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Effect of incorporation of crop residue and its influence on macro and micronutrient availability and nutrient uptake in chickpea (*Cicer arietinum*)

Suvarna Latha AJ, Ratna Prasad P, Trimurtulu N, Prasuna Rani P and Srinivasa Rao V

Abstract
Influence of Crop Residues on Glomalin Content, Fungal Population, and Soil Aggregate Stability in Chickpea under Rainfed Agro-climatic Conditions"
The influence of crop residues on glomalin content, fungal population, and soil aggregate stability is a topic of great importance in agricultural research. Soil aggregation plays a crucial role in preventing soil erosion, enhancing soil fertility, and promoting optimal crop production. Glomalin, a glycoprotein produced by arbuscular mycorrhizal fungi, has been identified as a key component in soil aggregation. It serves as a binding agent, holding soil particles together and forming stable aggregates. Understanding the impact of crop residues on glomalin content, fungal population, and soil aggregate stability in chickpea cultivation under rainfed agro-climatic conditions is essential for improving soil health and sustainable agricultural practices.
The use of cover crops and residues in agricultural systems has gained attention due to their potential benefits for soil health and crop production. Cover crops not only provide additional organic matter to the soil but also promote the growth of arbuscular mycorrhizal fungi study conducted by Wright and Anderson demonstrated that a crop rotation system involving a variety of crops led to higher levels of glomalin production. However, there is a dearth of data on the impact of cover crops on glomalin levels.

Keywords: Crop residue, microbial consortium, macro and micronutrient content and uptake in chickpea

Introduction
Crop residues refer to the remains of plants left in the field subsequent to harvesting and threshing activities. According to the Ministry of New and Renewable Energy (MNRE) under the Government of India (2019), approximately 500 million metric tons (Mt) of crop residues are generated on an annual basis. Among various crop types, cereals yield the highest amount of residues (352 Mt), followed by fibers (66 Mt), oilseeds (29 Mt), pulses (13 Mt), and sugarcane (12 Mt). Notably, cereal crops account for 70 percent of these residues, with rice constituting 34 percent, wheat at 22 percent, and millets aT$_1$4 percent within the total cereal residue inventory.
In the Indian context, crop residues are primarily utilized as cattle feed. However, due to the widespread adoption of combine harvesters, a significant portion of crop residues tends to remain in the field, impeding subsequent tillage and seeding operations. As a result, farmers are compelled to remove residues from the field or resort to burning them, enabling swift preparation for the next crop cycle. Out of the surplus 140 Mt of crop residues in India, a staggering 92 Mt are subjected to burning annually (NPMCR, 2019). The combustion of one ton of paddy straw emits 1460 kg of carbon dioxide, 60 kg of carbon monoxide, 3 kg of particulate matter, 200 kg of ash, and 2 kg of sulfur dioxide. Furthermore, residue burning leads to the loss of entire carbon content, 80 percent of nitrogen, 25 percent of phosphorus, 20 percent of potassium, and 50 percent of sulfur (Kumawat, 2021) [19]. Carbon depletion from the soil results in diminished microbial activity, affecting long-term soil functions such as nutrient cycling and detoxification capacity.
The recycling of crop residues offers the advantage of transforming surplus residues into valuable products that can cater to the nutrient demands of soil microorganisms and subsequent crops. While burning crop residues may temporarily enhance mineralization and nutrient availability for plant growth, the subsequent increase in surface soil temperature tends to eliminate a significant proportion of mesophilic organisms that play a crucial role in nutrient

transformation within the upper soil layer. Although this effect is transitory and microbial populations tend to regenerate after a few days, repeated burning can lead to a lasting decline in these populations. The burning of residues has an immediate and substantial adverse impact on bacterial and fungal populations in the upper 2.5 cm of soil.

Typically, crop residues comprise 15 to 60 percent cellulose, 10 to 30 percent hemicellulose, 5 to 30 percent lignin, and 2 to 15 percent protein (Paul and Clark, 1989) [23]. These residues form a physical layer over the soil surface, safeguarding it against various environmental factors such as temperature, light, and water. They also serve as a barrier against weed growth, prevent soil erosion caused by rainfall and wind, and provide a habitat for beneficial organisms. Additionally, crop residues act as a source of nourishment for soil microorganisms, triggering microbial activity and nutrient cycling (Ros *et al*. 2003, Rengel, 2007) [26, 25]. Around 25 percent of nitrogen and phosphorus, 50 percent of sulfur, and 75 percent of potassium taken up by cereal crops are retained in crop residues (Gupta *et al*., 2004) [10]. These residues also contribute to the soil's organic matter content, constituting approximately 40 percent of the total dry biomass. Moreover, they play a pivotal role in maintaining the stability of agricultural ecosystems.

The excessive use of chemical fertilizers and continuous farming practices have been observed to degrade soil health. This situation arises due to the presence of readily available nutrients in the form of fertilizers, disrupting the natural flow of nutrient immobilization and mineralization in the soil. Consequently, the growth of soil organisms is adversely impacted. In this context, employing previous crop residues for subsequent crops emerges as an eco-friendly approach that caters to the principles of sustainable and conservation agriculture, where the output of one activity becomes the input for another. Given the varying decomposition rates of crop residues under field conditions and limited non-crop intervals between consecutive crops, rapid decomposition techniques present an avenue for utilizing these residues as potential nutrient sources for succeeding crops. With these considerations in mind, this study was conducted to investigate the impact of incorporating residues from previous crops into the soil on nutrient availability and uptake by succeeding crops.

Materials and Methods

Study location

An incubation study was conducted at green house of Agricultural Research Station, Amaravathi of Acharya N.G. Ranga Agricultural University of Andhra Pradesh during 2017-18. The bulk surface soil collected from field number 4 was used for incubation experiment. Black cotton soil from field was processed and filled in 20 kg capacity cement pots. The korra crop residue was used for incorporation in soil @1.5 t ha^{-1} after chopping in to 3-4 cm size the except in control (T_1) and RDF (T_8). Total eight treatments including control were employed and each treatment was replicated thrice by following completely randomized block design. Turnings at weekly intervals were given and the residue was allowed for aerobic decomposition for 90 days and maintained at 60 per cent water filled pore space throughout incubation. Microbial consortium consists of decompo. A (fungal consortium of *Pleurotus ostreatus*, *Phanerochaete chrysosporium*, yeast and *Trichoderma*), decompo. B (bacterial consortium of *Bacillus sp*, *Lactobacillus* sp and *Pseudomonas sp*) developed at Agricultural Research Station, Amaravathi. The details of the treatment are as follows.

