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Weed and nitrogen management effects on weed suppression, soil properties and crop productivity in a maize (*Zea mays*) – wheat (*Triticum aestivum*) cropping system under conservation agriculture

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ABSTRACT

Weeds and nutrients, particularly N, are two crucial aspects of conservation agriculture (CA), whose management often poses challenge. The combined effects of weed and N management have hardly been studied under CA. This experiment was undertaken to evaluate their effects on weed suppression, soil properties and productivity in a maize (*Zea mays* L.) – wheat (*Triticum aestivum* L. emend Fiori & Paol) system under conservation agriculture during 2013-14 and 2014-15. Three weed control treatments as main plots and four nitrogen levels as sub-plots treatments were based on integrated weed management, soil test and plant sensor–GreenSeeker (GS)-aided approach. It was observed that the herbicide combination (atrazine + pendimethalin) and the brown manuring + 2,4-D weed management in maize resulted in 66% and 31% weed control index, respectively over weedy check. But, in wheat, clodinafop-propargyl + carfentrazone-ethyl (post-emergent) and pendimethalin + carfentrazone (pre-emergent) resulted in 81% and 58% weed control index, respectively. The mean maize grain and stover yields were increased by 12% and 8%, respectively due to the optimised GS–N treatments (N_2, N_3, and N_4) than entire N basal application (N_1). Also, mean wheat grain and straw yields increased by 9% and 8%, respectively over whole N basal application. The 'best optimised' GS–N (N_2– 50% basal + 25% broadcast at 25 DAS + rest N guided by GS) had 6%, 7% and 15% greater mean weight diameter, saturated hydraulic conductivity and microbial biomass carbon over whole N basal application after two years of cropping. While brown manuring (maize) + herbicide combination (wheat) had 4%, 7% and 6% greater mean weight diameter, saturated hydraulic conductivity and microbial biomass carbon, respectively over herbicide combinations alone. Available N, P, and K in soil were 8%, 11% and 2% higher in the optimised GS–N treatments over entire N applied as basal. It may be concluded that the integration of brown manuring (in maize)+ herbicide combinations (in wheat), and the optimisation and synchronisation of N fertilisation can suppress weeds, enhance soil fertility with improved maize and wheat productivity.

Key words: Brown manuring, Conservation agriculture, GreenSeeker, Herbicide combinations, Maize-wheat, Soil test value

Stagnating yield trends of the rice–wheat system in the Indo-Gangetic Plains (IGP) are the resultant of mismanagement of natural resources, namely soil and water. This has led to the call for a sustainable system, capable of enhancing productivity while sustaining the soil environment (Das *et al*. 2018). Conservation agriculture (CA) is a new paradigm for sustainable crop production intensification. It is a resource-saving technology for ecological agro-ecosystem (improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment) based on three principles applied simultaneously: minimum soil disturbance, permanent soil cover and crop rotation/diversification. When adapted into practice, minimum tillage reduces the effect of soil physical disturbance on soil structural stability. Residue retention on soil surface protects the soil from the impact of soil-water runoff and erosion, while crop diversification enforces nutrients recycling and breaks weed and disease cycles.

Continuous rice–wheat intensification in the IGP is becoming unsustainable due to the incessant puddling and intensive tillage associated with the rice crop (Ladha *et al*. 2003, Erenstein and Laxmi 2008, Nsanzabaganwa *et al*. 2014). These harm the soil ecosystem to function as a living system. Therefore, for soil health improvement and sustainable crop intensification, the diversification of the

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rice–wheat system and the conversion from conventional to conservation agriculture practices is envisaged. Maize (*Zea mays* L.) is a suitable replacement to rice as it avoids soil aggregate disintegration (absence of puddling) and produces high biomass residue. In India, maize is an emerging cereal crop and ranks third after rice and wheat (*Triticum aestivum* L.) with an area of 9.5 million ha and annual production of 24.5 million tonnes (USDA 2017).In addition, a diversification to maize–wheat rotation (Saad *et al*. 2016) offers a full CA based maize–wheat system in the Indo-Gangetic Plains.

