 6.25 | 8.76 | 9.38 |

Table 4. Effect of rice straw and nutrient management options on seed and stalk yield

| | Stalk yield (kg ha ⁻¹) | | | Seed Yield (kg ha ⁻¹) | | |
|---|------------------------------------|---------|--------|-----------------------------------|---------|--------|
| | 2022-23 | 2023-24 | Pooled | 2022-23 | 2023-24 | Pooled |
| T ₁ : Residue Burning + RDF | 4381 | 4596 | 4489 | 1500 | 1519 | 1510 |
| T ₂ : Residue Removal + RDF | 4319 | 4523 | 4421 | 1704 | 1850 | 1777 |
| T ₃ : Residue Retention + ZT SF + RDF | 5846 | 5631 | 5738 | 1675 | 2040 | 1858 |
| T ₄ : Residue incorporation as such + RDF | 4371 | 4825 | 4598 | 1525 | 1685 | 1605 |
| T ₅ : Adjustment of C:N of residue to 30: 1 before incorporation | 5701 | 5465 | 5583 | 1879 | 2278 | 2079 |
| T ₆ : Adjustment of C:P of residue to 30: 0.3 before incorporation | 5532 | 5526 | 5529 | 1538 | 1780 | 1659 |
| T ₇ : Adjustment of C:N:P of residue to 30:1: 0.3 before incorporation | 5968 | 5928 | 5948 | 1854 | 2305 | 2080 |
| SE(m)± for years | | | 77.19 | | | 31.02 |
| SE(m)± for treatments | 201.01 | 207.41 | 144.15 | 57.81 | 100.64 | 58.03 |
| SE(m)± for years X treatments | | | 203.23 | | | 82.07 |
| CD (P=0.05) for years | | | NS | | | 90.54 |
| CD (P=0.05) for treatments | 619.38 | 639.09 | 421.52 | 178.13 | 310.11 | 169.38 |
| CD (P=0.05) for years × treatments | | | NS | | | NS |
| CV (%) | 6.75 | 6.89 | 6.82 | 6.00 | 9.07 | 7.92 |

Table 5. Effect of rice straw and nutrient management options on economics of sunflower

| Treatment | Cost of cultivation (Rs/ha) | | | Gross Returns (Rs/ha) | | | Net Returns (Rs/ha) | | | B: C ratio | | |
|-----------|-----------------------------|---------|-------|-----------------------|---------|--------|---------------------|---------|-------|------------|---------|------|
| | 2022-23 | 2023-24 | Mean | 2022-23 | 2023-24 | Mean | 2022-23 | 2023-24 | Mean | 2022-23 | 2023-24 | Mean |
| T1 | 54636 | 58771 | 56703 | 96000 | 102668 | 99334 | 41364 | 43896 | 42630 | 1.76 | 1.75 | 1.75 |
| T2 | 57386 | 61271 | 59328 | 109067 | 125032 | 117049 | 51681 | 63761 | 57721 | 1.90 | 2.04 | 1.97 |
| T3 | 49511 | 54898 | 52204 | 107200 | 137904 | 122552 | 57689 | 83007 | 70348 | 2.17 | 2.51 | 2.34 |
| T4 | 56886 | 60021 | 58453 | 97600 | 113934 | 105767 | 40714 | 53913 | 47313 | 1.72 | 1.90 | 1.81 |
| T5 | 56886 | 60021 | 58453 | 120267 | 153959 | 137113 | 63381 | 93938 | 78659 | 2.11 | 2.57 | 2.34 |
| T6 | 56886 | 60021 | 58453 | 98400 | 120300 | 109350 | 41514 | 60279 | 50896 | 1.73 | 2.00 | 1.87 |
| T7 | 56886 | 60021 | 58453 | 118667 | 155762 | 137214 | 61781 | 95740 | 78761 | 2.09 | 2.60 | 2.34 |

T₁: Residue Burning+ RDF, T₂: Residue Removal+ RDF, T₃: Residue Retention + zero tillage sunflower sowing +RDF, T₄: Residue incorporation as such+ RDF, T₅: Adjustment of C:N of residue to 30: 1 before incorporation, T₆: Adjustment of C:P of residue to 30: 0.3 before incorporation, T₇: Adjustment of C:N:P of residue to 30:1: 0.3 before incorporation.