Treatments

T_1: Absolute control
T_2: Crop residue@1.5 t ha^{-1}
T_3: Crop residue@1.5 t ha^{-1}+ 3.0 kg Microbial consortia
T_4: Crop residue@1.5 t ha^{-1} +1.5 kg urea + 7.5 kg SSP
T_5: Crop residue@1.5 t ha^{-1} +3.0 kg urea + 15 kg SSP
T_6: Crop residue@1.5 t ha^{-1}+3.0 kg Microbial consortia + 1.5kg urea+ 7.5 kg SSP
T_7: Crop residue@1.5 t ha^{-1}+ 3.0 kg Microbial consortia + 3.0 kg urea + 15 kg SSP
T_8: RDF (20-50-0-40) of N,P_2O_5 and S ha^{-1}

Result and Discussion

Available macronutrient status

The data pertaining to the available macronutrient status *viz*., nitrogen, phosphorus and potassium at sowing and at harvest during 2017-18 and 18-19 are presented in table 1 and illustrated in figure 1

Nitrogen

The data presented in Table 1 illustrates a significant impact of different treatments on the available nitrogen content measured at the sowing and harvest stages of chickpea growth throughout the study period. Among the various treatments, the nitrogen content ranged from 137 to 190 kg ha^{-1} at sowing and from 93 to 140 kg ha^{-1} at harvest, with average values of 159 and 113 kg ha^{-1}, respectively, in the 2017-18 season. In the subsequent season of 2018-19, the nitrogen content ranged from 133 to 200 kg ha^{-1} at sowing and from 102 to 155 kg ha^{-1} at harvest, with average values of 164 and 133 kg ha^{-1}, respectively. Notably, the nitrogen content at sowing (45 days after initiation) exceeded that at harvest for all treatments. This divergence could be attributed to increased microbial activity at sowing, leading to higher nitrogen availability. Conversely, lower contents at harvest might be due to plant uptake and gaseous loss of nitrogen. The treatment labeled T_7 exhibited a 22.6 percent increase in available nitrogen content compared to the control at sowing.

At sowing, the treatment T_8 recorded the highest nitrogen content of 190 kg ha^{-1} in the 2017-18 season and 200 kg ha^{-1} in the 2018-19 season. Conversely, at harvest, treatment T_7 displayed the highest nitrogen content. This could be attributed to T_8's application of urea-based nitrogen, while T_7 relied on nitrogen released from decomposing crop residue. During the 2017-18 season, treatments T_7 and T_8 were statistically comparable at harvest, whereas in the 2018-19 season, T_7 was comparable to T_8, T_6, and T_3.

Remarkably, treatment T_2 (crop residue @1.5 t ha-1) exhibited the lowest available nitrogen content at sowing, while T_1 (absolute control) displayed the lowest nitrogen content at harvest in both study years. Treatment T_2, which only received crop residue, experienced immobilization, possibly causing nitrogen deficiency in the early stages of crop growth. Notably, improvements in available nitrogen content were observed in treatments that received crop residue (T_3 to T_7) compared to the initial status during sowing in both study years. The adequate decomposition period allowed before chickpea sowing facilitated mineralization. This practice mitigated the negative effects of nitrogen immobilization (Singh and Sidhu, 2014) [29].

Furthermore, the incorporation of crop residues was found to enhance nitrogen accumulation in the soil, thereby improving soil fertility. This enhancement could be attributed to the improved physical and chemical properties of the soil due to crop residue incorporation. The incorporated straw likely aided the conversion of soil nitrogen into a slowly available nitrogen pool, aligning with crop requirements and potentially enhancing nitrogen use efficiency, as noted by Zibilske *et al*. (2002) [35].

Incorporation of only korra residue (T_2) resulted in the lowest nitrogen content compared to treatments receiving both crop residue and supplementary inputs such as fertilizer and microbial consortia. This can be explained by the direct application of crop residue like korra, which consists of lignocellulosic materials with a high C: N ratio. Initially, these materials are resistant to microbial degradation, potentially leading to immobilization of nutrients inaccessible to soil microbes.

Throughout the study, inter-annual variations in soil nitrogen content exhibited a relatively stable trend, likely due to the slow and gradual changes resulting from management practices. The incorporation of low levels of residue in the soil, as indicated by Gong *et al*. (2018) [7], is known to bring about gradual and minor changes in soil total nitrogen and available nitrogen. Comparable findings were reported by Surekha *et al*. (2003) [30] and Bakht *et al*. (2009) [2].

Phosphorus

The available phosphorus status at both sowing and harvest stages of chickpea growth (as shown in Table 1) was significantly impacted by the different treatments implemented during the two years of experimentation. The available phosphorus status was expressed in terms of P2O5 (kilograms per hectare). Across all treatments, there was a notable improvement in available phosphorus status compared to the initial levels at both stages of crop growth over the two study years. This trend mirrored that observed for nitrogen levels.

The highest available phosphorus content was observed in treatment T_8, and it was on par with treatment T_7. These treatments involved the combined application of crop residue, a starter dose of nitrogen and phosphorus fertilization, and a microbial consortium. The enhanced available phosphorus content in treatment T_8 could be attributed to the addition of readily available phosphorus through inorganic fertilization.

Conventionally, the addition of crop residues can lead to reduced nutrient availability due to immobilization and adsorption. However, in the present study, the improved phosphorus status resulted from careful management of residue decomposition, aided by the application of inorganic fertilizers and microbial consortia. This approach expedited the release of phosphorus. Additionally, managing crop residues led to the accumulation of more organic matter at the soil surface, decreasing phosphorus sorption by inorganic colloids. While the crop residues added were not inherently rich in phosphorus (0.15%), their contribution improved soil physical properties and stimulated microbiological activity. These factors collectively made phosphorus in the soil more accessible to plants.

Research by Gupta *et al*. (2007) [11] demonstrated a significant increase in phosphorus availability in the soil under similar conditions. Likewise, studies involving green manuring, as noted by Narayan and Lai (2006) [21], also showcased enhanced phosphorus availability in the soil.

Potassium

The available potassium status at both sowing and harvest stages of chickpea growth, as presented in Table 1, exhibited significant variability based on the treatments applied during both years of experimentation. Available potassium status was measured in terms of K2O (kilograms per hectare). Across all treatments, there was an enhancement in available potassium levels at sowing, but at harvest, treatments receiving no inputs (T_1) and those solely relying on crop residue (T_2) witnessed a decline in available potassium content over the two study years. Among the treatments, the range of potassium content varied from 290 to 383 kg ha^{-1} at sowing and from 256 to 350 kg ha^{-1} at harvest, with average values of 329 and 295 kg ha^{-1}, respectively, during the 2017-18 season. In the subsequent season of 2018-19, the range of potassium content varied from 298 to 389 kg ha^{-1} at sowing and from 259 to 344 kg ha^{-1} at harvest, with average values of 331 and 302 kg ha^{-1}, respectively. The potassium content in the soil followed a similar trend to that of nitrogen and phosphorus.

At both stages of crop growth, the treatment T_7 recorded significantly higher potassium content in the 2017-18 season (383 kg ha^{-1} at sowing and 350 kg ha^{-1} at harvest) and in the 2018-19 season (389 kg ha^{-1} at sowing and 344 kg ha^{-1} at harvest). Treatment T_7 involved the application of crop residue along with a starter dose of nitrogen and phosphorus inorganic fertilization, and a microbial consortium. This treatment was statistically on par with all other treatments except T_1 and T_2 at sowing and except T_1 during the 2017-18 harvest and T_1 and T_2 during the 2018-19 harvest. Significantly, the lowest available potassium was recorded in treatment T_1 (absolute control) at both stages of chickpea growth during both study years.