However, increasing weed pressure (Susha *et al*. 2014a and b) and nitrogen immobilisation in CA is associated with yield reduction during the conversion phase (first three years of CA practice). This has so far limited its expansion in the IGP. The complexity of N availability and weed infestation in CA annual cropping systems can be resourcefully managed by the integration of best agronomic management practices incorporated within the core CA principles. Optimising the inherent soil N and reducing weed pressure at the onset of CA ensures the benefits are achieved in the short-time. Bijay-Singh *et al*. (2011) evaluated a plant sensor–Greenseeker (GS) to regulate N to crop demand, which enhanced N availability with increased yield in wheat. Precise N management with GS improved yield, enhanced soil properties and reduced the global warming potential in maize and wheat system (Kumar *et al*. 2014, Nsanzabaganwa *et al*. 2014, Sapkota *et al*. 2014, Pooniya *et al*. 2015). Spraying of non-selective herbicide at the commencement of CA can reduce weed seedbank. Likewise, herbicide combination can reduce weed resistance and dose application (Das and Yaduraju 2012), while residue retention in CA is effective in suppressing weed (Kumar *et al*. 2013, Susha *et al*. 2014b). Therefore, our hypothesis was that the integration of soil-test to optimise N availability and use of the GreenSeeker sensor to regulate and supplement N would enhance soil fertility build-up. Also, the inclusion of brown manuring and herbicide combinations would suppress weed and improve yield during the early stages of conversion to CA.

MATERIALS AND METHODS

Field experiment was conducted at the ICAR-Indian Agricultural Research Institute, New Delhi during *kharif* (rainy) – *rabi* (winter) seasons of 2013–2014 and 2014–2015. The soil texture (0–15 cm) is sandy loam (630 g/kg sand, 251 g/kg silt and 119 g/kg clay) with pH 7.8, EC 0.47 dS/m at the start of the experiment. The soil had 0.51 and 0.35% organic carbon; and 0.03 and 0.02% total N and exhibit a bulk density of 1.55 and 1.58 Mg/m^3 at 0–5 and 5–15 cm, respectively. Available N, P and K at 0–15 cm depth were 163 kg/ha 11.17 kg/ha and 235 kg/ha, respectively.

The experimental design was a split plot with weed management (three levels) as the main plot, and N fertilization (four levels) as the sub-plot treatments with three replicate blocks in a 4.2 m by 7.0 m (29.4 m^2) plot area. For maize: weed treatments were weedy check (control) (W_1), herbicide combination (W_2) – atrazine + pendimethalin (0.75 + 0.75 kg/ha, tank-mixed) as pre-emergent, and (W_3) – brown manuring + 2,4-D at 0.25 kg/ha. Whereas in wheat: weedy check (W_1), herbicide combinations *viz.* (W_2) – pendimethalin + carfentrazone-ethyl (1.0 + 0.02 kg/ha, respectively) as pre-emergent; and (W_3) – clodinafop-propargyl + carfentrazone-ethyl (0.06 + 0.02 kg/ha, respectively) as post-emergent at 30 DAS. The herbicide combinations were tank-mixed at the study site and sprayed as pre-emergent at 2 DAS and post-emergent at 30 DAS. *Sesbania aculeata* was broadcasted on the day of maize sowing to suppress weeds during the early stages of maize growth and killed by 2,4-D at 25 DAS. Weed dry weight, as considered a more reliable estimate for studying bio-efficacy of herbicides in crops (Das 2001) was recorded and weed control index (WCI) based on the weed dry weights was calculated (Das *et al*. 2010).

As a transition phase strategy for soil fertility enhancement, the native soil available N (0–15 cm) was assessed, which was considerably low (163 kg N ha), thus additional 50% N for soil enhancement was recommended. Therefore, N rates at 180 and 150 kg/ha for maize and wheat was designated as the optimized recommended N rate for improving productivity. The N rates were assigned at 4 levels, *viz.* N_1– 100% N as whole basal application; N_2–50% basal + 25% N broadcast at 25 DAS + rest N guided by GS; N_3– 50% basal + rest N guided by GS; N_4–80% basal + rest N guided by GS. For mid season N availability and requirement, GreenSeeker was used to measure crop reflectance and to calculate the normalized difference vegetative index (NDVI) for N supplementation.

