



## Strengthening soil health under rice (*Oryza sativa*) fallows in Eastern Plateau of India with dwarf rice and moisture conservation practices

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Received: 16 March 2017; Accepted: 28 June 2018

### ABSTRACT

There is great scope in converting rice (*Oryza sativa* L.) fallows into productive agro-ecosystems through appropriate crop based interventions involving suitable varieties and appropriate resource conservation technologies (RCTs). Pulses such as chickpea, lentil, lathyrus and blackgram -through rotation or relay with rice - are the candidate crops for efficient utilization of conserved and scarce resources including soil moisture. Therefore, studying bio-physical aspects of popular rice - chickpea rotation so as to conserve resources and deriving maximum benefits is important and is the crux of the current investigation. A study was carried out in a *vertisols* at Indira Gandhi Krishi Vishwavidyalaya, Raipur (India) during 2011-14 under the existing conditions guarded by a tropical sub-humid climate receiving an annual precipitation of 1582 mm. Two transplanted rice habit groups (a tall local rice Masuri, maturing at 130-140 days and a dwarf HYV of rice Swarna, with 110-120 days duration grown during rainy season) were combined with three residue management practices, viz. residue removal, stubble (30 cm) and mulch for growing two contrasting varieties of chickpea (early high biomass JG 130 and medium high biomass JG 226) grown during winter season. Chickpea was planted with a zero till drill after rice. The study showed that soil moisture depletion (SMD) pattern was decreased over the crop season in case of mulched or 30 cm stubble retained plots in comparison to absence of mulch due to its possible role as a soil cover. On the contrary, SMD was higher in case of tall rice (Masuri) habit due to its relatively longer duration as compared to dwarf rice (Swarna) habit. Similar although to a lower degree in SMD was apparent in case of early biomass accumulating variety (BAV) chickpea JG 130 over medium BAV JG 226. Soil health parameters in terms of its physical and microbiological parameters (like, bulk density, soil strength, dehydrogenase activity etc), crop physiological parameters (such as relative leaf water content (LWC) and specific leaf weight (SLW), plant population), nodulation activities (*Rhizobium* population, nodule number and its dry weights) and crop growth/yield parameters (pods/plant, root characteristics etc) were positively influenced by mulch or stubble retention (due to its beneficial role as a soil cover) and dwarf rice habit (Swarna). Small yet consistently superior values of soil fertility indicators, viz. soil organic carbon (SOC) and nutrients (NPKZn, Fe, Mn and Cu) availability status were also evident following mulch or retention of stubble on the soil surface, whereas the values were abysmally small when comparison was made between chickpea cultivars (early BAV JG 130 and medium BAV JG 226). Besides these, weed dynamics, grain yield attributes and the resultant grain yield were especially favoured following soil moisture conservation strategies involving dwarf rice habit and mulch/stubble retention since availability of soil moisture was fairly extended over a period of time following these measures. Thus, it is inferred from the study on rice-chickpea system that efficient agronomic management of soil and land resources is crucial for augmenting soil health and enhancing output in prevalent rice fallow of Eastern Indian Plateau.

**Key words:** Moisture conservation practices, Mulch, Residue retention, Rice-chickpea, Rice-fallow, Soil properties

Rice (*Oryza sativa* L.) fallows occupies around 11.7 million ha (M ha) in India that normally remains fallow

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in winter/summer after harvest of rainy/winter rice crop (Gumma *et al.* 2016). A majority of the country's rice fallows (around 4/5<sup>th</sup>) lies in east-central states, viz. Asom, Bihar, Chhattisgarh, Jharkhand, Madhya Pradesh, Odisha, West Bengal and North Eastern Hill states and the rest (around 1/5<sup>th</sup>) are in southern states covering Tamil Nadu, Karnataka and Andhra Pradesh (Ali *et al.* 2014, Ali and Kumar 2009). Amongst these, one of the potential areas is Chhotanagpur Plateau, that falls in Jharkhand, Odisha, Chhattisgarh and Dandakaranya, is geographically categorized under Eastern Plateau and Hill Zone (EPHZ comes under Agro-climatic

Zone VII). Besides experiencing a moderate air temperature (26-34°C in July while, 10-27°C in January), the region receives higher annual precipitation ranging in between 800-1500 mm. Soils are red and yellow with occasional patches of laterites and alluviums. Therefore, geographical location of these areas is such that it is endowed with for large scale exploitation through profitable cultivation of field crops especially pulses under rice fallows. However, the typical characteristics of this tract of India is that it is deficient in water resources due to its location as a plateau and occurrences of streams that are mostly non-perennial in nature. As a consequence, this region is mostly rainfed that involves growing of rice, maize and millets during rainy season. However, during fall or winter season, this tract mostly remains fallow by virtue of unfavourable inherent soil and topography associated factors, low moisture availability and related abiotic stresses and region specific biotic stresses (Singh *et al.* 2016). Yet, there is ample possibility of making these areas sustainable for food production through strengthening soil health, conservation of soil and rain water, and systematic adoptions of micro-level integrated watershed development approach (Kar *et al.* 2004). Thus, scope exists for cultivating short duration pulses and oilseeds that can fit well into the existing cropping systems.

On agronomic manipulation of microenvironment, crop management concerns with manipulation in large number of abiotic/biotic factors that are related to soil and water conservation and their appropriate utilization (Praharaj *et al.* 2017). These and related factors are largely responsible for low or stagnated pulse production in rice-fallows under EPHZ during the last decade or so. Yet, drought tolerant, low water requiring and short duration pulses such as chickpea, lentil and *lathyrus* (Khesari) have been found promising under such a stress situation (Praharaj *et al.* 2017).