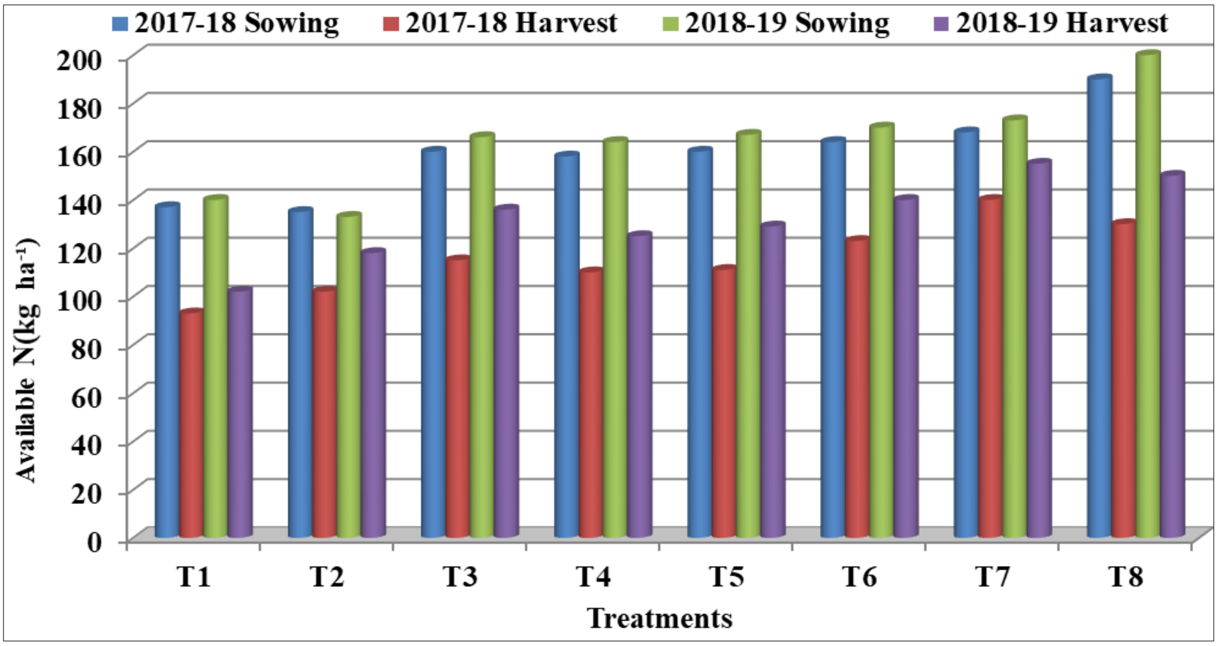
In this study, the positive effects of korra residue application on soil fertility were evident. This could be attributed to critical concentrations of nitrogen, phosphorus, and potassium in korra residue that facilitated the transition from immobilization to mineralization (Hoorman *et al*., 2010) [12]. The increase in available potassium due to crop residue application could be attributed to the direct addition of potassium to the soil's available pool, as well as the reduction of potassium fixation and the release of potassium due to the interaction between organic matter and clay particles (Tandon and Sekhon, 1988; Guled *et al*., 2002) [31, 8]. The decomposition of manures releases organic acids that mobilize non-exchangeable forms of potassium, rendering them available in the soil solution (Anuradha, 2003) [1].

The control plot exhibited the lowest potassium content, as cultivation without fertilization led to a decrease in water-soluble potassium. Similar enhancements in potassium status resulting from the incorporation of crop residues were reported earlier by Mishra *et al*. (2001) [20], Yadvinder Singh *et al*. (2004) [34], and Kaur and Benipal (2006) [16].

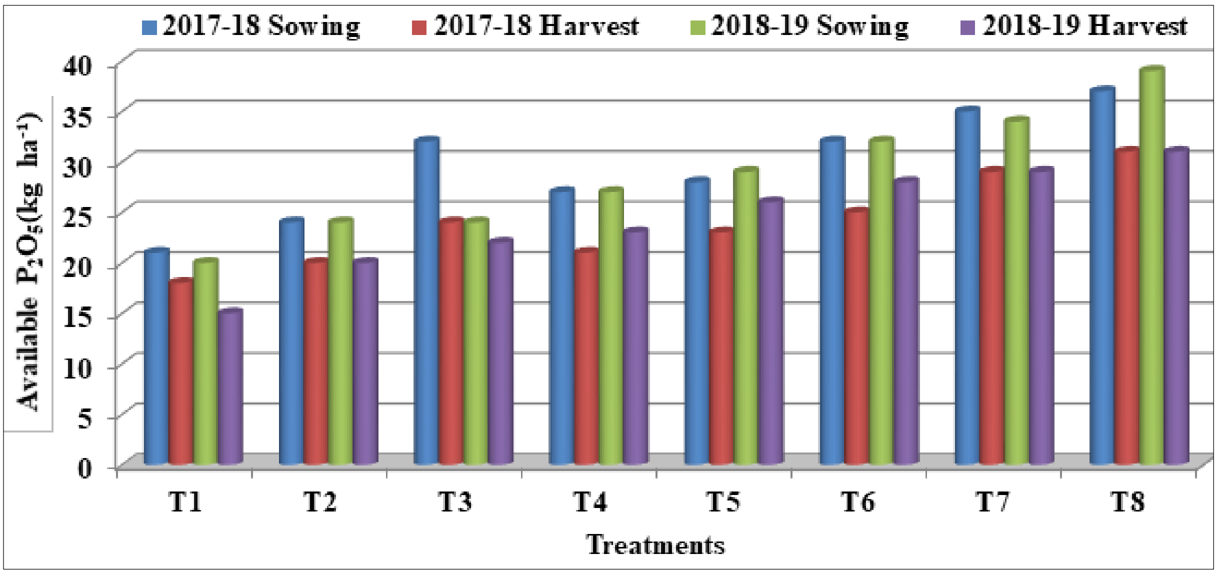
Table 1: Effect of incorporation of korra residue on available macro nutrient status of soil at sowing and harvest of chickpea

Treatment details	Macronutrient status (kg ha^{-1})											
	2017-18						2018-19					
	Sowing (45 DAI)			Harvest (135 DAI)			Sowing (45 DAI)			Harvest (135 DAI)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
T_1: Absolute control	137	21	290	93	18	256	140	20	298	102	15	259
T_2: Crop residue @ 1.5 t ha^{-1}	135	24	300	102	20	279	133	24	308	118	20	284
T_3: T_2 + 3.0 kg Microbial consortium	160	32	340	115	24	300	166	24	346	136	22	313
T_4: T_2 + 1.5 kg Urea + 7.5 kg SSP	158	27	315	110	21	286	164	27	315	125	23	297
T_5: T_2 + 3.0 kg Urea + 15 kg SSP	160	28	320	111	23	293	167	29	317	129	26	299
T_6: T_3 + 1.5 kg Urea + 7.5 kg SSP	164	32	348	123	25	313	170	32	362	140	28	321
T_7: T_3 + 3.0 kg Urea +15 kg SSP	168	35	383	140	29	350	173	34	389	155	29	344
T_8: RDF (20-50-40) of N,P_2O_5 & S kg ha^{-1}	190	37	340	130	31	280	200	39	318	150	31	300
SE (m)$\pm$	9.37	1.77	17.22	5.36	1.38	16.66	9.48	1.30	18.00	8.31	0.99	15.10
CD (0.05)	28.39	5.36	52.20	16.25	4.18	50.49	28.75	3.94	54.57	23.35	2.99	45.77
CV (%)	10.19	10.36	9.04	8.20	9.42	9.78	10.01	7.89	9.39	10.81	7.06	8.64