The GreenSeeker^{TM} was designed for N and crop management in precision agriculture. It is a patented technique used to measure crop reflectance and to calculate the normalized difference vegetative index (NDVI). The NDVI measures the fraction of the emitted visible red (VIS; 650±10nm) and near infrared (NIR; 770±15nm) radiation in the sensed area that is returned to the sensor (reflectance). These fractions are used within the sensor to compute NDVI according to the equation 1:

$$NDVI= (NIR–VIS)/ (NIR+VIS) \quad (1)$$

The GS has been calibrated for the South Asian IGP conditions (Bijay-Singh *et al*. 2011). A quantitative response index in maize and wheat to GS were evaluated in the previous year, where the average NDVI of N-rich (non-limiting) plots with 180 kg N/ha applied in split doses (i.e. N_2) divided by the average NDVI of the plots with fixed N fertilization at sowing (i.e., N_1) in a CA mode in the previous year. The response index is then multiplied with yield with no added fertilisation (YP_0; N_1) to determine the potential yield with added N fertilisation (YPn; N_2). The supplemental (in-season) fertiliser N dose to be applied using the GS was determined based on the difference between the YP_n and YP_0 N-uptake. The mean N contents of maize and wheat grain at harvest were multiplied with the YP_n and YP_0 values, respectively and then divided by 0.5 (efficiency factor for South Asian conditions) to estimate the fertiliser N requirement following equation 2 (Bijay-Singh *et al*. 2011).

$$\text{Fertilizer N requirement} = \frac{\text{N content of grains(\%)} \times (YP_n - YP_0)}{100 \times 0.5}$$

To reduce nutrient imbalance, P and K were attuned to match the optimized GS–N rate in the ratio 4:2:1. All P (DAP) and K (MOP) were applied as band placement beneath the seeds at the time of sowing. A turbo happy seeder cum fertilizer drill was used for sowing and fertilizer drilling into the initial surface residue (i.e. 40% and 50% of wheat and maize residue biomass produced plot-wise) retained on soil surface. The initial wheat residue in the first year was obtained from previous wheat cropping. Maize (*cv.* DHM–117) was sown in 7 July 2013 and 11 July 2014, while wheat (*cv.* HD–2967) was sown in 15 November 2013 and 4 November 2014.

Soil samples from soil depths (0–5, 5–15 cm) after two years of cropping were collected for analyzing soil organic carbon (SOC), total N, and available N, P, and K. Undisturbed soil samples were used for bulk density determination, and saturated hydraulic conductivity was measured using the constant head permeameter method. Weed data were subject to square-root transformation before analysis of variance (Das 1999) for reducing variations in data. Microbial biomass carbon in soil was estimated by chloroform fumigation method. The data were subjected to analysis of variance using the SAS software package (Version 9.0) to test whether significant differences existed between the treatments. The treatment means were compared with the least significant difference (LSD) test at $p \leq 0.05$.

RESULTS AND DISCUSSION

Weed suppression

Weed and nitrogen management significantly influenced weed dry weight at 70 DAS in maize and wheat (Table 1). Among the weed treatment effects in maize, the herbicide combination (atrazine + pendimethalin) resulted in 55% and 66% lower weed dry matter than brown manuring + 2,4-D, and weedy check, respectively. Susha *et al*. (2014b) observed similar results. Likewise in wheat, the clodinafop + carfentrazone (post-emergent) had 56% and 83% lower weed dry matter than the pendimethalin + carfentrazone (pre-emergent) and weedy check, respectively. Singh *et al*. (2013) reported similar efficacy of post-emergence application of metsulfuron-methyl in wheat. The optimised GS–N (50% basal + 25% broadcast + rest N guided by GS) had 15 and 16% lower weed dry matter in maize and wheat, respectively over the entire N basal application (N_1). The weed control index in maize were 66% in the atrazine + pendimethalin and 31% in brown manuring + 2,4-D over weedy check. In wheat, the weed control index were 81% and 58% in clodinafop + carfentrazone (post-emergent) and pendimethalin + carfentrazone (pre-emergent), respectively over weedy check. There were no significant interaction effect on weed dry weight and weed control index in both maize and wheat.