Typically low moisture content in the soil profile after rice harvest followed by fast decline in water table with the advancement of winter season further leads to seasonal (midseason and/or terminal) drought at critical stages of crop (flowering and pod filling stages) that adversely affects the productivity and profitability of even popular chickpea crop. Extreme moisture stress (especially terminal drought) coinciding with flower/pod initiation and their development increases leaf senescence, decreases net photosynthesis and translocation from leaf to developing grains. In addition, this hostile environment creates unfavorable condition for realizing adequacy in microbial activity, nutrient availability, root growth and water and nutrients uptake (Bandyopadhyaya *et al.* 2016, Ali *et al.* 2014). As a consequence, soil resources (particularly sub-soils) in rice fallows remains mostly underutilized and prone to diverse and differential loss with time and space (Singh *et al.* 2016).

Research evidence suggests that residues retention on soil surface or mulch has favorable effect on soil health involving diverse physical, chemical and biological properties of soil for which it invites use of appropriate resource conservation technology (RCT) to amalgamate for sustainable farming (Bandyopadhyaya *et al.* 2016, Kovac *et al.* 2005).

Resource conservation through appropriate choice of rice and pulse varieties could further boost the overall resource use efficiency (RUE) of rice-fallows (Singh *et al.* 2016). Similarly, on integration with suitable agronomic practices, these areas could be made green (cultivable) following adequate and timely utilization of residual soil moisture (Kar *et al.* 2004, Patil *et al.* 2013). Besides alleviating soil moisture depletion, these measures (residue retention and varietal intervention) could build-up organic matter content in soil enabling further improvement in soil physical and microbial health (Praharaj 2014, Praharaj *et al.* 2014).

Besides the constraints observed inherent to rice fallows including growing of profitable pulses cultivation in rotation with rice, suitable strategies for alteration in sowing windows with short duration varieties could boost in for conserving natural resources and higher productivity realization (Singh *et al.* 2016). Further, different rice habits offer differential productivity pattern offering further complementation to existing productivity of the system. Harnessing this opportunity in rice-pulse system could further scale-up the productivity of winter grown pulses without jeopardizing rice yields (Patil *et al.* 2013, Anonymous 2016). With this analogy, the current experiment was planned at IGKV, Raipur of Eastern Plateau region of India to investigate the influence of varietal intervention for both rice and chickpea and retention of crop residues on productivity, RUE and soil health of rice - chickpea cropping system.

#### MATERIALS AND METHODS

An experiment involving varietal selection and retention of rice stubbles under differential rice and chickpea growth habit was carried out at Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur (located at 21°14'N and 81°42' E) for three consecutive years, viz. 2011-14. The climate of the location is tropical sub humid receiving an annual precipitation of 1582 mm. Situated in the central India's sub tropical humid region of Chhattisgarh under Eastern Plateau region of India, the soil of the experimental site is clayey loam with 7.7 pH, 0.60% SOC (with low soil-N availability), 9.8 kg/ha available P, 197.3 kg/ha available K and 1.35 g/cc bulk density. The initial status in respect of microbiological parameters are same as that of no mulch condition (Table 5). The crop cycle recorded an annual maximum and minimum temperature of 42.3 and 11.6°C, respectively.

Twelve treatment combinations comprising two transplanted rice habits (a local long duration tall rice Masuri with 140 days duration and a dwarf high-yielding variety of rice Swarna with 120 days duration); and two varieties of chickpea (early high biomass accumulating variety JG 130 and medium high biomass variety JG 226) in vertical factor (strip); while three moisture conservation practices made through retention of rice residues (retaining rice stubble height up to 30 cm, mulch and residue removal) in horizontal factor (strip) were laid out in thrice replicated strip plot design. Chickpea was sown with a zero till seed

drill during last week of October following rice harvest, and was harvested in end of February. Normal agronomic practices were followed in rice-chickpea cropping system. In addition, common crop husbandry practices such as seed treatment with PSB and *Rhizobium* at sowing, and 2% urea spray were given to chickpea at pod development stage.

Observations on crop parameters such as plant population, nodule number and its dry weight, specific leaf weight, relative water content in leaves (LWC), root and shoot weights, yield attributes and grain yield were recorded as per the standard procedures set for these. Besides this, population of weed and its dry weight were also recorded using a square meter quadrat. The details of observation on soil moisture content (SMC) was taken periodically after chickpea sowing so as to record the depletion pattern in SMC following crop growth and development with time. From soil moisture dynamics, water use and water use efficiency (WUE) was also calculated. Soil moisture determinations were made from the soil samples taken from 0-100 cm depth at different soil horizon were made following standard procedures.

Soil physical parameters, viz. bulk density and soil strength was measured using core sampler and penetrometer. Soil pH was measured in a 1:2.5 soil:water suspension (McLean 1982). Likewise, nitrogen content in the sample was analyzed by micro-Kjeldahl method (Piper 1966). The phosphorus and potassium content was estimated by taking 1 g sample in a digestion flask with 10 ml tri-acid mixture ( $\text{HNO}_3$ :  $\text{HClO}_4$ :  $\text{H}_2\text{SO}_4$  : : 9:3:1) and digestion was carried out on a hot plate at 180-200°C until dense white fume of  $\text{H}_2\text{SO}_4$  and  $\text{HClO}_4$  were evolved (Jackson 1973). The digested materials were used for estimation of P and K content. The organic C was estimated by Walkley and Black method (1934). Micronutrients (Zn, Fe, Mn, Cu) were estimated by tri-acid digested material using AAS (Lindsay and Norvell 1978). For determination of soil biological parameters, rhizosphere soil samples were collected carefully by uprooting the root system and placed in a cool box for transport and stored at 4°C. Soil diazotrophs were measured by viable plate count technique and soil dehydrogenase activity (SDA) with iodinitrotetrazolium chloride following normal procedures. Nodulation, root studies, stress physiological observations (specific leaf weight, relative water content), weed dynamics, yield attributes and yield data were recorded following standard procedure.

