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RESEARCH ARTICLE

Influence of rice straw incorporation and recommended dose of primary nutrients on growth, productivity and nutrient use efficiency of *Rabi* maize (*Zea mays* L.)

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Abstract

Rice-maize-based cropping system is one of the important agricultural practices in India. Maize has a wider range of adaptability to various climatic and soil conditions, which allows the farmers to cultivate the crop at various locations throughout the year. During the present days, straw handling after rice crop harvesting has become a major problem to the farmers and the burning of rice straw is considered as a serious environmental threat causing air pollution. In this scenario, incorporation of rice straw in succeeding maize cultivation can be beneficial in various aspects like soil health improvement, increased productivity and proper waste management. Considering these, the present field study was conducted at the Post Graduate Research Farm of Centurion University of Technology and Management, Gajapathi, Odisha, India. The experiment was laid out in randomized complete block design with 8 treatments and each treatment was replicated 4 times. The details of the treatment are as follows, T_1: absolute control, T_2: 100 % RDF, T_3: 100 % RDF + rice straw incorporation (RSI) at 2 t/ha, T_4: 100 % RDF + RSI at 4 t/ha, T_5: 100 % RDF + RSI at 6 t/ha, T_6: 100 % RDF + RSI at 8 t/ha, T_7: 75 % RDF + RSI at 2 t/ha and T_8: 75 % RDF + RSI at 4 t/ha. The experimental results found that the superior values of growth attributes were obtained highest in treatments T_2: 100 % RDF, T_3: 100 % RDF + RSI at 2 t/ha. Further, the incorporation of rice straw at the rate of 2 t/ha (T_3) accounted for maximum grain yield (6354 kg/ha), stover yield (8429 kg/ha) and biological yield (14783 kg/ha) of maize and this treatment remained at par with T_2: 100 % RDF. The experiment concludes that application of the optimum dose of fertilizers (100 % RDF) along with the incorporation of 2 t/ha of rice straw can be recommended for better growth, yield and nutrient use efficiency of *Rabi* maize.

Keywords

Maize; Rice straw incorporation; Yield; CGR; Agronomic use efficiency.

Introduction

In India rice-based cropping systems namely the rice-wheat system in northern parts of the country and rice-rice or rice-maize system in tropical conditions are the most prominent cropping systems practiced under rainfed and irrigated conditions (1). These cereal-based cropping systems play an important role in the country's food security and nutritional supply to the majority of the population. Among these major cropping systems in India, cultivation of rice during *Kharif* followed by *Rabi* maize was practiced under tropical and sub-tropical conditions. Maize, one of the important cereal crops, was mostly cultivated next to rice and wheat in India. Though it is not a major staple food in countries like India the major portion of the grain is used as feed, fodder and other industrial purposes (2). Due to its versatile use, higher yield potential, adaptability to various agroclimatic conditions and stable demand, it grabbed the attention of many farmers for cultivating throughout the country. In India, maize is cultivated in more than 9.86 m ha with a productivity of 3.2 t/ha accounting for a total production of 31.6 million metric tons (3, 4). Maize is cultivated throughout the year in tropical conditions. It was preferably grown during *Rabi* season, which makes the crop more suitable for cultivation after the *Kharif* rice harvest.

After green revolution, by the use of fertilizers and high yielding cultivars, the grain yield and biomass production of cereal crops were increased in larger quantity. Though the increase in grain yield helped the country in achieving self-sustain in food production, the use of high chemical inputs in maize cultivation led to soil degradation, environmental pollution and unsustainable cultivation. However, with the change in cultural practices, mechanisation of agriculture and intensive farming the production of stover yield in modern agriculture has become a serious threat to agricultural sustainability (5). Due to intensive cropping system, farmers do not have enough time for handling the stover of previous rice crop. As a result, the farmers are burning the rice straw for making the field ready for the upcoming maize crop (6-8). Though straw burning is banned and made illegal in most of the regions, the farmers are unable to handle the residue management due to the scarcity of labour and the high cost involved in residue spreading and incorporation (9-11). In this scenario cultivation of maize as a succeeding crop with rice can be an alternative for the crop growers for proper handling and incorporation of rice straw in maize fields (12). These intensive cereal-based cropping systems are having an adverse impact such as deterioration of soil health and over-exploitation of natural resources.