The greater weed suppression by herbicide combinations is attributed to its broad-spectrum weed control effect. Herbicide combination is an effective weed management strategy to reduce herbicide resistance weeds (Das and Yaduraju 2012, Kumar *et al*. 2013). The lower weed dry matter in maize over wheat at 70 days growth stage is

Table 1 Weed and nitrogen management effects on weed dry weight in maize and wheat at 70 days after sowing (mean of two years)

Treatment	Maize		Wheat	
	Weed dry weight (g/m^2)	Weed control index (%)	Weed dry weight (g/m^2)	Weed control index (%)
Weed (W) management				
W_1–Weedy check	8.7	0.0	15.9	0.0
W_2–Herbicide combinations	3.0	65.5	6.3	58.4
W_3–Brown manuring (maize) + herbicide combinations (wheat)	6.7	31.2	2.8	80.7
SEm±	0.9	3.5	1.4	8.1
CD ($P \leq 0.05$)	3.7	13.7	5.7	31.8
Nitrogen (N) management				
N_1–100% basal	6.7	33.0	8.1	47.2
N_2–50% basal + 25% broadcast + rest N guided by GS[©]	5.7	27.4	6.7	48.2
N_3–50% basal + rest N guided by GS	6.0	35.0	9.8	43.2
N_4–80% basal + rest N guided by GS	6.0	33.4	8.7	46.9
SEm±	0.3	2.2	0.6	3.2
CD ($P \leq 0.05$)	0.8	6.5	1.7	NS

[©]GS= GreenSeeker

due to the maize morphology (vigorous growth, higher plant height), which provided greater interference on weeds. Unlike in maize, wheat provided less competitive advantage against weeds at the later stage of growth (70 DAS). Thus, it indicates the efficacy of post-emergent clodinafop + carfentrazone to suppress weed over the pre-emergent pendimethain + carfentazone (Das 2001). Also, the mid season N supplementations were efficiently utilised by maize crop due to its competitive advantage as against wheat, where weed pressure had an advantage to utilise supplemental N fertilisations. The brown manuring weed suppression effect in maize provided an important weed management approach to reduce herbicide applications and to mitigate herbicide residues in soils and grains thus promotes ecological-environmental sustainability.

Maize and wheat growth

Weed and nitrogen management significantly influenced growth attributes (plant height, LAI and dry matter production) of both maize and wheat at 70 DAS (Table 2). Brown manuring (maize) + herbicide combinations (wheat) increased mean plant height and dry matter production of maize by 7.5% and 7.8%, respectively over weedy check. Similarly, N management as 50% basal + 25% broadcast + rest N guided by GS recorded 11% higher plant height, 5.6% higher LAI and 16.1% higher dry matter production compared to application of N as 100% basal. In succeeding wheat, brown manuring (maize) + herbicide combinations, i.e. clodinafop-propargyl+carfentrazone-ethyl (0.06+ 0.02 kg/ha, respectively) in wheat had positive effect on mean plant height, LAI and dry matter production over weedy check. Under N management, nitrogen application as 50% basal + 25% broadcast + rest N guided by GS improved LAI and dry matter of wheat by 8.4% and 9.6% respectively over N applied as 100% basal. The greater plant height, LAI and dry matter production both in maize and wheat under brown manuring (maize) + herbicide combinations (wheat) was due to the better control of weeds *vis-a-vis* lower crop-weed interference. Improvement in LAI and dry matter production due to brown manuring with *sesbania* in maize was also reported by Susha *et al*. (2014b). The GS–N fertilisation is largely attributed to synchronisation and sustained application of N during the growing season. This led to the improvement in plant height, LAI and dry matter production of crops.

Maize–wheat productivity

Weed and nitrogen management had significant influence on grain and stover/straw yields of maize and wheat (Fig. 1). Average over the optimised GS–N fertilisation treatments (i.e. N_2, N_3 and N_4), the mean maize grain and stover yields increased by 12% and 8%, respectively over entire N applied as basal (N_1). While, mean wheat grain and straw yields increased by 9% and 8%, respectively in the optimised GS–N treatments than in whole N basal application. The post-emergent clodinafop-propargyl + carfentrazone resulted in 10% and 21% higher mean grain yield than the pre-emergent pendimethalin + carfentrazone, and weedy check, respectively. The mean straw yield in clodinafop-propargyl + carfentrazone was 6% and 17% higher over the pendimethalin + carfentrazone, and weedy check, respectively. There were no significant interactions between the treatment effects in wheat. However, there were consistent significant interaction effects in maize grain and stover yield.