## RESULTS AND DISCUSSION

### Dynamics of SMC

Dynamics of SMC and its storage in soil in relation to time and quantity normally indicates availability of water in soil profile for replenishing moisture deficit faced by the crops (Singh *et al.* 2016). In the current investigation, periodic soil moisture content under rice - chickpea cropping system indicated very high SMC after rice crop under the existing neutral pH clayey loam soil with medium SOC

status. It was apparent that at the time of sowing of chickpea, SMC in plots was high (close to the maximum water holding capacity of soil) after which it followed a declining trend as crop (chickpea) traversed through different phenophases as a consequence of exposing up soil/plant surfaces to diverse demands in evapo-transpiration (ET) and crop uptake. Critical constants for available water content at different soil profile depth are given in Table 1.

Not only the chickpea varieties but also the treatments involving 30 cm stubble retention did influence dynamics of SMC. SMC observed at 7 days interval revealed the apparent depletion pattern with both time and constraints imposed (Fig 1 and 2). However, soil moisture depletion pattern was relatively lower especially in upper soil profile depth in case of stubble retention at 30 cm cutting depth (Bandyopadhyay *et al.* 2016) and mulch. This was obviously due to better and higher crop cover in the said treatments. In the later stages of plant growth and within the varieties, faster moisture depletion was observed in the plot where chickpea JG 130 was grown as it had developed higher biomass early in the season as compared to variety medium BAV JG 226. Nevertheless, as per quantitative water use/ consumptive use of water by different chickpea varieties evaluated, maximum soil moisture depletion was recorded under JG 226 especially under long rice habit since it stayed for longer duration as compared to JG 130. This was in fact established despite the fact that the chickpea was sown and grown under zero tillage.

When comparison was made for total SMC and soil moisture storage up to 100 cm soil depth, higher SMC was recorded in JG 130 under dwarf rice Swarna with its stubbles retained at a cutting height of 30 cm than that in tall rice Masuri (Fig 1 and 2). Here the lowest SMC was analyzed under JG 226 followed after tall rice. Similar was the trend for other soil profile depths, wherein maximum soil moisture depletion up to 20-30 cm soil depth was recorded in tall rice habit with stubble maintained at a height of 30 cm especially in JG 226 which eventually fell below wilting point in soil water availability during later part of vegetative period (end of November) in comparison to dwarf

Table 1 Available water content (AWC) at different soil depths in experimental Vertisols

Soil depth (cm)	WHC ( $\text{cm}^3/\text{cm}^3$ )	Field capacity ( $\text{cm}^3/\text{cm}^3$ )	Permanent wilting point ( $\text{cm}^3/\text{cm}^3$ )	Available water content ( $\text{cm}^3/\text{cm}^3$ )	Total water content (cm/m profile)
0-5	0.70	0.47	0.24	0.23	1.15
5-10	0.70	0.47	0.24	0.23	1.15
10-15	0.71	0.47	0.24	0.23	1.15
15-30	0.66	0.43	0.22	0.21	3.05
30-40	0.64	0.42	0.21	0.21	2.10
40-60	0.66	0.39	0.20	0.19	3.80
60-100	0.67	0.39	0.18	0.21	8.40

