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FULL-LENGTH RESEARCH ARTICLE

Enhancing Water and Phosphorus Use Efficiency Through Moisture Conservation Practices and Optimum Phosphorus Application in Rainfed Maize–Chickpea System in Vertisols of Central India

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Abstract Conserving soil moisture in the rainfed region is a challenging task as it plays a significant role in crop productivity and livelihood security of rainfed farmers. The soil moisture conservation practices (MCPs) coupled with the addition of root augmenting nutrition are crucial for sustaining crop yields and maintaining soil phosphorus (P) in a rainfed Vertisol of Central India. Thus, a study was conducted to evaluate the long-term effect of MCPs and P application in maize–chickpea in a Vertisol. A five-year study showed that the MCPs integrated with P nutrition significantly helped in growing chickpea (*Cicer arietinum*) without irrigation or with limited irrigation. Under the normal rainfall conditions such as normal onset time, distribution and cessation time during the experimentation, the MCPs proved useful in obtaining chickpea yields in the range of 776 to 933 kg ha^{-1}. The best MCP was the practice of late intercultural operations + *Gliricidia* cover in the inter-row spaces of standing maize (@ 5 t ha^{-1} fresh weight basis) + maize stover application (after sowing up to germination), which recorded higher chickpea grain yield (932 kg ha^{-1}) on account of higher moisture content in the soil and reduced stress in the plants. Another comparable treatment was *Gliricidia* cover + one pre-sowing irrigation of 6 cm for chickpea, which recorded 933 kg ha^{-1} of chickpea yield. Both the treatments recorded significantly higher yields than the under control (637 kg ha^{-1}). We also found that the application of *Gliricidia* cover on the soil surface coupled with either pre-sowing irrigation and/or late intercultural operations had beneficial effect on soil physical conditions increasing soil moisture which in turn affected the crop growth. Under normal monsoon years, the best treatments (MCP4 and MCP5) recorded around 46% higher chickpea yield as compared to the control. It is concluded that these soil MCPs are very useful in rainfed areas for sustaining crop yield.

Keyword Soil management · Moisture conservation practices · Plant moisture stress · Rainfed chickpea · *Gliricidia* cover

Introduction

Soil moisture conservation in rainfed areas with special reference to carry over the monsoonal moisture for sowing of *Rabi* crops becomes essential to increase crop productivity. In Central and Peninsular India, after withdrawal of monsoons, utilization of stored soil moisture starts in the month of October. With advancing time and age of *Rabi* crops, the soil moisture utilization increases, while the soil moisture deficit also increases till January [16, 24, 25]. As the moisture from the upper soil layer is depleted through ET, the soil develops cracks between crop rows. The moisture loss through the lateral surface of the cracks is

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about 55% of that evaporated at the surface [2], resulting in desiccation of root zone. Consequently, there is a need for conserving soil moisture through organic mulches available in the field to avert moisture deficit at the time of sowing of *Rabi* crops and also during crop growth [5, 7, 8, 28]. This may also increase productivity of *Rabi* crops through increased nutrient use efficiency under favorable moisture conditions. It is established that beneficial effects of organic mulches is mainly due to their efficacy to reduce evaporation by moderating soil temperature and conserving soil moisture [3] and to augment water retention capacity through improvement of soil physical conditions [11, 12, 25] and increasing availability and use efficiency of nutrients [1, 13, 18]. To make best use of conserved moisture, selection of crops with low water requirement is also important in rainfed region. In semiarid situations, where the probability of winter rains is negligible, chickpea is a suitable crop raised under receding moisture situations [6, 21, 25, 29, 30]. The productivity of cropping systems involving rainfed chickpea in semiarid tropics is reported to be high compared to other crops [26]. Stimulating the roots to grow deeper to '*tap the untapped water*' from deeper layers can further augment the moisture availability. This is possible as the soils of the region are deep and able to retain/contain sufficient water in lower layers. The crop needs proper nutrition especially phosphorous (P), and the doses have to match with the moisture available. Application of phosphorous increases rooting depth, root proliferation and nodulation [18], which also helps in more moisture extraction from deeper layers and helps in enhancing more nitrogen fixation and productivity. Hence, this study was conducted with hypothesis: Various soil moisture conservation practices and phosphorus levels may enhance moisture storage and water and nutrient use efficiencies and also affect the plant and root growth characteristics. Therefore, the present study was undertaken to assess the effect of various soil moisture regimes and P doses on the water and P use efficiency under maize–chickpea cropping system in a rainfed Vertisol.