The greater yields in maize and wheat under the

Table 2 Weed and nitrogen management effects on growth attributes in maize and wheat at 70 days after sowing (mean of two years)

Treatment	Maize			Wheat		
	Plant height (cm)	LAI	Dry matter (g/m^2)	Plant height (cm)	LAI	Dry matter (g/m^2)
Weed (W) management						
W_1–Weedy check	193.5	4.28	137.4	55.2	4.92	163.0
W_2–Herbicide combinations	205.5	4.34	142.6	57.4	5.15	176.7
W_3–Brown manuring (maize) + herbicide combinations (wheat)	208.1	4.32	148.1	57.6	5.36	177.9
SEm±	3.2	0.05	2.6	0.5	0.07	3.7
CD ($P \leq 0.05$)	12.6	NS	10.2	2.0	0.26	14.5
Nitrogen (N) management						
N_1–100% basal	193.0	4.18	132.0	56.4	4.90	163.5
N_2–50% basal + 25% broadcast + rest N guided by GS	214.3	4.43	153.2	57.2	5.31	179.2
N_3–50% basal + rest N guided by GS	203.5	4.34	146.5	56.8	5.28	177.5
N_4–80% basal + rest N guided by GS	198.5	4.30	139.1	56.5	5.09	169.9
SEm±	4.0	0.04	2.9	0.5	0.11	2.0
CD ($P \leq 0.05$)	11.9	0.22	8.6	NS	0.32	6.1

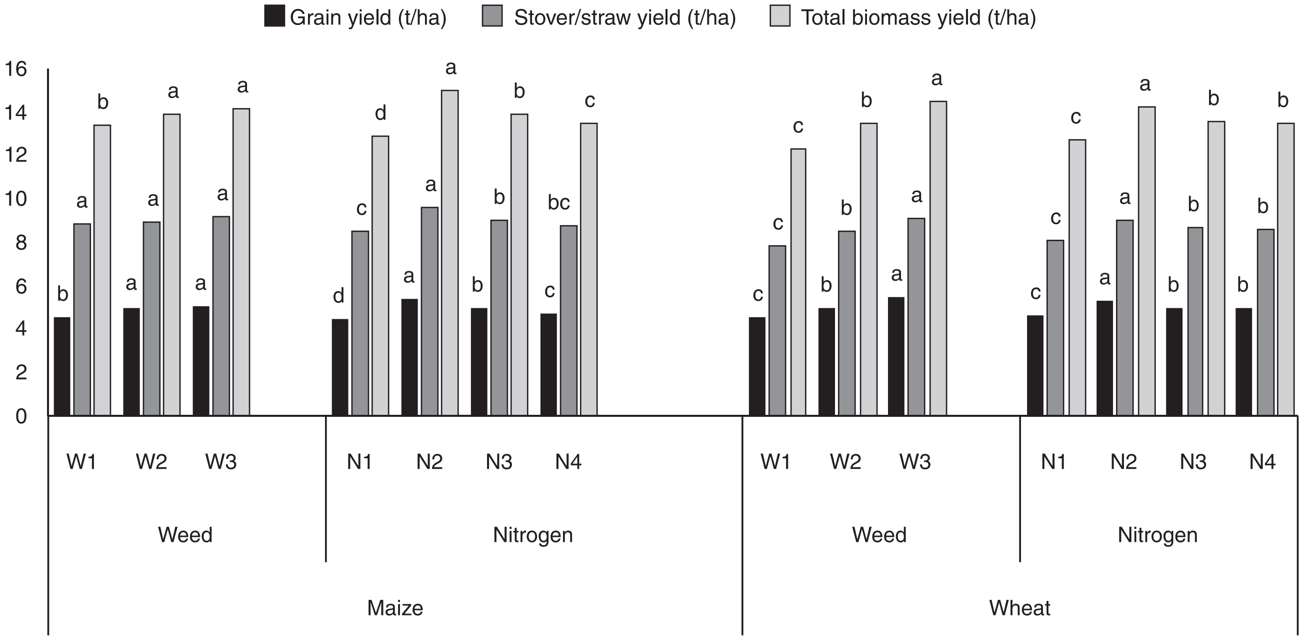

Fig 1 Maize and wheat yields (mean of two years) as influenced by weed and N management. The respective grain, stover/straw, and total biomass yield with different letters in columns across weed and N management treatments are significantly different at $P \leq 0.05$.