AWC /100 cm soil profile : 20.8 cm/m

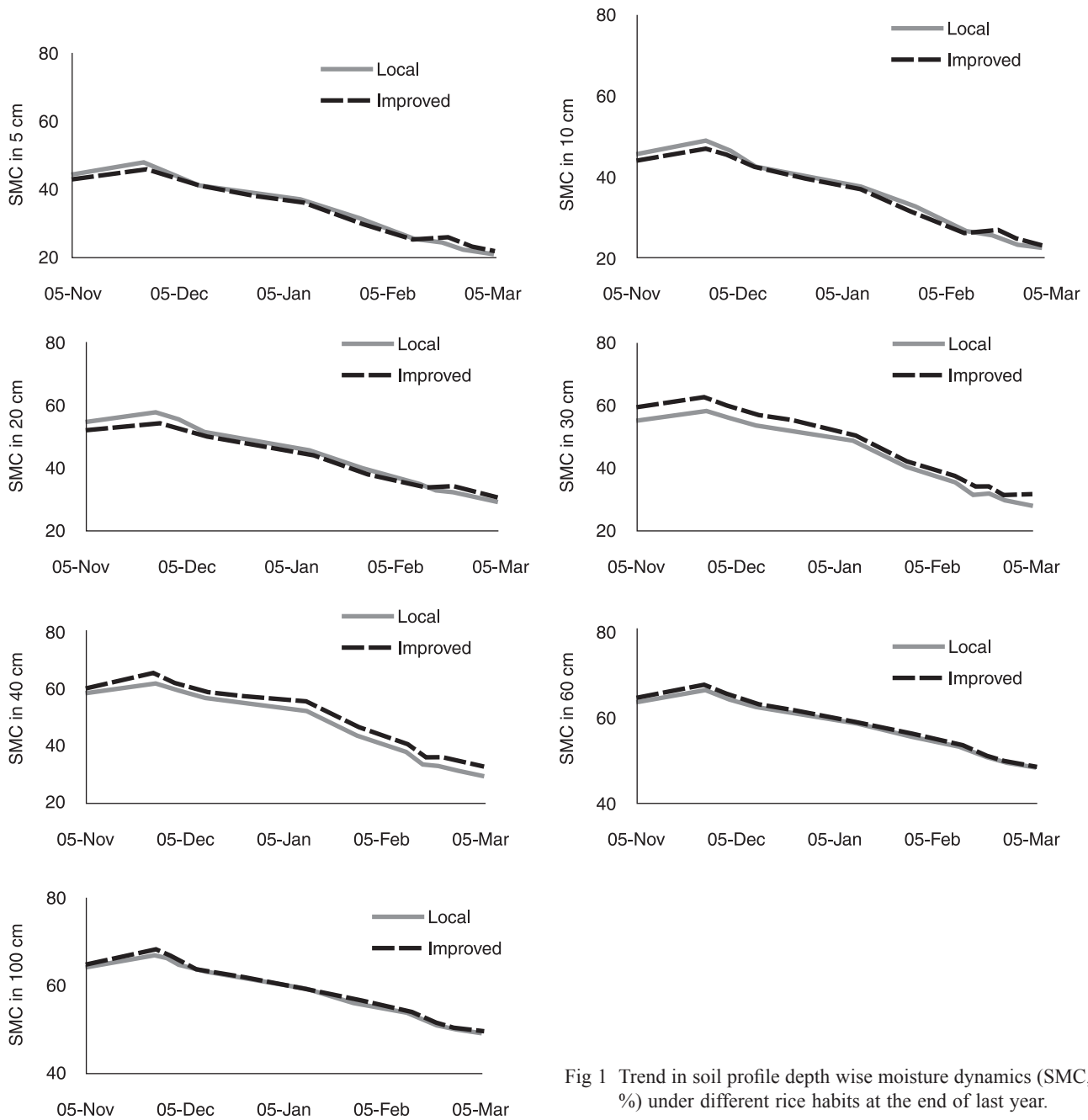


Fig 1 Trend in soil profile depth wise moisture dynamics (SMC, %) under different rice habits at the end of last year.

rice habit. Therefore, tall habit proved its inefficiency in terms of higher SMC in soil profile and extended period of optimum water availability (Bandyopadhyay *et al.* 2016, Mondal *et al.* 2012). The reasons attributed such an inefficiency is due to relatively long duration of tall rice varieties (Masuri) depleting more moisture in comparison to dwarf rice (Swarna).

On total water use measured in terms of consumptive water use, maximum water used was recorded under tall rice habit Masuri followed by dwarf rice habit Swarna. Hence, the period and amount of water availability was less to succeeding crop of chickpea in rotation in case of the former. The minimum water use was observed under tall rice habit when it was cut at a height of 30 cm followed by mulch and no residue retention. Therefore, soil moisture

depletion was more in tall variety up to the root zone of 0-40 cm as compared to dwarf rice. As rice crop is mainly a surface feeder, the differences in SMC in lower depths beyond the depth of effective root activity (> 40 cm) could be insignificant and marginal.

SMC and soil moisture storage are unique characteristics of soil that are dependent upon soil texture (which in turn is dependant on soil mineralogy), soil organic matter content and other crop husbandry practices including mulches, crop rotation, conservation tillage etc (Kovac *et al.* 2005). These conditions altered the resultant SMC at a particular time/space which could also influence seed germination, seedling emergence and crop establishment. Due to disruption in soil structure also, the effect could be on soil water deficit, poor aeration and mechanical impedance especially in