Materials and Methods

Experimental Details

A field experiment was conducted for 5 years (2002–03 to 2006–07) on a deep heavy clay soil (Typic Haplustert) at the research farm of ICAR, Indian Institute of Soil Science, Bhopal, India (23°18' N, 77°24' E, 485 m above mean sea level). The soil of the experimental site was low in organic carbon (0.44%), available N (112 mg kg^{-1}) and available P (2.6 mg kg^{-1}) but high in available K (230 mg kg^{-1}). Daily rainfall distribution during the study period (2002–06) is given in Fig. 1.

This experiment was conducted with a split plot design with three replications. Main plot treatment consists of 6 moisture conservation practices (MCP), *viz.* MCP_1: control, MCP_2: *Gliricidia* cover in the standing maize, MCP_3: *Gliricidia* cover in the standing maize + maize stover (i.e., after harvest, the maize stover was applied on soil surface till germination of chickpea crop), MCP_4: late interculture + *Gliricidia* cover + maize stover (i.e., after harvest of maize, the maize stover was applied on soil surface till germination of chickpea crop), MCP_5: *Gliricidia* cover +pre-sowing irrigation, MCP_6: *Gliricidia* cover in the standing maize + no-tillage. The subplot treatments consisted of 3 levels of phosphorus *viz*., P_0 (no phosphorus), P_{20} (20 kg P_2O_5 ha^{-1}) and P_{40} (40 kg P_2O_5 ha^{-1}) (Table 1). The maize hybrid Kanchan was sown in last week of June every year (except 2005, sown in 3rd week of July due to late monsoon) with recommended dose of fertilizers (RDF). FYM was applied as blanket dose of 5 t ha^{-1} during *Kharif* season in specified plots to impose the treatments. In one of the treatments, one late intercultural operation was done in the treatment plots before applying the *Gliricidia* cover. In the rainy (*Kharif)* season, short duration/early maturing maize variety (*cv* Kanchan-Pro Agro 4212) was grown with recommended dose of fertilizers (120:60:40 N, P_2O5 and K_2O). At the time of monsoon recession, *Gliricidia (Gliricidia sepium L.)* biomass was applied to the specified plots @ 5 t ha^{-1} (fresh weight basis) in the inter-row spaces of standing maize. *Gliricidia* contains 2.76% N, 0.28% P_2O_5 and 4.60% K_2O on dry weight basis. After harvest of maize, the stover was applied on the soil surface in the specified treatments @ 14 t ha^{-1} (fresh weight basis) and subplot treatments were imposed. Soon after harvest of maize crop, short duration chickpea (*cv* JG-74) was sown during the first week of October every year with three variable doses of P_2O_5 (0, 20 and 40 kg ha^{-1}) coupled with recommended dose of N and K to experimental crops. At sowing of chickpea, maize stover was applied in specified treatments and removed after the germination of chickpea seeds.

Observations like soil moisture, evapotranspiration and biometric parameters were recorded following standard procedure. For determining root length density (RLD), root samples were collected at pod filling stage of chickpea using root sampling cores (6 cm height, 8.6 cm diameter) up to a depth of 30 cm. Collected roots samples were properly washed in root washer unit and then stained, and the root length density was determined with the help of Delta-T scanner. The root length was divided by core volume to estimate the RLD. Plant moisture stress was measured using pressure bomb apparatus (PMS Instrument