In conventional rice-maize cropping systems, the use of high inorganic inputs has led to yield stagnation and loss of inherent fertility of the soil (13). In this scenario, addition of organic inputs such as rice straw is a sustainable cultural practice to enhance soil organic carbon, and nutrient availability and minimize the fertilizer application (14, 15). In heavy feeders like maize, incorporation of straw can replace some quantity of fertilizer requirement, thereby reducing the chemical load in the soil (16). Burying of rice straw under the soil provides a good amount of phosphorous and potassium to the soil. But during the initial period, the availability of nitrogen may be reduced in soil due to the high C:N ratio of rice straw (17, 18). The microbes take the available nitrate or ammonia in the process of straw decomposition during the initial stages (19). However, the straw incorporation returns significant amount of plant essential nutrients to the soil and further enhancing the microbial population, physical and chemical properties in long term application (20). RSI can maximize the nutrient availability and mobility of plant nutrients which in turn increases the nutrient uptake and productivity of maize crop (21).

In nutrient demanding crops like maize, straw incorporation cannot be a complete replacement for inorganic nutrients (22, 23). The integrated approach of applying a recommended dose of primary nutrients in optimum level along with straw incorporation can have a synergistic effect of each other resulting in better nutrient supply, improved growth and productivity (24, 25). Considering the above scenario, the present field study was conducted to evaluate the influence of rice straw incorporation and recommended dose of primary nutrients on growth, productivity and nutrient use efficiency of *Rabi* maize.

Materials and methods

Experimental area

The present experiment on maize was carried out at the Post Graduate Research Farm of Centurion University of Technology and Management, Gajapathi, Odisha, India. The geo-coordinates of the experimental site were 18.805377' N latitude and 84.179114' E longitude (Fig. 1) at 64 m above mean sea level. The crop was grown during *Rabi* season from December 2022 to April 2023 (Fig. 2 and 3). The experimental site falls under hot and sub-humid regions in brown forest soils. The meteorological data during the cropping period were collected from meteorological observatory at Centurion University of Technology and Management from 23rd December, 2022 to 28th April, 2023 (Fig. 4). The weather data depicts that the maximum and minimum temperatures ranged between 28 °C to 41 °C and 13 °C to 29 °C respectively. During the crop period, the maximum and minimum relative humidity varied between 79 % to 96 % and 37 % to 68 % respectively. The cropping season received a total rainfall of 114.9 cm and the average sunshine hours during the experimental period ranged between 4 h/day and 9 h/day. After the primary tillage, the soil was collected randomly from the experimental site and the soil sample analysis was done using standard operational practices. The experimental soil was sandy loam in texture with nearly

Fig. 1. Drone view of the experimental area.

Fig. 2. Experimental field at 20 DAS.

Fig. 3. Experimental field at 90 DAS.