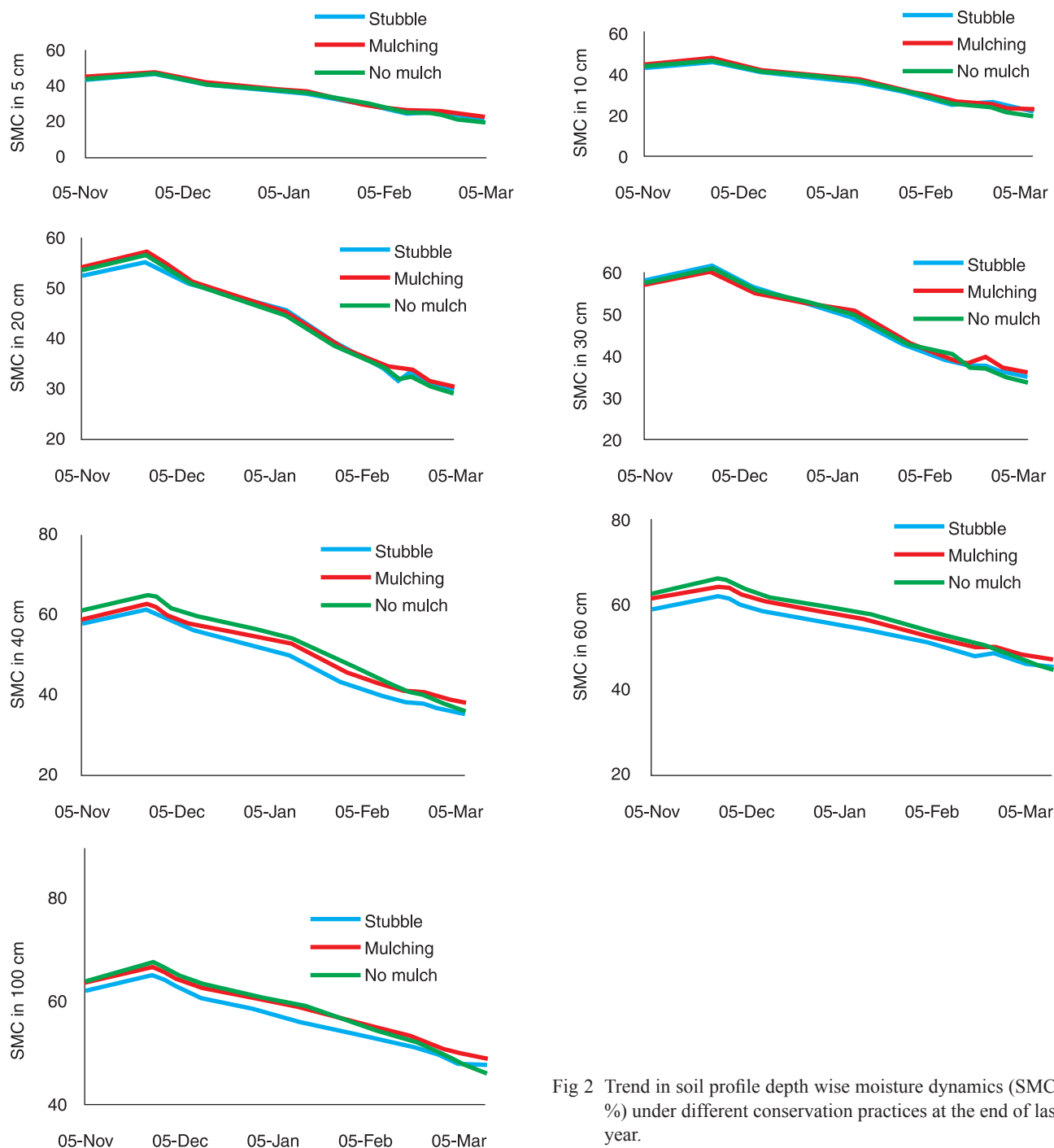


Fig 2 Trend in soil profile depth wise moisture dynamics (SMC, %) under different conservation practices at the end of last year.

the seed zone. Hence, an effective strategy by way of *in situ* early sowing of succeeding crop after rice ensures extended period of availability of adequate soil moisture that further enhances plant establishment and crop performance (Pratibha *et al.* 1996, Kar *et al.* 2004). This could also happen in the backdrop of high yielding dwarf rice variety without curtailing much on its critical duration (and thus, without jeopardizing the potential yield of rice). This dual benefit of rotational cropping involving pulse in a dwarf rice system was also inevitable in the present investigation (Patil *et al.* 2013).

In addition to enabling enhanced soil quality through

leaf litter fall and deep root system (Praharaj *et al.* 2017), pulses including chickpea with their unique ability to biological N<sub>2</sub> fixation (BNF) are a potent source for crop diversification (Singh *et al.* 2016). Reinforcing this, adequate and appropriate combination of crop management practices (in this case 30 cm residue retention or mulch in presence of early genotypes both for rice and chickpea) could possibly add the much needed strength to counter the existing abiotic stresses (especially terminal drought) faced by pulses. In the present investigation, the measures (such as retention of stubble/mulch and varietal interventions for both rice and pulses) had rendered in alleviating soil

moisture depletion (with subsequent favourable effects on organic matter build-up and improvement in soil health associated with physical, chemical structure and microbial population) which could possibly strengthen soil fertility further besides realizing potential productivity from these pulses grown under rice fallows (Praharaj 2014, Praharaj *et al.* 2014, Singh *et al.* 2016).

It was inferred from dynamics of SMC study that higher moisture content was evident under mulched plots as compared to 30 cm stubbles and residue removal in the upper layer of soil. However, in the later stages of plant growth within the varieties, soil moisture depletion was obviously fast in the soil where chickpea JG 226 (a medium biomass forming variety with lots of vacant spaces for evaporation to takes place) was grown. In the lower depth (below 40 cm), soil moisture depletion was less as compared to upper depth. Again after mid January, soil moisture depletion rate was increased abruptly and maximum depletion was observed in plots grown with chickpea JG 226 after rice Masuri under residue removal. Thus, soil moisture depletion was maximum in tall rice Masuri as compared to dwarf rice Swarna and under residue removal than stubble and mulch. Similarly, total soil moisture storage up to 100cm depth was more in rice Swarna combined with mulch under JG 130 (27.5 cm) and minimum under Masuri rice cultivar + stubble in chickpea JG 130 (25.4 cm). As a result, the cumulative infiltration was also higher under improved rice Swarna and mulch treatment.

#### Soil health

Pulses are considered as soil building crops as these essentially improve soil properties through significant biological nitrogen fixation (BNF), amount of leaf fall and left-over root biomass or residues. This could possibly be accumulated over time and space following crop rotation involving pulses (Bandyopadhyaya *et al.* 2016). In the present case, some of the associated physical and chemical soil properties were improved or at least altered following rice-chickpea cropping system. Although bulk density (BD) observed at 0-5 cm and 5-10 cm depth in different

treatments showed slight variation in the range of 1.34 to 1.37 Mg/m<sup>3</sup>, the same as a whole was increased slightly as a result of no mulch, medium high biomass JG 226 and tall rice masuri possibly due to higher rate of compaction in these treatments (Table 2). However, soil strength - another quantitative characteristic for soil compaction - recorded after harvest of rice indicated higher order variation (0.17 to 0.35 MPa). This could explain fairly higher order sensitivity of soil strength to rotational rice-chickpea cropping situation in comparison to the relatively stable physical attribute of soil, i.e. bulk density.

Closely related to soil strength, hydraulic conductivity (HC) of different treatments determined by Guelph *in-situ* permeameter that precisely measured *in situ* HC also varied slightly. Similar marginal changes did occur in respect of soil porosity, pH (6.67 to 6.95) and EC (0.12 to 0.14 dS m) at 15 cm profile depth under different factors at the end of each rotational rice-chickpea cycle. This interactive effect involving treatments indicated exhibition of relative soil resilience to possible alteration due to rice-chickpea cropping system. Moreover, as a result of slow depletion of SMC under stubbles retained at 30 cm height or mulch, soil organic carbon status was greatly enhanced under the said treatment (Table 3) which was more evident under tall rice (in comparison to dwarf rice due to soil cover for more time due to standing rice crop) and 30 cm stubble retention (compared to farmer practice) and was also pertinent in both varieties of chickpea (Table 3). Thus, soil organic carbon played a critical role in resource conservation and could possibly lead to higher carbon sequestration following pulses inclusion in the rice based cropping systems (Venkatesh *et al.* 2013, Mishra *et al.* 2012, NAAS 2013).