* DAI-Days after incorporation



(a)



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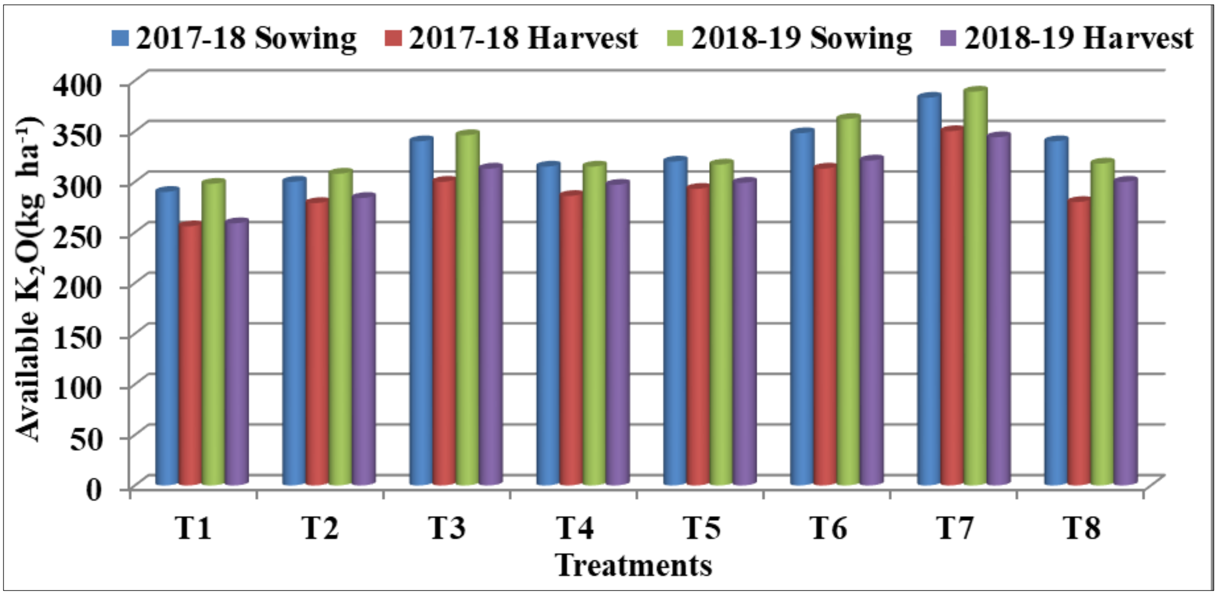


(c)

Fig 1: Effect of incorporation of korra residue on soil macronutrient (nitrogen (a), phosphorus (b) and potassium(c)) status in chickpea during 2017-18 and 2018-19

Table 2: Effect of incorporation of korra residue on available micronutrient status of soil at sowing and harvest of chickpea

Treatment details	Available micronutrients(mg kg^{-1})															
	2017-18								2018-19							
	Sowing (45 DAI)				Harvest (135 DAI)				Sowing (45 DAI)				Harvest (135 DAI)			
	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu	Zn	Fe	Mn	Cu
T_1: Absolute control	0.63	12.83	10.50	0.57	0.60	12.20	9.97	0.51	0.67	10.67	10.17	0.56	0.62	9.00	10.00	0.54
T_2: Crop residue @ 1.5 t ha^{-1}	0.75	14.33	10.67	0.66	0.70	13.00	10.44	0.63	0.83	11.00	11.00	0.63	0.71	10.00	10.33	0.61
T_3: T_2 + 3.0 kg Microbial consortium	0.81	15.33	11.67	0.69	0.77	13.67	10.93	0.71	0.94	13.67	11.67	0.70	0.82	10.67	11.00	0.65
T_4: T_2 + 1.5 kg Urea + 7.5 kg SSP	0.77	14.67	11.00	0.67	0.73	13.33	10.84	0.67	0.85	12.33	11.33	0.63	0.75	9.67	10.33	0.60
T_5: T_2 + 3.0 kg Urea + 15 kg SSP	0.79	15.33	11.33	0.70	0.73	13.50	10.93	0.68	0.93	13.33	11.67	0.68	0.79	10.33	10.83	0.63
T_6: T_3 + 1.5 kg Urea + 7.5 kg SSP	0.82	16.00	11.67	0.77	0.77	14.33	10.66	0.73	0.95	14.00	12.00	0.73	0.87	11.67	11.87	0.70
T_7: T_3 + 3.0 kg Urea +15 kg SSP	0.85	16.67	11.78	0.79	0.83	14.67	11.53	0.75	0.99	14.67	13.00	0.77	0.90	12.33	12.00	0.73
T_8: RDF (20-50-40) of N,P_2O_5 & S kg ha^{-1}	0.72	15.67	11.35	0.62	0.63	14.00	10.27	0.58	0.97	13.33	11.67	0.62	0.80	9.67	10.33	0.56
SE (m)$\pm$	0.04	0.95	0.69	0.04	0.04	0.85	0.65	0.04	0.06	0.87	0.85	0.04	0.05	0.69	0.66	0.04
CD (0.05)	0.12	NS	NS	0.12	0.13	NS	NS	0.13	0.19	NS	NS	0.12	0.16	NS	NS	0.11
CV (%)	9.23	10.86	10.58	9.76	10.26	10.79	10.54	11.36	12.36	11.70	12.71	9.89	11.33	11.45	10.55	10.07

Available micronutrient status

Zinc

The available zinc status, as presented in Table 2, exhibited a significant influence of treatments at both stages of crop growth. The zinc content ranged from 0.63 to 0.85 mg kg^{-1} at sowing and from 0.60 to 0.83 mg kg^{-1} at harvest, with average values of 0.77 and 0.72 mg kg^{-1}, respectively, during the 2017-18 season. In the subsequent season of 2018-19, the zinc content ranged from 0.67 to 0.99 mg kg^{-1} at sowing and from 0.62 to 0.9 mg kg^{-1} at harvest, with average values of 0.89 and 0.78 mg kg^{-1}, respectively. Zinc content was highest at sowing across all treatments, gradually decreasing with the progression of crop growth. Significantly, the highest zinc content was observed at sowing (0.85 and 0.99 mg kg^{-1}) and harvest (0.83 and 0.9 mg kg^{-1}) during the 2017-18 and 2018-19 seasons, respectively, in treatment T_7. Conversely, the lowest zinc content was observed in treatment T_1 (absolute control). This discrepancy could be attributed to the incorporation of crop residue leading to reduced soil pH, thereby increasing zinc solubility. The decay of crop residues produces various biochemical substances such as organic acids, polyphenols, amino acids, and polysaccharides, which enhance the solubility, transport, and availability of zinc. Moreover, the increased organic matter content fosters complex formation, potentially boosting zinc availability in the soil. The addition of organic matter-rich crop residue to the soil introduces an optimal concentration of micronutrients, enhancing their availability to plants. Elevated soil organic matter levels facilitate various micronutrient reactions, leading to the formation of more stable micronutrient complexes. Similar findings were reported by Singh *et al*. (2011) [28] and Kumari *et al*. (2017) [18], emphasizing the role of crop residue incorporation in improving micronutrient availability.