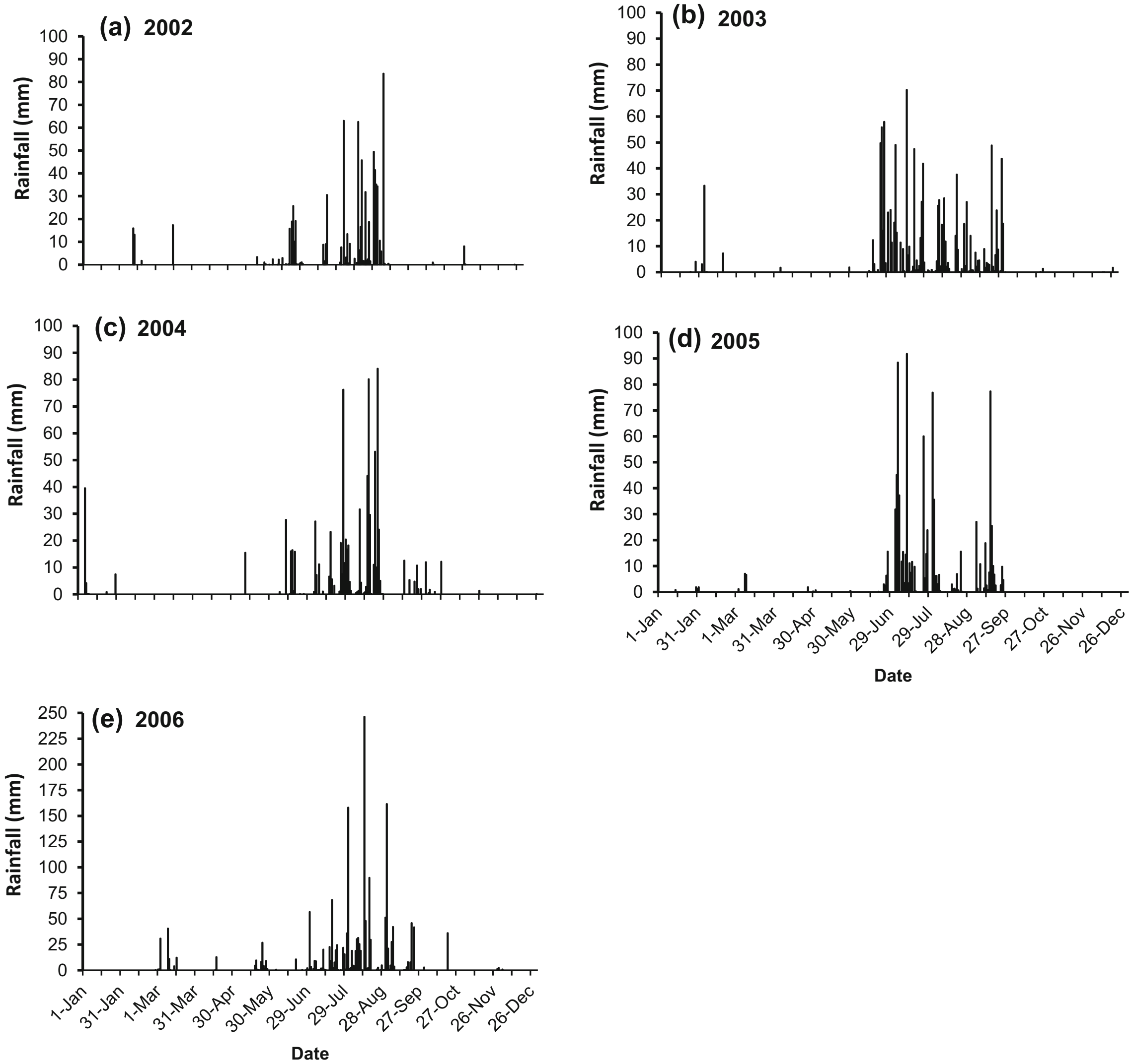


Fig. 1 Daily rainfall distribution during the study period: **a** 2002, **b** 2003, **c** 2004, **d** 2005 and **e** 2006

Table 1 Soil moisture conservation practices and different phosphorus levels

Main plot (moisture conservation practices)*	Subplot treatments: phosphorous (P) levels
MCP_1: Control (no *Gliricidia* cover)	
MCP_2: *Gliricidia* cover in the standing maize	P_0 (No P applied—control)
MCP_3: *Gliricidia* cover in the standing maize + maize stover	P_{20} (P applied @ 20 kg P_2O_5 ha^{-1})
MCP4: Interculture + *Gliricidia* cover + maize stover	P_{40} (P applied @ 40 kg P_2O_5 ha^{-1})
MCP5: *Gliricidia* cover +pre-sowing irrigation	
MCP6: *Gliricidia* cover in the standing maize + no-tillage (NT)	

*At the time of monsoon recession, Gliricidia biomass from vegetative barriers and field peripheral boundaries was applied @ 5t/ha on fresh weight basis between the rows of standing maize, when the soil was around field capacity facilitating the operation

CO, Oregon, USA). Soil aggregation and water stability of aggregates were analyzed following the procedure outlined by Kemper and Roseanu [14]. Water use efficiency (WUE) was calculated using the following equation. Evapotranspiration (ET) was determined by quantifying water loss from 0 to 30 cm soil depth at regular intervals. Toward this, the volumetric water content was converted in to water height by multiplying with soil depth. Then the difference in water height (mm) after each time interval (between two consecutive readings) was determined (ET). Then the cumulative ET (mm) was calculated by summing up the water lost from 0 to 30 cm depth under different treatments during the chickpea growth. During crop growth (Rabi), no irrigation was given and negligible or no rainfall was received.