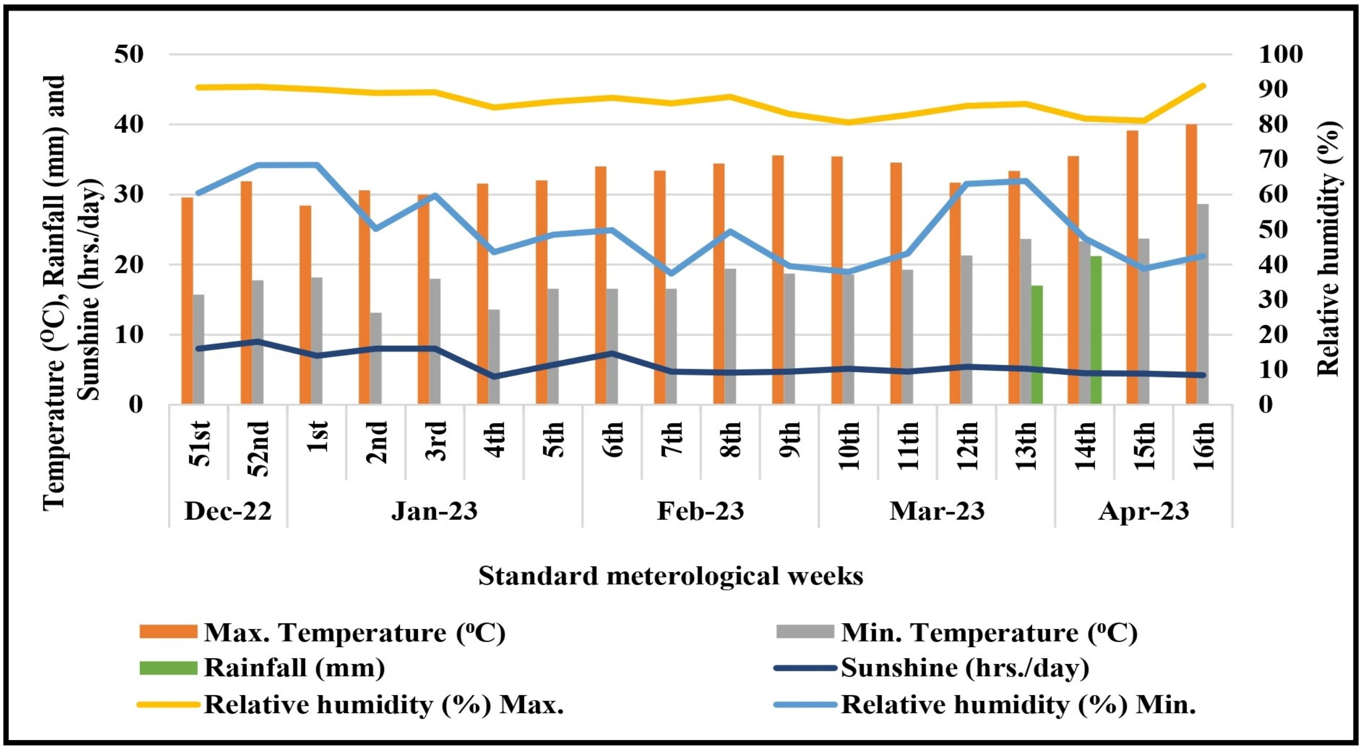

Fig. 4. Meteorological data for the crop period December 2022 to April 2023.

Source: Agro-meteorological observatory, Centurion University, Gajapathi, Odisha.

neutral pH (6.68). The electrical conductivity of the soil was 0.24 dS/m and containing a soil organic carbon of 0.43 %. The nutrient availability of the experimental soil consists of 234.3 kg/ha of nitrogen, 12.7 kg/ha of phosphorous and 125.6 kg/ha of potassium.

The field study was laid out in randomized complete block design with eight treatments and each treatment was replicated for 4 times. The details of the treatment are as follows, T_1: absolute control, T_2: 100 % RDF, T_3: 100 % RDF + rice straw incorporation (RSI) at 2 t/ha, T_4: 100 % RDF + RSI at 4 t/ha, T_5: 100 % RDF + RSI at 6 t/ha, T_6: 100 % RDF + RSI at 8 t/ha, T_7: 75 % RDF + RSI at 2 t/ha and T_8: 75 % RDF + RSI at 4 t/ha. The size of each experimental plot was 4.8 m x 4.2 m. The recommended dose of fertilizers (RDF) considered for maize were 120:60:60 kg/ha of N: P_2O_5: K_2O respectively. The maize hybrid VNR 4226 was used during the study and the duration of the hybrid was 120 days. In straw incorporation treatments, the rice straw was spread according to the quantity and tillage was done until the straw was mixed properly into the soil. After incorporation, the maize seeds were sown by dibbling method with a spacing of 60 cm x 25 cm row to row and plant to plant respectively. A total of 6 irrigations are provided for the crop during the crop period in regular intervals as per the crop requirement. To maintain the plots free from weeds, the selective herbicide Topramezone 33.6 % SC was applied during 12 DAS and 45 DAS respectively.