In terms of available iron content, the highest levels were observed in treatment T_7 during both years of experimentation (16.67 and 14.67 mg kg−1 at sowing, 14.67 and 10.67 mg kg−1 at harvest for 2017-18 and 2018-19, respectively). Conversely, the lowest iron content was recorded in the control soil (12.83 and 12.20 mg kg−1 at sowing, 12.33 and 9.0 mg kg−1 at harvest for 2017-18 and 2018-19, respectively). Treatments that received crop residue demonstrated comparably higher iron content than those without residue application (T_1 and T_8). This suggests that crop residue application increased the presence of organic compounds in the soil, leading to enhanced iron complexation with organic matter, ultimately boosting iron phytoavailability. This observation aligns with the findings of Kabirnejad *et al*. (2014). The status of iron content initially increased and gradually declined after reaching maturity across all treatments during both study years. The application of korra residue positively influenced iron availability through the solubilization of native insoluble iron, coupled with enhanced diffusion and mass flow in the immediate vicinity of the plant, as noted by Dhaliwal *et al*. (2019) [5].

Manganese

A comprehensive analysis of the data presented in Table 2 highlights a significant impact of treatments on available manganese (Mn) content during chickpea growth. Among the treatments, the manganese content ranged from 10.5 to 11.78 mg kg^{-1} at sowing and from 9.97 to 11.53 mg kg^{-1} at harvest, with average values of 11.25 and 10.7 mg kg^{-1}, respectively, during the 2017-18 season. In the subsequent season of 2018-19, the manganese content ranged from 10.67 to 13.0 mg kg^{-1} at sowing and from 10.0 to 12.0 mg kg^{-1} at harvest, with average values of 11.63 mg kg^{-1} and 10.84 mg kg^{-1}, respectively. The manganese content exhibited a trend similar to that of zinc and iron across both stages of crop growth. Significantly, the highest manganese content was observed at sowing (11.78 and 13.0 mg kg^{-1}) and at harvest (11.53 and 12.0 mg kg^{-1}) in treatment T_7 during both years, while the lowest content was observed in treatment T_1 (absolute control). This variation could be attributed to the rapid decomposition of added crop residue facilitated by the presence of inorganic fertilizers and microbial consortia.

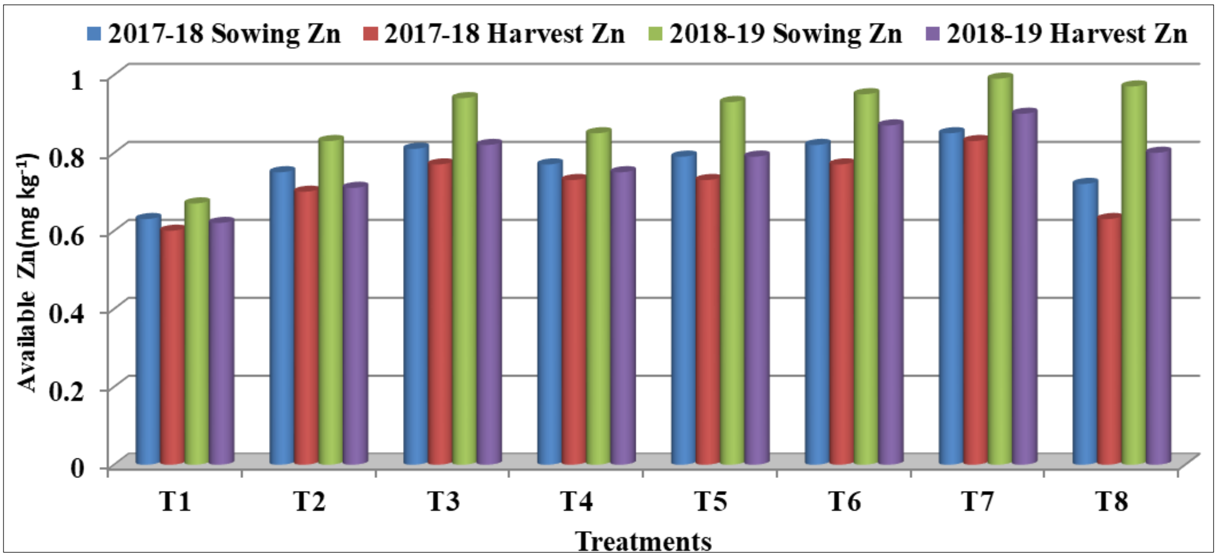
Consistent with the findings for zinc and iron status, higher manganese content was recorded in treatments that received crop residue at both stages of crop growth. This enhancement could be attributed to the improvement in soil organic matter status within treatments incorporating crop residue. This improvement favors a reduced environment (lower redox potential) that enhances the availability of micronutrient cations in the soil. Within a reduced environment, the addition of soil organic matter leads to the formation of complexed forms of micronutrients. Furthermore, the accumulation of soil organic matter converts adsorbed fractions of micronutrients into forms more accessible to plants.

It's worth noting that the improvement in iron and manganese status over the initial conditions, absolute control, and recommended dose of fertilizer (RDF) with crop residue incorporation was not statistically significant. This observation could be attributed to soil organic matter's stronger binding affinity for zinc and copper compared to iron and manganese, as the former are less sensitive to changes in redox conditions. This pattern aligns with the findings of Dhaliwal *et al*. (2019) [5].