Similarly, small increments in respect of different soil fertility attributes were also observed following chickpea cultivation in rice-fallows. The mean effects (Table 4) indicated that the differences observed in respect of soil available N (an interactive effect of 187 to 234 kg/ha), soil-P (11.6 to 13.9 kg/ha), soil-K (425 to 464 kg/ha) after the harvest of rice were nominal to influence residual or cumulative effect on diversified crop attributes. Similar

Table 2 Effect of rice stubbles, rice habits and chickpea varieties on soil strength\*

Variety	Soil strength (MPa, 10 cm)				Soil strength (MPa, 20 cm)			
	Stubble	Mulch	No mulch	Mean	Stubble	Mulch	No mulch	Mean
<i>Tall rice habit (Masuri)</i>								
JG 130	0.20	0.20	0.11	0.17	0.23	0.22	0.13	0.19
JG 226	0.15	0.14	0.35	0.21	0.17	0.16	0.21	0.18
Mean	0.17	0.17	0.23	0.19	0.2	0.19	0.17	0.18
CD (P=0.05)			0.02				0.03	
<i>Dwarf rice habit (Swarna)</i>								
JG 130	0.17	0.16	0.18	0.17	0.17	0.19	0.18	0.18
JG 226	0.13	0.15	0.18	0.15	0.16	0.19	0.17	0.17
Mean	0.15	0.15	0.18	0.16	0.17	0.19	0.17	0.18
CD (P=0.05)			0.01				NS	

\*Observation made at the end of 3<sup>rd</sup> year before chickpea planting.

Table 3 Effect of rice stubbles, rice habit and chickpea varieties on bulk density (Initial stage)

Variety	Bulk density (Mg/m <sup>3</sup> in 0-5 cm depth)				Bulk density (Mg/m <sup>3</sup> in 5-10 cm depth)			
	Stubble	Mulch	No mulch	Mean	Stubble	mulch	No mulch	Mean
<i>Tall rice habit (Swarna)</i>								
JG 130	1.34	1.35	1.35	1.34	1.36	1.36	1.36	1.36
JG 226	1.35	1.34	1.35	1.34	1.37	1.34	1.37	1.36
Mean	1.34	1.34	1.35	1.34	1.36	1.35	1.36	1.36
CD (P=0.05)			NS				NS	
<i>Dwarf rice habit (Masuri)</i>								
JG-130	1.34	1.35	1.34	1.34	1.36	1.37	1.36	1.37
JG-226	1.35	1.35	1.34	1.34	1.37	1.37	1.37	1.37
Mean	1.34	1.35	1.34	1.34	1.36	1.37	1.37	1.36
CD (P=0.05)			NS				NS	

was the case for other essential micronutrients also (an interactive effect of 3.0 to 3.4 ppm Cu, 15.7 – 17.8 ppm Fe, 0.22-0.35 Zn and 3.7-6.1 ppm Mn). These ranges were observed in different combination of treatments imposed on the crop (Table 3).

#### Microbiology of soil

Microbiological analysis (Table 5) of composite soil samples taken from surface depth revealed that rhizobial population was the least ( $7.93 \times 10^4$  CFU/g of soil) in the plots where chickpea was grown following tall rice habit Masuri in comparison to that after dwarf rice habit Swarna ( $8.04 \times 10^4$  CFU/g of soil). Similarly, the lowest rhizobia population ( $7.84 \times 10^4$  CFU/g of soil) was analyzed in plots without application of mulch (no mulch) in comparison to those under retention of 30 cm stubble ( $7.90 \times 10^4$  CFU/g of soil) and mulch ( $8.30 \times 10^4$  CFU/g of soil) due to the least rhizobial activity (as the rhizosphere soils had the least organic matter). As a result of early biomass accumulation, chickpea JG 130 had higher rhizobial activity in the rhizosphere soils over that in JG 226. Moreover, maximum population of rhizobia was recorded in the plots

where chickpea JG 130 ( $8.73 \times 10^4$  CFU/g of soil) was followed after Swarna + mulch in comparison to that in Masuri + mulch ( $8.57 \times 10^4$  CFU/g of soil). Similar trend was found in respect of above factors so far other microbial parameters were concerned.

Quite similar to rhizobia population, maximum population of phosphate solubilizing bacteria (PSB) was counted in chickpea plots followed after dwarf rice Swarna ( $4.56 \times 10^5$  CFU/g of soil), retention of 30 cm rice stubbles/mulch ( $4.50-4.52 \times 10^5$  CFU/g of soil) and JG 130 ( $4.59 \times 10^5$  CFU/g of soil) in comparison to respective comparable treatments (tall rice habit, no mulch and JG 226, respectively). So far as population of other diazotrophs (mostly bacteria and other microorganisms that fix atmospheric N into more usable form non-symbiotically requiring more energy from symbiosis) under rice-chickpea cropping system was concerned, dwarf rice habit and mulched plots had comparatively higher population ( $2.55-2.63 \times 10^5$  CFU/gm of soil) of these compared to tall habit and no mulch, respectively ( $2.50-2.52 \times 10^5$  CFU/g of soil). On the contrary, medium high biomass JG 226 plots had slightly higher population of diazotrophs over that in