The growth attributes of maize namely, plant height, dry matter accumulation and leaf area index were measured at every 30 days interval from 30 DAS to harvest. The yield attributes and yield were calculated for each treatment after harvest by standard operation procedures. The leaf area index and the crop growth rate were computed (26) and agronomic nutrient use efficiency (27).

$$\text{Leaf area index (LAI)} = \frac{\text{Leaf area}}{\text{Ground area}}$$

$$\text{Crop growth rate (CGR) (g/m}^2\text{/day)} = \frac{W_2 - W_1}{d\,(t_2 - t_1)}$$

Where, W_1 and W_2 are the plant dry matter at time t1 - t2 respectively d is the ground area.

Agronomic use efficiency (AE) (kg/kg) =

$$\frac{\text{(Grain yield nutrient plot- grain yield in control plot)}}{\text{Total nutrient applied}}$$

The collected data were statistically analysed by using analysis of variance (ANOVA), standard error of means and LSD at a 5 % probability level of significance (28). Further, the significant differences among the treatments and data grouping were analysed using the mean variability test and the R studio, version 4.3.1. R foundation for statistical analysis in Vienna, Austria was adopted.

Results

Growth attributes

The growth attributes mainly, plant height, dry matter, leaf area index and crop growth rate had found a significant influence with respect to RDF and rice straw incorporation. In case of plant height and dry matter accumulation the highest values were obtained in T_2: 100 % RDF, T_3: 100 % RDF + RSI at 2 t/ha at all the growth stages of maize (Table 1). These 2 treatments remained statically at par with each other and significantly superior to all other treatments of RDF and straw incorporation. Further, the treatments such as T_4: 100 % RDF + RSI at 4 t/ha and T_7: 75 % RDF + RSI at 2 t/ha also remained on par with each other and significantly superior to all other treatments except T_2 and T_3 in the expression of plant height and dry matter during 30, 60 and 90 DAS and at harvest. Due to no application of primary nutrients, the least values of plant height and dry matter were obtained in T_1: absolute control. The results clearly reveal that the application of the recommended dose of fertilizer with no straw incorporation had made the primary nutrient availability to the maize plant which may resulted in better growth attributes of maize. The incorporation of an excess amount of rice straw i.e., T_6: 100 % RDF + RSI at 8 t/ha, T_5: 100 % RDF + RSI at 6 t/ha may result in less availability of nutrients with more emphasis on nitrogen fertilizer. It may be due to more C: N ratio of rice straw which may result in reduced availability of nitrogen fertilizer to the crop throughout the growth period (29, 30). These findings are in confirmatory with the previous studies of (31-33).

In the case of leaf area index (LAI) and crop growth rate (CGR), a similar trend was observed during all growth stages of maize (Table 2). The LAI gradually increased to 60 DAS and obtained the highest values at this growth stage. It then gradually reduced till harvesting which may be due to the continuous senescence of elder leaves as the crop leads to maturity. In the case of LAI and CGR the highest values were obtained in T_2: 100 % RDF, T_3: 100 % RDF + RSI at 2 t/ha and T_4: 100 % RDF + RSI at 4 t/ha. Further, these 3 treatments remained statically at par with each other and significantly superior to all other treatments during all the growth stages of maize. The other treatments namely T_5: 100 % RDF + RSI at 6 t/ha, T_6: 100 % RDF + RSI at 8 t/ha and T_7: 75 % RDF + RSI at 2 t/ha also remained on par with each other and significantly superior to T_8: 75 % RDF + RSI at 4 t/ha and T_1: absolute control. The data revealed that the increasing straw incorporation from 2 t/ha to 8 t/ha had gradually reduced the growth attributes of maize which may be due to the reduction in the applied nutrient availability under straw incorporation conditions. The application of rice residue at 2 t/ha may result in quick decomposition of the straw. Releasing the nutrient present in the rice straw residue may further fulfil the nutrient requirement of the maize plant resulting in obtaining maximum effect. Due to no application of nutrients and rice straw, the control treatment (T_1) resulted in registering the inferior growth attributes of maize which might be due to the unavailability of optimum required nutrients for maize plant growth (32). These results are similar with the findings of previous studies (32, 33).