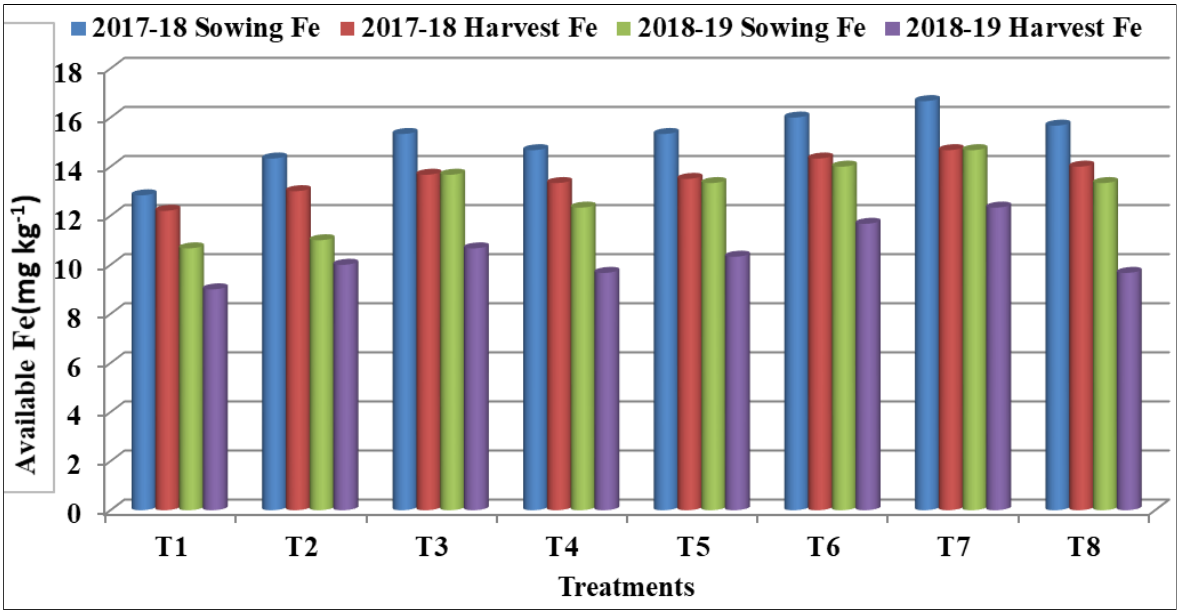
Copper

The available copper (Cu) status, as indicated in Table 2, demonstrated a significant influence of treatments at both stages of chickpea growth. Among the treatments, the copper content ranged from 0.57 to 0.79 mg kg^{-1} at sowing and from 0.51 to 0.75 mg kg^{-1} at harvest, with average values of 0.68 mg kg^{-1} and 0.66 mg kg^{-1}, respectively, during the 2017-18 season. In the subsequent season of 2018-19, the copper content ranged from 0.56 to 0.77 mg kg^{-1} at sowing and from 0.54 to 0.73 mg kg^{-1} at harvest, with average values of 0.67 mg kg^{-1} and 0.63 mg kg^{-1}, respectively. The copper content followed a trend similar to that of zinc, iron, and manganese across both stages of crop growth. Significantly, the highest copper content was observed at sowing (0.79 and 0.75 mg kg^{-1}) and at harvest (0.77 and 0.73 mg kg^{-1}) during the 2017-18 and 2018-19 seasons, respectively, in treatment T_7. Conversely, the lowest copper content was recorded in treatment T_1 (absolute control). However, treatments that received crop residue recorded higher copper content at both stages of crop growth. This increase could be attributed to the soil's reduced state and the subsequent enhanced complex formation of copper facilitated by the addition of organic matter through crop residue. Similar enhancements in copper content resulting from residue addition in rice were reported earlier by Singh *et al*. (2005) [27] and Gupta *et al*. (2007) [11].

The elevated availability of iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu) in treatments that received crop residue can be attributed to their release through mineralization. Additionally, the production of chelating agents contributes to a reduction in their adsorption, fixation, and precipitation, resulting in enhanced availability within the soil. This perspective is in line with the findings of Dhanushkodi *et al*. (2009) [6].

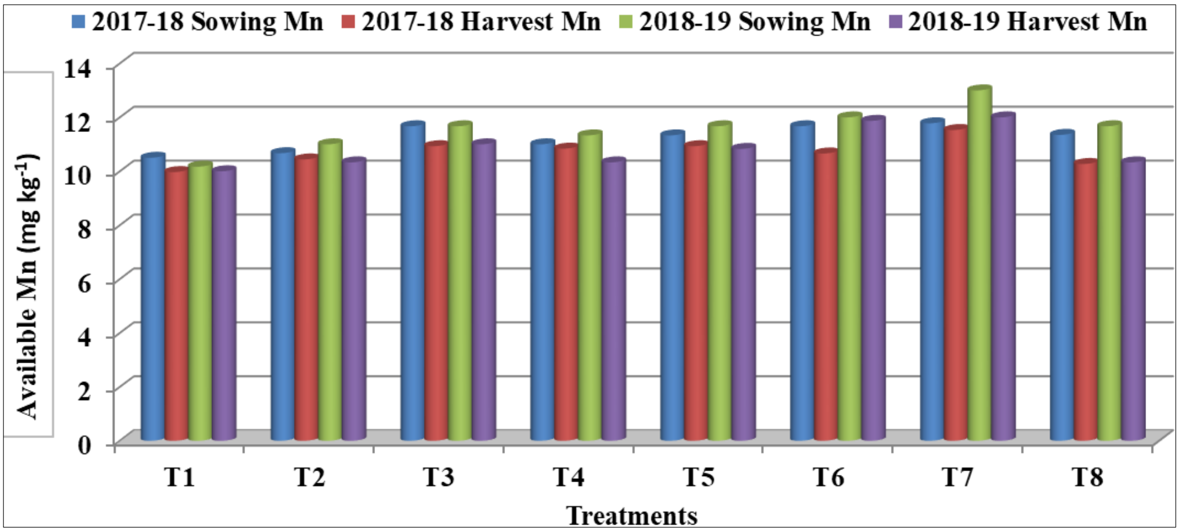


(a)

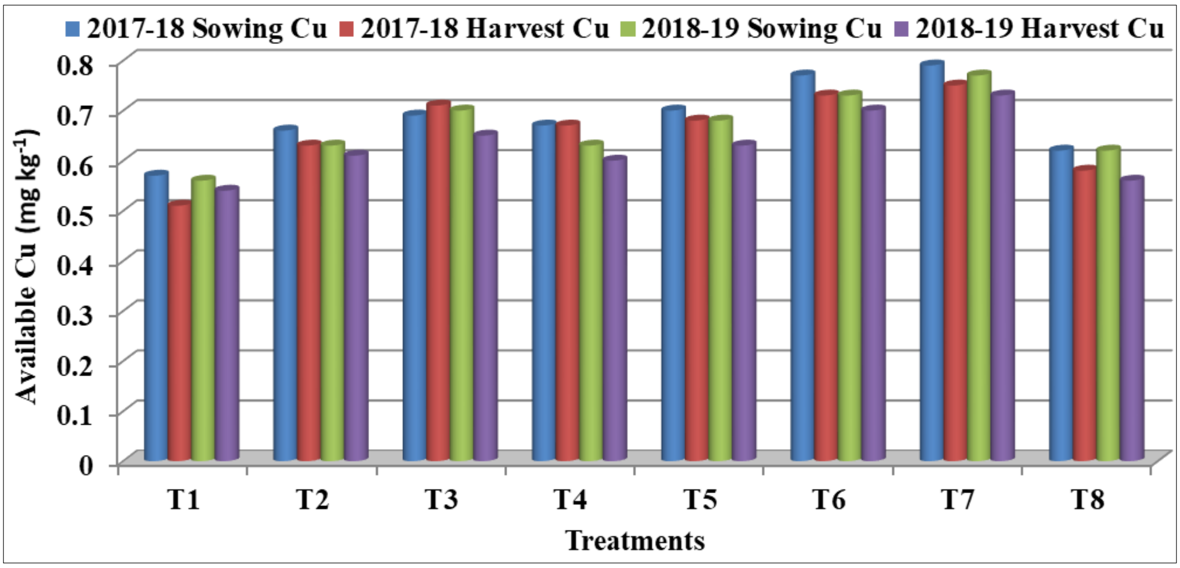


(b)

Fig 2: Effect of incorporation of korra residue on available zinc (a) and iron (b) status of soil in chickpea during 2017-18 and 2018-19



(a)



(b)

Fig 3: Effect of incorporation of korra residue on available manganese (a) and copper (b) status of soil in chickpea during 2017-18 and 2018-19

Nutrient uptake

The treatment T_8 (RDF) recorded significantly the highest nitrogen uptake of 47.19 and 30.56 kg ha^{-1} in grain and straw, respectively during 2017-18 and was 42.99 and 31.45 kg ha^{-1} in grain and straw, respectively and in 2018-19 whereas the lowest nitrogen uptake was recorded in T_1 (absolute control) (19.29, 14.09 during 2017-18 and 20.16, 14.37 kg ha^{-1}).