Table 4 Soil chemical properties after rice harvest as per treatments

Treatment	pH	EC (dS/m)	N (Kg/ha)	OC (%)	P (Kg/ha)	K (Kg/ha)	Zn (ppm)	Fe (ppm)	Cu (ppm)	Mn (ppm)
<i>Rice habit</i>										
Masuri (Tall)	6.78	0.13	212.8	0.76	13.10	439.4	0.26	16.10	3.22	4.48
Swarna (Dwarf)	6.84	0.13	218.1	0.75	12.47	443.1	0.30	16.43	3.17	5.15
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Stubble retention</i>										
Stubble	6.79	0.13	218.8	0.76	12.95	436.7	0.28	16.23	3.28	5.08
Mulch	6.88	0.14	210.8	0.77	12.75	443.6	0.28	16.55	3.23	4.68
No mulch	6.77	0.14	216.8	0.73	12.65	443.5	0.27	16.03	3.08	4.70
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
<i>Chickpea variety</i>										
JG 130	6.78	0.13	218.6	0.77	12.88	446.0	0.27	16.10	3.18	4.87
JG 226	6.84	0.13	212.3	0.74	12.68	436.5	0.28	16.43	3.20	4.77
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5 Effect of rice cultivar and residue management practices on microbial and physiological parameter activity of chickpea

Treatment	Microbiological observation			Physiological observation				
	Rhizobia population (10 <sup>4</sup> CFU/g soil)	PSB population (10 <sup>5</sup> CFU/g soil)	Dizotrophs (10 <sup>5</sup> CFU/g soil)	Dehydrogenase activity (µg TPF/g soil/24 hr)	Plant population (No./m row length)	Nodules/plant	Nodule dry wt. (mg/plant)	Specific leaf weight (g/cm <sup>2</sup> )
<i>Rice habit</i>								
Masuri (Tall)	7.93	4.49	2.52	75.14	33	26	0.05	0.20
Swarna (Dwarf)	8.04	4.56	2.55	75.69	34	27	0.05	0.23
CD (P=0.05)	0.01	0.009	NS	NS	NS	NS	NS	NS
<i>Stubble retention</i>								
Stubble	7.90	4.50	2.47	75.15	35	26	0.045	0.20
Mulch	8.30	4.52	2.63	77.07	37	29	0.06	0.22
No mulch	7.84	4.45	2.50	74.01	33	25	0.045	0.22
CD (P=0.05)	0.012	0.019	0.001	0.002	0.02	0.18	0.023	NS
<i>Chickpea variety</i>								
JG-130	8.07	4.59	2.59	75.88	35	27	0.048	0.22
JG-226	7.90	4.47	2.48	74.96	34	27	0.051	0.22
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

early high biomass JG 130 (Table 5). The reason for higher microbial biomass under mulch or dwarf rice habits might be attributed to more congenial microclimate favoured by shading effect; and as a result of this, availability of soil moisture was extended over the growth duration of crop compared to control plots (no mulch or tall habits).

Dehydrogenase activity (DHA) - a microbial oxidative activity in the soil environment is considered as a fairly good measure of enzymatic activities carried out in the soil. In the above rice - chickpea cropping system, higher DHA was observed in plots under dwarf rice habit, mulch/stubble retained at 30 cm height and chickpea JG 130 (75.15- 77.07 µg TPF/g Soil/Day) over those plots with comparable treatments (tall rice habit, no mulch and 'JG 226); and the minimum activity was evident under no mulch (Table 5). Therefore, depending on the constraints imposed, microbiology of rhizosphere was altered to the advantage of crop growth and development which in turn had an influence on BNF and crop performance (Venkatesh *et al.* 2013, Bandyopadhyaya *et al.* 2016).

#### Nodulation and crop growth

As a result of modification in microclimate following imposition of treatments, both crop growth and nodulation parameters were altered. Since plant population was similar irrespective of diverse treatments, the differences observed in crop growth and nodulation behavior was mainly attributed to imposition of treatments. The study revealed that apparently higher number of nodules/plant was recorded in plots grown with dwarf rice habit followed by mulch/stubble retention before chickpea sowing. Evidently, highest number of nodules/plant was observed in chickpea JG 130 under the combined application of Swarna + mulch; while the lowest number of nodules/plant was recorded under Masuri

+ residue removal (especially under chickpea JG 130). Similar was the trend for nodule dry weight and specific leaf weight (an attribute showing accumulation of photosynthates as a result of physiological activity indicating symbiosis efficiency) for the above treatments (higher values were evident with dwarf rice habit and mulch/stubble retention) (Table 5). As a result, higher relative leaf water content was analyzed at 30, 60 and 90 DAS in plots grown with chickpea JG 130 following Swarna + stubble retention (Fig 3). Similar was the trend for specific leaf weight.

Other important growth attributes, viz. root shoot ratio and root volume was similarly influenced by the treatment(s) imposed, and the specific parameter in question (Table 6). Commensurating crop growth and nodulation, higher root shoot ratio (0.59) was observed in dwarf rice habit with little deviations under mulch/stubble retention, and chickpea JG 130. On the same fashion, the higher root volume (10.09 cm<sup>3</sup> × 10<sup>-3</sup>) was recorded (Table 6). Thus, not only different rice habit but also soil cover (mulch/stubble retained) did influence crop growth via resource conservation (following availability of soil moisture for an extended period, Gangwar *et al.* 2006). This could be useful for higher resource saving and enhanced input use efficiency (Praharaj *et al.* 2014, Bandyopadhyaya *et al.* 2016, Mondal *et al.* 2012, Singh *et al.* 2016).