Table 1. Effect of recommended dose of fertilizers and straw incorporation on plant height and dry matter accumulation of maize.

Treatment details	Plant height (cm)				Dry matter accumulation (g/m^2)			
	30 DAS	60 DAS	90 DAS	Harvest	30 DAS	60 DAS	90 DAS	Harvest
T_1: absolute control	28.4^{f}	93.2^{e}	135.2^{c}	144.3^{d}	119^{e}	366^{e}	610^{e}	757^{d}
T_2: 100 % RDF	51.6^{a}	175.5^{a}	233.4^{a}	250.4^{ab}	364^{a}	840^{a}	1302^{ab}	1469^{a}
T_3: 100 % RDF + rice straw incorporation at 2 t/ha	47.5^{ab}	170.0^{ab}	242.3^{a}	258.6^{a}	346^{a}	814^{ab}	1349^{a}	1497^{a}
T_4: 100 % RDF + rice straw incorporation at 4 t/ha	47.2^{ab}	151.0^{bc}	206.0^{b}	220.3^{bc}	293^{b}	751^{bc}	1182^{bc}	1398^{a}
T_5: 100 % RDF + rice straw incorporation at 6 t/ha	40.3^{cd}	143.5^{cd}	194.4^{b}	213.8^{c}	267^{bc}	596^{d}	1068^{c}	1197^{bc}
T_6: 100 % RDF + rice straw incorporation at 8 t/ha	35.6^{de}	137.3^{cd}	189.0^{b}	208.3^{c}	241^{cd}	569^{d}	1049^{c}	1184^{bc}
T_7: 75 % RDF + rice straw incorporation at 2 t/ha	42.4^{bc}	149.0^{c}	200.1^{b}	218.5^{c}	284^{b}	705^{c}	1139^{c}	1365^{ab}
T_8: 75 % RDF + rice straw incorporation at 4 t/ha	34.4^{e}	127.9^{d}	186.4^{b}	202.7^{c}	226^{d}	568^{d}	858^{d}	1025^{c}
S.Em	1.87	7.12	9.14	10.23	12.83	27.82	50.09	65.62
LSD	5.52	20.95	26.90	30.11	37.75	81.84	147.34	193.00
F -Test	**	**	**	**	**	*	**	**

* and ** represents the significant difference at 5 % and 1 % probability level respectively. The alphabets in continuous columns describe the multiple comparison test and different alphabets refer to the significant differences between the treatments at a 5 % probability level.

Table 2. Effect of the recommended dose of fertilizers and straw incorporation on leaf area index and crop growth rate of maize.

Treatment details	Leaf area index				Crop growth rate (g/m²/day)		
	30 DAS	60 DAS	90 DAS	Harvest	30 - 60 DAS	60 - 90 DAS	90 DAS - Harvest
T_1: absolute control	1.79^{e}	3.54^{e}	2.51^{d}	2.20^{d}	8.23^{c}	8.15^{c}	4.88^{b}
T_2: 100 % RDF	2.5^{a}	5.22^{a}	4.39^{ab}	3.45^{a}	15.85^{a}	15.40^{a}	5.58^{b}
T_3: 100 % RDF + rice straw incorporation at 2 t/ha	2.42^{ab}	5.10^{ab}	4.51^{a}	3.53^{a}	15.61^{a}	17.83^{a}	4.92^{b}
T_4: 100 % RDF + rice straw incorporation at 4 t/ha	2.28^{abc}	4.65^{bc}	4.08^{ab}	3.01^{b}	15.28^{a}	14.35^{ab}	7.19^{a}
T_5: 100 % RDF + rice straw incorporation at 6 t/ha	2.07^{cde}	4.52^{cd}	3.53^{c}	2.66^{bc}	10.98^{b}	15.72^{a}	4.30^{b}
T_6: 100 % RDF + rice straw incorporation at 8 t/ha	1.98^{de}	4.43^{cd}	3.49^{c}	2.63^{bc}	10.94^{b}	15.99^{a}	4.49^{b}
T_7: 75 % RDF + rice straw incorporation at 2 t/ha	2.21^{bcd}	4.58^{bc}	4.03^{b}	2.94^{b}	14.03^{a}	14.46^{ab}	7.51^{a}
T_8: 75 % RDF + rice straw incorporation at 4 t/ha	1.92^{e}	4.01^{de}	3.59^{c}	2.46^{cd}	11.46^{b}	9.62^{bc}	5.58^{b}
S.Em	0.09	0.18	0.14	0.14	0.84	1.94	0.51
LSD	0.28	0.54	0.43	0.42	2.45	5.69	1.50
F -Test	**	*	**	**	**	*	**