The treatment, T_8 was on par with T_7 which received crop residue @ 1.5 t ha^{-1} along with 3.0 kg microbial consortia and 3.0 kg urea + 15 kg SSP (36.63 and 26.72 kg ha^{-1} during 2017-18 and 39.69 and 28.45 kg ha^{-1} during 2018-19 in grain and straw, respectively). The treatment T_7 was on par with T_6 and T_3 with respect to nitrogen uptake in grain. It was observed that application of crop residue along with microbial consortia and N and P fertilization had enhanced the uptake of nitrogen content in the plant tissue. Increased nitrogen uptake might be due integrated use of crop residue along with microbial consortia to early release of nitrogen as a result of decomposition of applied residue. Similar results were observed by (Verma and Pandey (2013) [33] and Gundlur *et al*. (2015) [9].

The treatment T_8 (RDF) recorded significantly highest phosphorus uptake (2.78, 2.73 kg ha^{-1} during 2017-18, and 2.68, 2.71 kg ha^{-1} during 2018-19 in grain and straw, respectively) followed by T_7 which received crop residue @ 1.5 t ha^{-1} along with 3.0 kg microbial consortia and 3.0 kg urea + 15 kg SSP (2.54, 2.42 kg ha^{-1} during 2017-18 and 2.57, 2.48 kg ha^{-1} during 2018-19 in grain and straw, respectively). The lowest Phosphorus uptake was recorded in T_1 (absolute control) (1.23, 0.66 kg ha^{-1} during 2017-18 and 1.20, 0.69 kg ha^{-1} during 2017-18 in grain and straw, respectively). The lower phosphorus uptake might be due to lower yields but the phosphorus nutrient concentration values are of normal range.

The treatment T_7 was on par with T_6 and T_3 with respect to phosphorus uptake in grain. Similar results were observed by Kachroo and Dixit (2005) [14] Pathak *et al*. (2005) [22] and Thenmozhi and Paulraj (2009) [32].

The treatment T_8 (RDF) recorded significantly the highest potassium uptake during 2017-18 (26.71 kg ha^{-1} 37.87 kg ha^{-1} in grain and straw, respectively) and 2018-19 (24.08 kg ha^{-1} in grain and 37.40 kg ha^{-1} in straw, respectively) followed by T_7 (crop residue @ 1.5 t ha^{-1} along with 3.0 kg microbial consortia and 3.0 kg urea + 15 kg SSP) with potassium uptake value of 23.29 and 32.36 kg ha^{-1} in grain and straw, respectively during 2017-18 and 23.34 and 32.17 kg ha^{-1} in grain and straw, respectively during 2018-19. The lowest potassium uptake was recorded in T_1(absolute control) (10.11 kg ha^{-1} and 13.76 kg ha^{-1} in grain and straw, respectively during 2017-18 and 10.20 and 14.34 kg ha^{-1} in grain and straw, respectively during 2018-19). The treatment T_7 was on par with T_6, T_5 and T_3 with respect to potassium uptake in grain.

Higher uptake of potassium with crop residue might be due to release of potassium during decomposition and increase of native potassium availability due to release of organic acids by rhizobacteria are able to chelate metals and mobilize potassium from native potassium - containing minerals. The rapid decomposition and mineralization in the presence of microbial consortia and nitrogen and phosphorus fertilization resulted higher dry matter production and nutrient concentration led to increased potassium uptake by crop. Similar results were earlier reported by Bhandari *et al*. (1992) [3] and Rajkhowa (2012) [24].

In all the treatments it was observed that the uptake of nitrogen and phosphorus was more in grain than straw while the uptake of potassium was more in straw than in grain.

Table 3: Effect of incorporation of korra crop residue on macronutrient uptake by succeeding chickpea crop at harvest

Treatment details	Macronutrient uptake (kg ha^{-1})											
	2017-18						2018-19					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1: Absolute control	19.29	14.09	1.23	0.66	10.11	13.76	20.16	14.37	1.20	0.69	10.20	14.34
T_2: Crop residue @ 1.5 t ha^{-1}	21.33	16.09	1.61	0.79	13.58	15.58	21.02	16.39	1.55	0.94	13.34	18.06
T_3: T_2 + 3.0 kg Microbial consortium	32.84	24.00	2.23	1.71	20.22	23.01	34.80	23.97	2.15	1.70	21.20	25.91
T_4: T_2 + 1.5 kg Urea + 7.5 kg SSP	27.44	19.40	1.73	1.24	15.80	18.23	27.76	18.89	1.61	1.24	15.38	18.57
T_5: T_2 + 3.0 kg Urea + 15 kg SSP	28.31	20.12	1.72	1.61	17.45	20.66	29.46	19.81	1.70	1.60	18.80	20.63
T_6: T_3 + 1.5 kg Urea + 7.5 kg SSP	34.20	25.75	2.25	2.24	20.50	27.54	36.34	24.98	2.20	2.18	21.14	27.45
T_7: T_3 + 3.0 kg Urea +15 kg SSP	36.63	26.72	2.54	2.42	23.29	32.36	39.69	28.45	2.57	2.48	23.34	32.17
T_8: RDF (20-50-40) of N,P_2O_5 & S kg ha^{-1}	47.19	30.56	2.78	2.73	26.71	37.87	42.99	31.45	2.68	2.71	24.08	37.40
SE (m)$\pm$	2.69	1.50	0.17	0.13	1.16	2.14	1.87	1.82	0.14	0.15	1.22	1.88
CD (0.05)	8.15	4.54	0.52	0.41	3.51	6.48	5.67	5.51	0.42	0.46	3.71	5.70
CV (%)	15.06	11.74	14.71	13.85	10.86	15.67	10.27	14.12	12.17	15.54	11.51	13.39

Micronutrient uptake

The uptake of zinc, as presented in Table 4, in both grain and straw at harvest was significantly influenced by the application of crop residue during both study years. Among the treatments, the highest uptake of zinc was consistently observed in the treatment supplied with recommended dose of fertilizer (RDF) (T_8). Specifically, during the 2017-18 season, zinc uptake in grain and straw was 17.23 and 13.10 g ha^{-1}, respectively, in T_8, while during the 2018-19 season, it was 16.97 and 11.72 g ha^{-1}, respectively. Conversely, the lowest zinc uptake was recorded in treatment T_1 (absolute control) for both years, with values of 8.02 and 6.43 g ha^{-1} in grain and straw, respectively, during the 2017-18 season, and 7.82 and 6.56 g ha-^{1} in grain and straw, respectively, during the 2018-19 season. Treatment T_8 was comparable to T_7 in terms of zinc uptake in both grain and straw throughout both study years.

The application of crop residues, combined with inorganic fertilizers and microbial consortia, led to a significant increase in iron uptake as well, as depicted in Table 4. This increase was observed in both grain and straw at harvest during both study years. Among the treatments, the highest iron uptake occurred in the treatment supplied with RDF (T_8). In the 2017-18 season, iron uptake in grain and straw was 119.57 and 103.96 g ha^{-1}, respectively, in T_8, while in the 2018-19 season, it was 115.60 and 106.17 g ha^{-1}, respectively.

Conversely, the lowest iron uptake was observed in treatment T_1 (absolute control) for both years. Specifically, iron uptake in grain and straw was 58.62 and 51.01 g ha^{-1}, respectively, during the 2017-18 season, and 58.88 and 56.73 g ha^{-1}, respectively, during the 2018-19 season. Treatment T_8 was comparable to T_7 and T_6 in terms of iron uptake in grain during both study years.