$$\mathrm{WUE} = \frac{\text{Grain Yield } \left(\mathrm{kgha}^{-1}\right)}{\text{Evapotranspiration (ET, mm)}}$$

$$\mathrm{PUE\ (AE)} = \frac{\text{Grain yield (kg) with } P_2O_5\text{application} - \text{Grain yield (kg) without } P_2O_5\text{application.}}{\text{Amount of } P_2O_5\text{applied (kg)}}$$

where PUE (AE) = phosphorus use efficiency (agronomic efficiency).

Results and Discussion

Effect of soil moisture conservation practices and P doses is discussed for various parameters studied.

Soil Moisture Content

Various moisture conservation practices to carry over the soil moisture stored during the monsoon to *Rabi* season crops showed that soil moisture content at 0–15 cm depth under different treatments at sowing of chickpea was in the range of 31.5–41% by volume in normal monsoon years (Fig. 2). The moisture content was highest (41%) in *Gliricidia* cover + pre-sowing irrigation (MCP5) followed by 35.8% in late interculture+ Gliricidia cover- maize stover (MCP4), while it was lowest (31.5%) in control (MCP1). In the deficit years, the trend was the same, but moisture content even in treated plots was comparatively lower (31–35.5%) than normal years but certainly higher than control (28–32%). In the 120 cm profile, the trend was same with total storage under treatments in the range of 42–48 cm compared to 34.5 cm in control in normal monsoon years. In deficit years, the profile water was in the range of 38–44 cm with moisture conservation practices and minimum 32.2 cm in control. We presume that application of *Gliricidia* cover on the soil surface has the positive effect on soil physical conditions by reducing evaporation losses, increasing soil moisture and moderating soil temperature, which in turn affected the crop growth. Chakraborty et al. [6] reported that application of organic mulch (rice husk) to be superior in maintaining optimum soil moisture condition for crop productivity in wheat as compared to synthetic mulches such as transparent and black polyethylene. The higher soil moisture status indicated role of mulch in conserving the moisture in soil, though the effects between the kinds of mulches varied. Rice husk seemed to be the best in maintaining moisture in both surface and subsurface layers from sowing to harvest, closely followed by transparent polyethylene (TP) mulch. Similar findings under rice straw mulch were reported by Rahman et al. [22]. Application of *Gliricidia* cover helps in

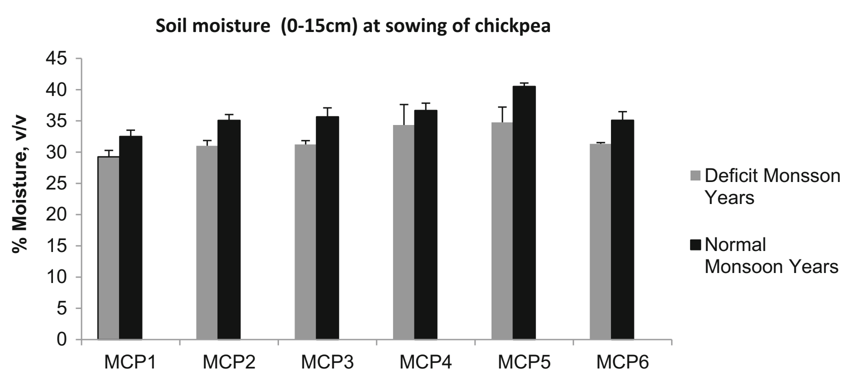


Fig. 2 Soil moisture (%, v/v) under different moisture conservation practices. [MCP_1: Control, MCP_2: Gliricidia cover in the standing maize, MCP_3: Gliricidia cover in the standing maize + maize stover, MCP_4: Interculture + Gliricidia cover + maize stover, MCP_5: Gliricidia cover +pre-sowing irrigation, MCP_6: Gliricidia cover in the standing maize + no-tillage]

slow drying of soil, resulting in prolonged water availability during crop growth and development. The effect was particularly noticeable during dry periods, where no irrigation was given to the crop or no rain occurred. Conserving water at lower depths would be useful to crops during grain filling, even though irrigation or rainwater was not available to the crop [17] and might have positive effect on yield of chickpea, which is in conformity with other findings [9, 17, 20].