* and ** represents the significant difference at 5 % and 1 % probability level respectively. The alphabets in continuous columns describe the multiple comparison test and different alphabets refer to the significant differences between the treatments at a 5 % probability level.

Yield attributes

The yield attributes of maize recorded at the time of harvest had found a significant influence with application of RDF and rice straw incorporation (Table 3). Among the yield attributes such as length of the cob, girth of the cob, number of grains per row, number of cobs per plant, number of grain rows per cob and number of grains per cob, the highest values were obtained in T_2: 100 % RDF and T_3: 100 % RDF + RSI at 2 t/ha. Further, these 2 treatments remained statistically at par with each other and significantly superior to all other treatments in the expression of the length of the cob, girth of the cob and number of grain rows per cob. However, the treatments T_2 and T_3 remained statistically on par with T_4: 100 % RDF + RSI at 4 t/ha in obtaining the superior values of the number of grains per row, number of grain rows per cob and number of grains per cob. The other treatments, namely T_5: 100 % RDF + RSI at 6 t/ha, T_6: 100 % RDF + RSI at 8 t/ha, T_7: 75 % RDF + RSI at 2 t/ha and T_8: 75 % RDF + RSI at 4 t/ha, remained significantly inferior to T_4: 100 % RDF + RSI at 4 t/ha. But these above-mentioned treatments performed superiorly to T_1: absolute control in expression of the yield attributes of maize. The application of 100 % RDF and RDF along with 2 t/ha of rice straw incorporation had resulted in a ready supply of applied fertilizers throughout the crop period which may result in obtaining the optimum yield attributes of maize (32-34). Further, the reduced application of recommended fertilizers (75 % RDF) and increased incorporation of rice straw (4, 6, 8 t/ha) may not help in the optimum supply of nutrients which may result in the least values of yield attributes (35). The treatments with superior performance in growth attributing characters (T_2 and T_3) showed a direct relation with yield attributing characters. This shows the importance of growth attributes and their contribution to yield attributing characters. The test weight of maize does not find a significant difference with the application of various levels of RDF and rice straw incorporation (36). This may be due to the stable genetic character of the hybrid which may not be influenced due to different agronomic practices. These findings are in pipeline with the results of previous reports (22, 33, 37).

Table 3. Effect of the recommended dose of fertilizers and straw incorporation on yield attributes of maize.

Treatment details	Yield attributes						
	Length of the cob (cm)	Girth of the cob (cm)	No. of grain rows per cob	No. of cobs per plant	No. of grains per row	No. of grains per cob	100 grain weight (g)
T_1: absolute control	14.2^{e}	12.3^{c}	10.0^{c}	1.1^{e}	16.2^{c}	156.9^{e}	21.7
T_2: 100 % RDF	20.3^{ab}	16.8^{a}	13.1^{ab}	1.6^{ab}	19.9^{a}	252.0^{ab}	25.7
T_3: 100 % RDF + rice straw incorporation at 2 t/ha	21.0^{a}	17.1^{a}	13.6^{ab}	1.7^{a}	20.8^{a}	268.0^{a}	25.6
T_4: 100 % RDF + rice straw incorporation at 4 t/ha	18.8^{bc}	14.9^{b}	12.8^{ab}	1.5^{bc}	19.1^{ab}	233.7^{abc}	24.4
T_5: 100 % RDF + rice straw incorporation at 6 t/ha	16.8^{cd}	14.6^{b}	14.4^{a}	1.4^{cd}	13.8^{d}	214.6^{cd}	23.4
T_6: 100 % RDF + rice straw incorporation at 8 t/ha	15.2^{d}	13.7^{bc}	13.4^{ab}	1.3^{cd}	13.7^{d}	211.8^{cd}	22.0
T_7: 75 % RDF + rice straw incorporation at 2 t/ha	18.1^{c}	14.8^{b}	12.2^{b}	1.5^{bc}	18.9^{ab}	229.2^{bcd}	24.0
T_8: 75 % RDF + rice straw incorporation at 4 t/ha	15.5^{d}	12.5^{c}	11.9^{b}	1.2^{de}	17.5^{bc}	198.0^{d}	23.6
S.Em	0.70	0.60	0.57	0.05	0.66	11.99	0.99
LSD	2.06	1.78	1.68	0.17	1.95	35.27	NS
F -Test	**	**	**	*	**	**	