Table 4: Effect of incorporation of korra residue on zinc and iron uptake by succeeding chickpea crop at harvest

Treatment details	Zinc and iron uptake (g ha^{-1})							
	2017-18				2018-19			
	Zn		Fe		Zn		Fe	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1: Absolute control	8.02	6.43	58.62	51.01	7.82	6.56	58.88	56.73
T_2: Crop residue @ 1.5 t ha^{-1}	9.29	7.63	71.42	68.93	9.05	8.32	69.22	60.99
T_3: T_2 + 3.0 kg Microbial consortium	13.20	10.16	97.02	88.95	12.58	9.97	95.06	84.82
T_4: T_2 + 1.5 kg Urea + 7.5 kg SSP	9.40	8.87	79.62	75.08	9.59	8.79	79.36	66.34
T_5: T_2 + 3.0 kg Urea + 15 kg SSP	10.31	8.88	81.30	76.31	10.16	9.33	80.87	70.99
T_6: T_3 + 1.5 kg Urea + 7.5 kg SSP	13.60	10.52	94.97	94.96	13.78	10.71	97.56	89.20
T_7: T_3 + 3.0 kg Urea +15 kg SSP	15.56	11.23	109.86	97.72	15.77	11.65	110.12	93.81
T_8: RDF (20-50-40) of N,P_2O_5 & S kg ha^{-1}	17.23	13.10	119.57	103.96	16.97	11.72	115.60	106.17
SE (m)±	0.78	0.44	6.10	4.67	0.74	0.57	6.21	4.30
CD (0.05)	2.38	1.32	18.49	14.15	2.23	1.73	18.84	13.03
CV (%)	11.24	7.87	11.88	9.85	10.64	10.28	12.22	10.01

Table 5: Effect of incorporation of korra residue on manganese and copper uptake by succeeding chickpea crop at harvest

Treatment details	Manganese and copper uptake (g ha^{-1})							
	2017-18				2018-19			
	Mn		Cu		Mn		Cu	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
T_1: Absolute control	37.79	26.44	11.73	10.37	38.85	25.43	12.61	13.18
T_2: Crop residue @ 1.5 t ha^{-1}	40.59	28.14	11.83	11.18	43.56	26.41	13.09	13.91
T_3: T_2 + 3.0 kg Microbial consortium	62.10	43.00	17.34	17.23	64.95	41.31	17.51	17.71
T_4: T_2 + 1.5 kg Urea + 7.5 kg SSP	48.79	33.32	13.48	12.60	48.13	31.58	13.74	14.81
T_5: T_2 + 3.0 kg Urea + 15 kg SSP	51.87	33.90	14.46	13.21	51.89	32.31	14.86	15.86
T_6: T_3 + 1.5 kg Urea + 7.5 kg SSP	66.94	43.03	18.31	19.32	65.11	40.24	17.23	18.14
T_7: T_3 + 3.0 kg Urea +15 kg SSP	75.45	48.44	20.59	23.31	74.45	49.55	19.87	20.01
T_8: RDF (20-50-40) of N,P_2O_5 & S kg ha^{-1}	78.39	52.17	21.59	23.97	74.50	51.22	20.42	24.46
SE (m)±	3.60	3.38	1.33	1.29	3.92	3.43	1.30	1.52
CD (0.05)	10.90	10.25	4.02	3.91	11.90	10.40	3.94	4.61
CV (%)	10.79	15.19	14.21	13.63	11.78	15.94	13.91	15.25

The application of crop residues along with inorganic fertilizers and microbial consortia resulted in a significant increase in manganese uptake in both grain and straw at harvest, as noted in the data. Among the treatments, the highest manganese uptake was consistently recorded in the treatment supplied with the recommended dose of fertilizer (RDF) (T_8). Specifically, during the 2017-18 season, manganese uptake in grain and straw was 78.39 and 52.17 g ha^{-1}, respectively, in T_8, while during the 2018-19 season, it was 74.50 and 51.22 g ha^{-1}, respectively. Conversely, the lowest manganese uptake was observed in treatment T_1 (absolute control) for both years, with values of 37.79 and 26.44 g ha^{-1} in grain and straw, respectively, during the 2017-18 season, and 38.85 and 25.43 g ha^{-1} in grain and straw, respectively, during the 2018-19 season. Treatment T_8 was comparable to T_7 in terms of manganese uptake in grain during both study years. Additionally, treatments T_7, T_6, and T_3 showed comparable manganese uptake in grain during both study years.

Similarly, the application of crop residues in conjunction with inorganic fertilizers and microbial consortia significantly increased copper uptake in both grain and straw at harvest. Among the treatments, the highest copper uptake was consistently recorded in the treatment supplied with RDF (T_8). In the 2017-18 season, copper uptake in grain and straw was 21.59 and 23.97 g ha^{-1}, respectively, in T_8, while in the 2018-19 season, it was 20.42 and 24.46 g ha^{-1}, respectively. Conversely, the lowest copper uptake was observed in treatment T_1 (absolute control) for both years, with values of 11.73 and 10.37 g ha^{-1} in grain and straw, respectively, during the 2017-18 season, and 12.61 and 13.18 g ha^{-1} in grain and straw, respectively, during the 2018-19 season. Treatments T_7, T_6, and T_3 exhibited comparable copper uptake in grain during both study years.

The substantial improvement in the uptake of micronutrients, including zinc, iron, manganese, and copper, upon incorporating crop residues alongside a starter dose of inorganic nitrogen and phosphorus fertilizers in the presence of microbial consortia can be attributed to the release of these micronutrients during the mineralization of applied organic materials. Additionally, the production of organic acids during the decomposition of organic materials can solubilize previously insoluble compounds, thereby contributing to increased micronutrient uptake. During mineralization, chelating compounds capable of complexing with micronutrients are produced, aiding in holding these nutrients in soluble complexes and making them more available to plants. This mechanism also helps to reduce the precipitation of micronutrients into hydroxides and carbonates. These findings align with previous studies by Chandel *et al.* (2013)

[4] and Kamini Kumari and Prasad (2014) [15].

Conclusion

The status of available macronutrients, namely nitrogen, phosphorus, and potassium, at both sowing and harvest of chickpea was significantly affected by the different treatments during both study years. It was observed that the macronutrient content in the soil at sowing was higher compared to the content at harvest in all treatments. This difference could be attributed to the increased microbial activity present in the soil during the sowing stage. Conversely, lower macronutrient contents at harvest could be due to plant uptake and various losses or fixation mechanisms operating in the soil.

Among the treatments, the highest nitrogen and phosphorus contents were consistently recorded in treatment T_8, which was comparable to T_7. Similarly, the highest potassium content was observed in treatment T_7 during both study years and at both stages of crop growth.

The treatments exhibited a significant influence on zinc and copper contents, while their influence on iron and manganese contents was found to be non-significant at both stages of crop growth during both study years. However, the treatments that received crop residue along with microbial consortia and a higher starter dose of nitrogen and phosphorus fertilizers maintained higher contents of micronutrients at the harvest of chickpea.

The different treatments applied had a substantial impact on the availability of macronutrients in the soil, particularly nitrogen, phosphorus, and potassium. The influence on micronutrients such as zinc and copper was significant, and treatments incorporating crop residue along with microbial consortia and increased starter doses of nitrogen and phosphorus fertilizers demonstrated higher levels of these micronutrients at the chickpea harvest stage. The effects on iron and manganese.

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