GS–N fertilisation were largely attributed to the sustained application of N during the growing season. The synchronisation of N fertilisation in the GS–N treatments indicates that sufficient N requirement during mid season crop growth required sustained N availability for enhance grain development and yield. Sapkota *et al*. (2014) reported that wheat grain yield increased by 5% and 14% due to precise nutrient management over state recommendation and farmers' practice, respectively under CA in the IGP. Enhanced maize and wheat yield and soil properties with precise nutrient management by site-specific nutrient management–nutrient expert have also been reported in the western IGP (Pooniya *et al*. 2015, Kumar *et* al. 2014). Yadvinder-Singh *et al*. (2015) reported that appropriate N

Table 3 Weed and nitrogen management effects on some soil physical, chemical and microbiological properties (0–15 cm) after two years of cropping

Treatment	£MWD	€Ks (cm/h)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)	$MBC µg C/g soil
Weed (W) management						
W_1–Weedy check	1.87	0.60	174.0	17.7	255.1	153.4
W_2–Herbicide combinations	1.81	0.59	170.0	16.6	249.5	143.6
W_3–Brown manuring (maize) + herbicide combinations (wheat)	1.88	0.63	173.9	18.1	249.2	152.5
SEm±	0.16	0.02	5.3	0.4	9.5	2.4
CD (P ≤ 0.05)	NS	NS	NS	NS	NS	9.8
Nitrogen (N) management						
N_1–100% basal	1.82	0.59	162.6	16.1	248.1	138.9
N_2–50% basal + 25% broadcast + rest N guided by GS	1.92	0.63	179.1	18.0	254.9	159.3
N_3–50% basal + rest N guided by GS	1.88	0.60	174.9	17.7	252.0	159.2
N_4–80% basal + rest N guided by GS	1.85	0.59	174.1	17.9	250.1	141.9
SEm±	0.11	0.01	6.6	1.1	16.7	2.7
CD (P ≤ 0.05)	NS	NS	NS	NS	NS	8.0

£MWD= mean weight diameter, €Ks= saturated hydraulic conductivity; $MBC= microbial biomass carbon; Initial soil available N, P and K at 0–15 cm depth were 163, 11.2, and 235 kg/ha, respectively.

fertilisation with crop residue retention enhanced biomass yield. This corroborated our results.

Soil properties

Weed and N management effects influenced the soil physical, chemical and microbiological properties (Table 3). Optimised GS–N treatments resulted in 3.5 and 2.8% higher mean weight diameter (MWD) and saturated hydraulic conductivity compared to the entire N basal application. Additionally, brown manuring (maize) + herbicide combinations (wheat) resulted in 4% and 7% higher mean weight diameter and saturated hydraulic conductivity than herbicide combinations alone. Weedy check had comparable MWD and saturated hydraulic conductivity compared with the brown manuring + herbicide combinations. Microbial biomass carbon (MBC) in soil was increased by 6% in weedy check and brown manuring+ herbicide combinations, respectively than herbicide combinations alone.

The optimised GS–N treatments resulted in 10% greater MBC over the entire N basal application. Available N, P and K increased by 8%, 11% and 2% in the optimised GS–N treatments over the entire N applied as basal. However, there was no significant difference between the treatments.

The improvement in soil physical, chemical and microbiological properties was greatly influenced by the optimisation and synchronisation of N fertilisation, residue retention and the inclusion of brown manuring. Soil physical properties like mean weight diameter (MWD), saturated hydraulic conductivity were not significantly influenced in one or two years by N management and herbicides application alone, but may have long term effect with brown manuring and herbicide combination. Optimisation and synchronisation of N fertilisation combined with crop residues influenced organic matter mineralisation, aggregate size, microbial biomass C and hydraulic conductivity (Bhattacharyya *et al*. 2013). The influence of brown manuring with *Sesbania* also supplied additional N and biomass C both in the above- and below-ground soil layers. Higher soil aggregation and size distribution (MWD) and hydraulic conductivity were attributed to sufficient residue retention combined with optimised N fertilisation. Thus, the enhanced organic residue mineralisation led to greater microbial activities, and higher N, P, and K contents.

It may be concluded that optimising the inherent soil N by soil test and the mid-season supplementation of N with GreenSeeker, while reducing weed pressure by integrating weed management measures can ensure the benefits of CA in short-time. The optimised GS–N (N_2– 50% basal + 25% broadcast at 25 DAS + rest N by GS) and the brown manuring (maize) + herbicide combinations (wheat) could suppress weed, improve maize and wheat productivities and enhance soil health (microbial biomass C, soil aggregate size, hydraulic conductivity and available N, P, and K) after two years of cropping.

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