* and ** represents the significant difference at 5 % and 1 % probability level respectively. The alphabets in continuous columns describe the multiple comparison test and different alphabets refer to the significant differences between the treatments at a 5 % probability level.

Yield

The grain, stover and biological yield had found a significant impact due to the application of primary nutrients and straw incorporation (Table 4). In the case of grain and stover yield the superior values were obtained in the treatment T_3: 100 % RDF + RSI at 2 t/ha and T_2: 100 % RDF. These 2 treatments remained on par with each other and significantly superior to all other treatment combinations of RDF and straw incorporations. Further, the remaining treatments, namely T_4: 100 % RDF + RSI at 4 t/ha, T_5: 100 % RDF + RSI at 6 t/ha, T_6: 100 % RDF + RSI at 8 t/ha and T_7: 75 % RDF + RSI at 2 t/ha, remained on par with each other and significantly superior to T_8: 75 % RDF + RSI at 4 t/ha and T_1: absolute control in expression of grain and stover yield of maize. In the case of biological yield, similar to grain and stover yield the highest biological yield was obtained in the treatment T_3: 100 % RDF + RSI at 2 t/ha and T_2: 100 % RDF. However, these 2 treatments remained statistically at par with T_4: 100 % RDF + RSI at 4 t/ha, T_5: 100 % RDF + RSI at 6 t/ha and T_7: 75 % RDF + RSI at 2 t/ha. The other treatments such as T_6: 100 % RDF + RSI at 8 t/ha and T_1: absolute control performed inferiorly when compared with all other treatments in obtaining the maximum biological yield of maize. Application of optimum level of straw incorporation (2 t/ha) along with the recommended dose of fertilizer had increased the grain yield of maize which may be due to the availability of nutrients through fertilizers during the early growth stages of maize and the supplement of released nutrients from the decomposed rice straw during the later growth stages (31, 38, 39). The better growth and yield attributes obtained in T_3 and T_2 may also further enhance the yield of maize (40-42). In the case of the harvest index, there was no significant difference among the treatments. However, the marginally increased harvest index was recorded with the treatments T_4: 100 % RDF + RSI at 4 t/ha, T_7: 75 % RDF + RSI at 2 t/ha and T_8: 75 % RDF + RSI at 4 t/ha (22, 32, 43, 44).

Agronomic nutrient use efficiency

The agronomic use efficiency (AE) of maize derived by considering the grain yield and nutrient applied to the treated plot with control are represented in Table 5. The AE of nitrogen, phosphorus and potassium had found a similar trend with each other among the treatments of RDF and straw incorporation. The data revealed that the highest AE of N, P and K were obtained in the treatment T_7: 75 % RDF + RSI at 2 t/ha and this treatment was closely followed by T_3: 100 % RDF + RSI at 2 t/ha and T_2: 100 % RDF. However, the least use efficiency of nitrogen, phosphorus and potassium was recorded with the treatments T_6: 100 % RDF + RSI at 8 t/ha and T_5: 100 % RDF + RSI at 6 t/ha respectively. The reduced application of fertilizer (75 % RDF) along with lower quantity incorporation of rice straw resulted in higher nutrient use efficiency (45). Interestingly, the higher rate of rice straw incorporation (T_5 and T_6) accounted for the least nutrient use efficiency of maize which shows the loss of applied nutrients in the soil due to the higher quantity of rice straw incorporation (46, 47).

