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Productivity and Profitability of Sunflower (*Helianthus annuus* L.) under Different Straw Management Options in Rice Fallows

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A fixed field plot experiment was carried out for two consecutive *rabi* seasons of 2022-23 and 2023-24 at Agriculture Research Station, Tornala, Telangana, India to evaluate various rice residue management options on the performance and economics of sunflower grown after dry direct sown

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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.

Keywords: 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 *kharif* and *rabi* seasons 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 CO_2, into the atmosphere. Amongst the different crops according to FAO (2019) globally, maize (45%) contributes the highest emissions (CO_2 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 CO_2 and other GHGs since burning of 1 Mg rice straw emits 280 kg CO_2–C, 3 kg CH_4–C, 0.07 kg N_2O–N, with global warming potential (GWP) of 1,118 kg CO_2-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 18º06'35" North latitude and 78º44'27" 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 (209.6kg/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 75-90-30kg 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.,*T_1: Burning of rice residue 2 weeks after harvesting + RDF, T_2: Rice residue removal + RDF, T_3: Rice residue retention and zero till sowing of sunflower + RDF, T_4: Incorporation of residue as such after harvest + RDF, T_5: 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, T_6: 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 T_7: 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 m^2. 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 (T_4 to T_7), 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 (T_1 and T_2), cultivator twice followed by rotavator was adopted. In case of T_3, 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 (94.42cm), flowering (122.21cm) and harvest (151.75cm) was recorded with residue retention + zero tillage of sunflower + RDF, *i.e.*, T_3 treatment and was superior over all other treatments. While lowest plant height at all the stages was recorded in T_4 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]. Babu et 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 (T_7), exhibited the highest dry matter accumulation (2523kg/ha), and closely followed by residue retention + zero tillage sowing of sunflower + RDF as recommended (T_3- 2365kg/ha)and adjusting the straw C: N ratio to 30:1 prior to incorporation treatment (T_5-2240kg/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 (T_6-2108kg/ha) and residue incorporation as such+ RDF as recommended (T_4-1982kg/ha) are on par at each other and significantly lowest dry matter was recorded in residue burning + RDF (T_1-1518kg/ha) followed byresidue removal + RDF (T_2-1577kg/ha) treatmentare 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 (T_3- 3706kg/ha), followed by adjusting the straw C: N: P ratio to 30: 1: 0.3 prior to incorporation (T_7) with 3531kg/ha and adjusting the straw C: N ratio to 30: 1 prior to incorporation treatment (T_5) 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 (T_6) with 3092kg/ha. Residue burning + RDF (T_1) with 2670kg/ha are on par with residue removal + RDF (T_2) with 2721kg/ha and residue incorporation as such+ RDF as recommended (T_4-2588kg/ha).At harvest, adjusting the straw C: N: P ratio to 30: 1: 0.3 prior to incorporation (T_7) recorded highest dry matter production (8028kg/ha), followed by adjusting the straw C:N ratio to 30:1 prior to incorporation treatment (T_5) with 7662kg/ha and residue retention + zero tillage sowing of sunflower + RDF as recommended (T_3) with 7646 kg/ha are on par with each other and significantly superior over other treatments. Residue incorporation as such+ RDF as recommended (T_4-6203 kg/ha), residue removal + RDF (T_2- 6198 kg/ha) and residue burning +RDF (5998kg/ha) are significantly on par. Similar results are reported by [18-20]. 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 (T_3), followed by straw C: N ratio adjustment to 30: 1 (T_5) treatment (11.50cm). The lowest head diameter (10.98cm) was recorded in straw C: P ratio adjustment to 30:0.3 treatment (T_6). 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 (T_1-573.3), 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 T_4 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 (T_1- 651.33), straw incorporation with adjustment of C: P ratio to 30:0.3 (T_6-668.40) and residue removal (T_2-647.53) 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.

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: ResidueBurning+ 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}, ZTSF = 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

	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_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

T_1: Residue Burning + RDF, T_2: Residue Removal + RDF, T_3: Residue Retention + zero tillage sunflower sowing + RDF, T_4: Residue incorporation as such + RDF, T_5: Adjustment of C: N of residue to 30: 1 before incorporation, T_6: Adjustment of C: P of residue to 30: 0.3 before incorporation, T_7: Adjustment of C: N: P of residue to 30: 1: 0.3 before incorporation

Pooled data of two (Table 3) years indicated an on par performance of residue retention + zero tillage + RDF (T_3-662.54), straw C: N ratio adjustment to 30: 1 (T_5) treatment (653.97) and straw C: N: P ratio adjustment to 30: 1: 0.3treatment (T_7-644.45) and superior over other treatments. While significantly lowest number of seeds per head was recorded with treatment T_4 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 (T_5), followed by (4.23g) straw C: N: P ratio adjustment to 30: 1: 0.3 (T_7). The least test weight of seed (3.84g) was recorded in straw incorporation without adjustment of C: N or C: P ratio (T_4).

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 (T_5) recorded maximum sunflower seed yield (1879 kg/ha) and it was on par with treatment T_7 (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 T_2 (Rice residue removal + RDF - 1704 kg/ha) and T_3 (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 T_5 and T_7 but superior over T_1, T_4 and T_6. Lowest yield was recorded with residue burning (T_1-1500 kg/ha) and the yield under the treatments T_4 (Incorporation of residue as such after harvest + RDF -1525 kg/ha) and T_6 (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 (T_7-2305 kg/ha), closely followed by incorporation of straw by adjusting the C:N ratio to 30:1 (T_5-2278 kg/ha) both of which were on par with each other and with Zero till sunflower (T_3-2040 kg/ha) and superior over residue burning (T_1-1519 kg/ha) or residue incorporation as such (T_4-1685 kg/ha). However, zero till sunflower (T_3-2040 kg/ha) and residue removal (T_2-1850 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 (T_7) recorded the highest seed yield (2080kg/ha), it was statistically on par with adjustment of straw C:N ratio to 30:1 (T_5) treatment (2079kg/ha),which are significantly superior over the retest of the treatments, followed by residue retention + zero tillage + RDF(T_3) 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 (T_1) 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 T_7 (5948kg/ha) treatment, which was on par with T_3 (5738kg/ha) and T_5(5583kg/ha) and T_6 (5529 kg/ha). Lowest stalk yield was recorded in T_2 (4421kg/ha). The other treatments could be ranked as $T_7>T_3>T_5>T_6>T_4>T_1>T_2$. Similar findings were also stated by Mukherjee et al [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 T_1 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 Mahavishnan et al [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 CO_2 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 ratio was worked out for different straw and nutrient management options of this experiment (Table 5). Cost of cultivation of *rabi* 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 (T_2) 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 *rabi* 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 (T_7) treatment followed by Rs. 137113/ha in adjustment of straw C: N ratio to 30:1 (T_5) and Rs. 122552/ha in residue retention + zero tillage + RDF (T_3) compared with Rs. 99334 ha^{-1}in residue burning (T_1) treatment. Similar trend was also observed in net returns. However, B: C ratio of irrigated *rabi* sunflower was similar in residue retention + zero tillage + RDF (T_3-2.34) and with incorporation of the straw with adjustment of C: N ratio to 30: 1 (T_5) (2.34) and adjustment of straw C: N: P ratio to 30:1:0.3 (T_7-2.34) treatments. Residue burning (T_1) recorded lowest B: C ratio (1.75). These findings are in similar with Mallick and Majumder (2023).

4. 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 T_7 and T_5 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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of this manuscript. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

Details of the AI usage are given below:

1. I declare that no generative AI technologies, such as Large Language Models or text-to-image generators, were used in the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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