Application of *Gliricidia* biomass @ 5 t ha^{-1} on fresh weight basis as surface cover at the time of recession of monsoon between the rows of standing maize (cv. Kanchan) spaced at 60 cm and one late intercultural operation prior to *Gliricidia* application (MCP4) conserved higher moisture compared to control (MCP1). Maize yield and ET rates were also higher in mulch covered plots (3 mm day^{-1}) compared to control because of higher moisture storage. Results further indicated that *Gliricidia* cover + pre-sowing irrigation (MCP5) recorded higher soil moisture content (0–15 cm depth) at the time of sowing of chickpea. Similar trends were observed in 15–30 cm depth. Late intercultural operation + *Gliricidia* cover + maize stover application (MCP4) was next best with respect to carry over soil moisture and yield of chickpea and also higher in comparison with the *Gliricidia* cover only (MCP2) and *Gliricidia* cover +maize stover (MCP3) treatment. Alharbi [4] reported that soil moisture and mulch had a strong indirect influence on the amount of available soil nitrogen, phosphorus and potassium. The highest value of total nitrogen in the soil was recorded in the presence of mulch with the availability of 100% of the recommended irrigation.

During the chickpea growing period, the soil moisture variation at surface (0–15 cm) layer (Fig. 3a, b, c, d, e) revealed that MCP4 and MCP5 maintained higher soil moisture right from sowing up to near maturity stage followed by MCP3 and MCP2 in comparison with control (MCP1). However, during the monsoon deficit years (2002–03 and 2004–05) even the initial moisture content was lower at around 30% v/v basis in comparison with normal monsoon years (around 35% v/v).

The evapotranspiration (ET) was monitored from late interculture/Gliricidia application in the standing maize till chickpea harvesting. The cumulative ET was higher in *Gliricidia* applied plots compared to control during 2006–07 (Fig. 4). The highest ET was observed in *Gliricidia* cover + pre-sowing irrigation (MCP5) followed by late intercultural operation + *Gliricidia* cover + maize stover application (MCP4) (Fig. 4). Our results corroborated with the findings of Zhang et al [33]. Among the P treatments, cumulative ET was higher under higher levels of P application (@40 kg P_2O_5 ha^{-1}) compared to 20 and 0 kg P_2O_5 ha^{-1} applied.

Plant Moisture Stress

Plant moisture stress measured between flowering and pod development stage revealed that in deficit monsoon years, the stress was higher than that in normal monsoon years and was recorded in the range of 20–22, 14–15 and 11–14 bars in control, late interculture + *Gliricidia* cover + -maize stover (MCP4) and one pre-irrigation treatments (MCP5), respectively (Fig. 5). We observed that plant stress was lower in plots with increased application of P_20_5 doses. Results indicated that it was higher (16–22 bars) in *Gliricidia* cover+ no-tillage treatment (MCP6) probably due to excessive moisture loss though surface cracks [10, 27]. The trends in plant moisture stress were similar in normal years with lesser values in treated plots compared to control, but overall values were lower than deficit monsoon years (Fig. 5).

Root Length Density (RLD) of chickpea

At surface 0–7.5 cm depth, maximum root length density (RLD) of chickpea was recorded in the plots receiving *Gliricidia* cover in the standing maize + maize stover (MCP_3) at pod filling stage during 2006–07 (Fig. 6a). Among the phosphorus treatments, the RLD values were recorded high with the application of 40 kg P_2O_5 ha^{-1}, followed by 20 kg P_2O_5 ha^{-1} and no application of P_2O_5. This indicates that suitable MCPs with higher dose of P favoured root growth of chickpea. RLD was significantly higher at 0–7.5 and 7.5–15 cm depths compared to lower depths (Fig. 6b). Similarly, Hati et al. [11] reported higher RLD at 0–7.5 and 7.5–15 cm depths and the tillage treatments significantly affected the root length density (RLD) of soybean. In a similar line, Chakraborty et al [6] reported that maximum root length density at 0–15 cm soil depth was observed under adequately irrigated wheat. Among different mulches, RLD was significantly higher under rice husk applied as mulch, regardless of soil depths. Lesser mechanical resistance from soil through conservation of moisture enhanced the root growth under these treatments, which is in agreement with other findings [22, 25]. Li et al [17] reported that higher root development could enhance water and nutrient absorption capacity, thereby increasing the grain yield. Moreover, covering the soil with organic/inorganic materials (mulches) can minimize soil evaporative losses and suppress weeds and moderate soil temperature, which enhance the crop growth and development [19].