Conclusion

The application of different levels of rice straw incorporation and RDF had found a significant influence on growth, productivity and nutrient use efficiency of maize. The incorporation of rice straw at the rate of 2 t/ha enhanced the growth and yield attributes of maize by providing the required nutrients to the maize plant at the later growth stages. However, the increase in straw quantity resulted in a negative impact on growth and yield of maize with reduced nutrient use efficiency. From the study, it may be concluded that considering the straw handling and soil health, the application of a 100 % recommended dose of fertilizers along with the incorporation of 2 t/ha of rice straw can be recommended for better growth, yield and nutrient use efficiency of *Rabi* maize.

Table 4. Effect of the recommended dose of fertilizers and straw incorporation on yield of maize.

Treatment details	Yield (kg/ha)			Harvest index (%)
	Grain yield	Stover yield	Biological yield	
T_1: absolute control	2408^{d}	3989^{d}	6507^{d}	38.9
T_2: 100 % RDF	6111^{a}	8354^{a}	14465^{abc}	42.2
T_3: 100 % RDF + rice straw incorporation at 2 t/ha	6354^{a}	8429^{a}	14783^{a}	43.0
T_4: 100 % RDF + rice straw incorporation at 4 t/ha	5672^{bc}	7172^{b}	12844^{ab}	44.2
T_5: 100 % RDF + rice straw incorporation at 6 t/ha	4628^{c}	7163^{b}	11790^{abc}	39.1
T_6: 100 % RDF + rice straw incorporation at 8 t/ha	4420^{c}	7050^{b}	11570^{bc}	39.0
T_7: 75 % RDF + rice straw incorporation at 2 t/ha	5468^{b}	7068^{b}	12536^{ab}	43.7
T_8: 75 % RDF + rice straw incorporation at 4 t/ha	4531^{c}	5876^{c}	10407^{cd}	43.7
S.Em	223.48	325.93	82.31	4.86
LSD	657.25	958.56	242.09	NS
F -Test	**	**	**	

* and ** represents the significant difference at 5 % and 1 % probability level respectively. The alphabets in continuous columns describe the multiple comparison test and different alphabets refer to the significant differences between the treatments at a 5 % probability level.

Table 5. Effect of the recommended dose of fertilizers and straw incorporation on agronomic nutrient use efficiency of maize.

Treatment details	Agronomic nutrient use efficiency (kg/kg)		
	Nitrogen	Phosphorous	Potassium
T_1: absolute control	-	-	-
T_2: 100 % RDF	30.86	61.72	61.72
T_3: 100 % RDF + rice straw incorporation at 2 t/ha	32.88	65.77	65.77
T_4: 100 % RDF + rice straw incorporation at 4 t/ha	27.20	54.40	54.40
T_5: 100 % RDF + rice straw incorporation at 6 t/ha	18.50	36.99	36.99
T_6: 100 % RDF + rice straw incorporation at 8 t/ha	17.06	34.12	34.12
T_7: 75 % RDF + rice straw incorporation at 2 t/ha	34.00	68.00	68.00
T_8: 75 % RDF + rice straw incorporation at 4 t/ha	23.59	47.18	47.18

Limitations and future scope of research

- Since the present study was carried out for one season, the long-term study may reveal the actual potential of straw incorporation with more influence on soil properties.
- Since the present research has been focused on residue conservation and incorporation, further research can be conducted on improving the soil properties under long-term study.
- Further research may focus on C: N ratio to which the soil organic carbon can be improved along with the optimum availability of nitrogen.
- Further research can better evaluate the problems associated with rice straw burning and advanced incorporation methods in rice-based cropping systems.
- Further studies can be conducted on the availability of plant essential nutrients under the incorporation of rice straw residue.

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Authors' contributions

CVR, RSK and BD: Conducted field experiment, collected data and wrote the manuscript, CVR, RSK and TS: Framing out the research work and designing the experiment, SM: Manuscript drafting. RS, MS and CVR: Statistical analysis, RSK, MS: Revision of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors declare that they don't have any conflict of interest.

Ethical issues: None.

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