#### Weed attributes

The maximum weed population at 60 DAS (28.5/m<sup>2</sup>) was recorded in plots under tall rice Masuri due to exposure of rice crop for longer duration in comparison to that in dwarf rice Swarna. Because early and adequate soil cover and lesser depletion of resources for nourishment of weeds, lower weed population was counted in plots with mulch/stubble retention, and chickpea JG 130 over corresponding

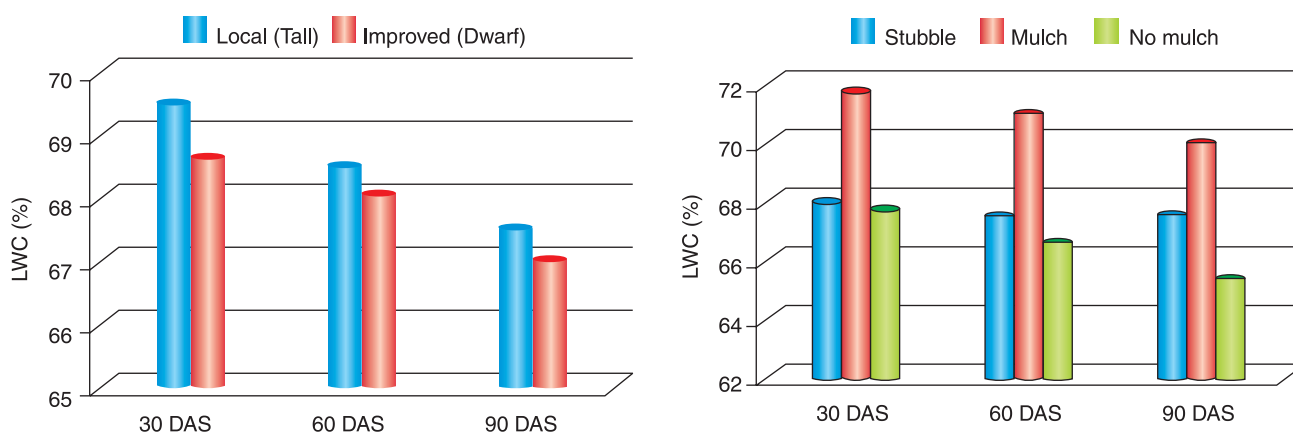


Fig 3 Relative leaf water content (%) under different rice cultivars and conservation practices at different dates after sowing at the end of last year.

comparable treatments (no mulch and chickpea JG 226) (Table 6). In the similar manner, dry matter accumulation in weeds was also influenced. Apparently, when crop covers the ground early in the season (by early biomass forming genotypes), it has a smothering effect on weed growth. Thus, the highest weed density was recorded under JG 130 followed after Masuri + residue removal. Therefore, for a holistic crop management strategy, both biotic and abiotic constraints have their say (Mishra *et al.* 2012, Praharaj 2013, Praharaj *et al.* 2014).

#### Grain yield and its attributes

The study also confirmed higher number of pods per plant recorded in plots under dwarf rice habit, mulch/stubble retention at a height of 30 cm and chickpea JG 130 over corresponding comparable treatments (tall rice habit, no mulch and chickpea JG 226). As a result, the highest grain yield of chickpea was recorded in chickpea plots grown

with mulch (1470 kg/ha) and JG 130 (1389 kg/ha) (Table 6). In combination, highest grain yield of chickpea (1793 kg/ha) was realized with JG 130 followed after Swarna+ mulch; and was followed by chickpea JG 226 after Swarna and mulch (1547 kg/ha). The lowest yield (973 kg/ha) was evident in JG 130 under Masuri + residue removal. Thus, in rice fallows of central India, short duration rice varieties could be a boon for realizing its untapped potential as it could be used as a component in rice-chickpea sequential cropping along with appropriate soil moisture conservation practices like, retention of stubbles or rice residues (30 cm height) or its mulching (Singh *et al.* 2016).

Apparently, the difference in grain yields of chickpea following different rice habits was minimal due to the complex factors determining the yield formation. Yet, the yield difference was insignificant confirming the fact that unfavourable effects of tall rice habits could not perform the best in the long run. Therefore, optimum crop performance

Table 6 Effect of rice cultivar and residue management practices on relative water content (RWC), root characters and weed population in chickpea

Treatment	RWC (%)			Root characters		Weed population		Yield and its attributes	
	30 DAS	60 DAS	90 DAS	Root volume (cm <sup>3</sup> ×10 <sup>-3</sup> )	Root shoot ratio	Weed population (No./m <sup>2</sup> )	Weed DW (g/m <sup>2</sup> )	Pods/plant	Grain yield (kg/ha)
<i>Rice habit</i>									
Masuri (Tall)	69.50	68.51	67.50	9.84	0.56	28.5	12.74	50	1302
Swarna (Dwarf)	68.63	68.06	67.00	10.09	0.59	24.8	10.12	51	1283
CD (P=0.05)	NS	NS	NS	0.008	0.001	0.2	0.96	NS	NS
<i>Stubble retention</i>									
Stubble	67.94	67.42	67.47	9.82	0.56	25	11.02	51	1308
Mulch	71.63	70.89	69.88	10.23	0.58	24	9.85	60	1470
No mulch	67.62	66.53	65.50	9.84	0.59	30	13.2	41	1100
CD (P=0.05)	0.28	0.37	0.54	0.02	NS	0.86	1.12	0.03	120
<i>Chickpea Variety</i>									
JG-130	69.14	68.33	67.29	10.04	0.57	26.5	11.58	54	1389
JG-226	69.00	68.24	67.20	9.9	0.57	26.8	11.82	47	1197
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

could definitely a function of prevalence of optimum condition during life cycle of crop plants.

The study suggested that dwarf rice habit of rice was found consistent in conserving maximum soil moisture in comparison to tall rice habit. So was the case for early biomass accumulating chickpea JG 130 over JG 126. Mulch or stubble retention had a bearing on adequate crop growth as it acted as a soil cover and favoured with the benefits accrued as a consequence of it. Consequent to higher moisture storage/extended availability and further utilization, yield attributes and grain yield were enhanced following mulching or stubble retained at 30 cm height. Furthermore, rhizospheric microbial population and crop physiological attributes, such as relative leaf water content etc were also similarly influenced as it was higher in chickpea following dwarf rice over that in tall rice. Therefore, growing suitable crop varieties and keeping adequate soil cover for aiding in optimum crop performance could be an efficient way for better management of soil and land resources besides realizing or stabilizing necessary gain in output from chickpea grown as a sequential crop in rice fallows (Singh *et al.* 2016).

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