In general, higher root length density at surface depth (0–15 cm) was recorded during all the 5 years under MCP4, in the range of 1.75 to 2.20 cm cm^{-3} (normal monsoon years). Similar trend was observed at 15–30 cm with RLD values less than those at 0–15 cm depth. With

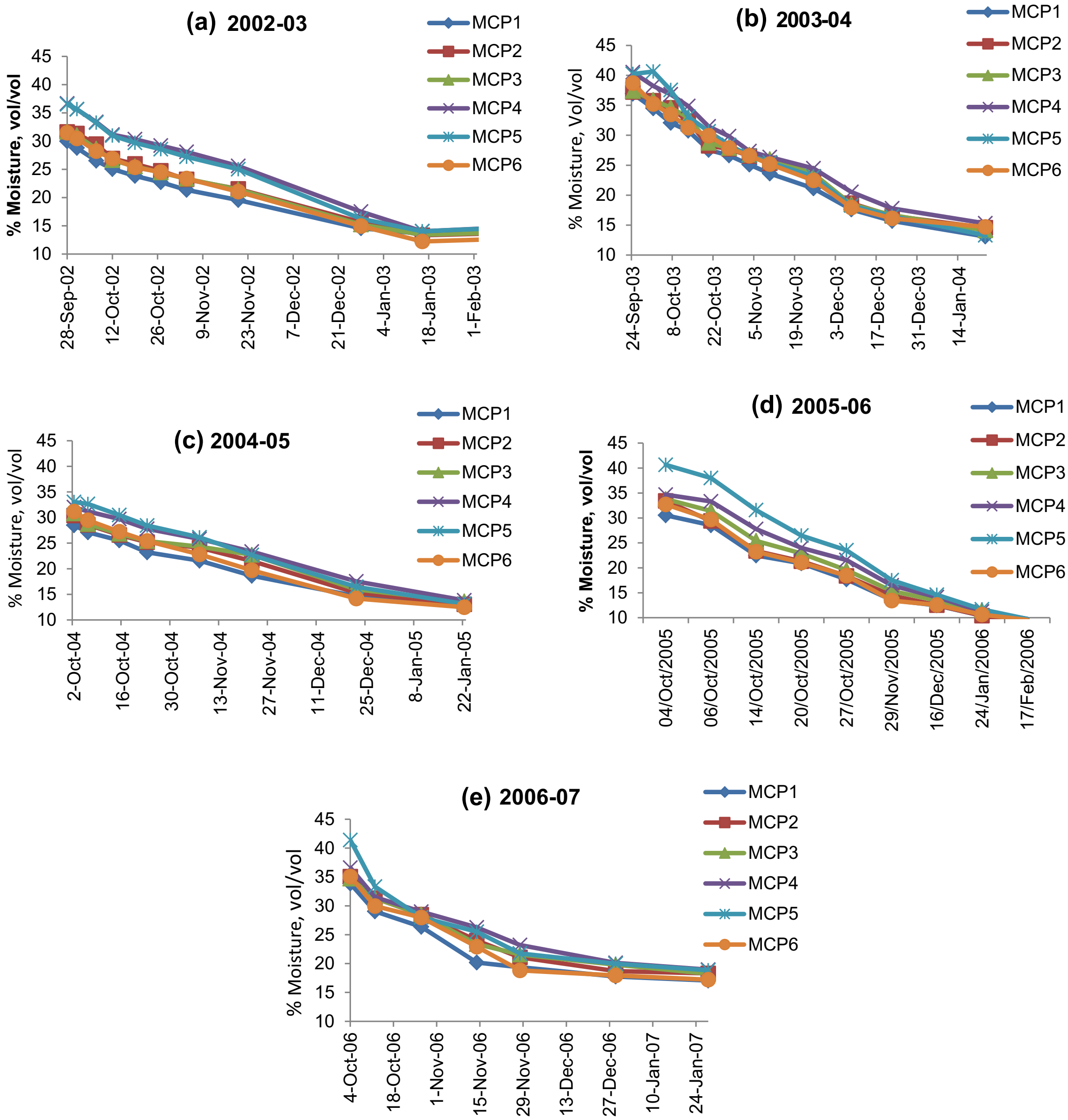


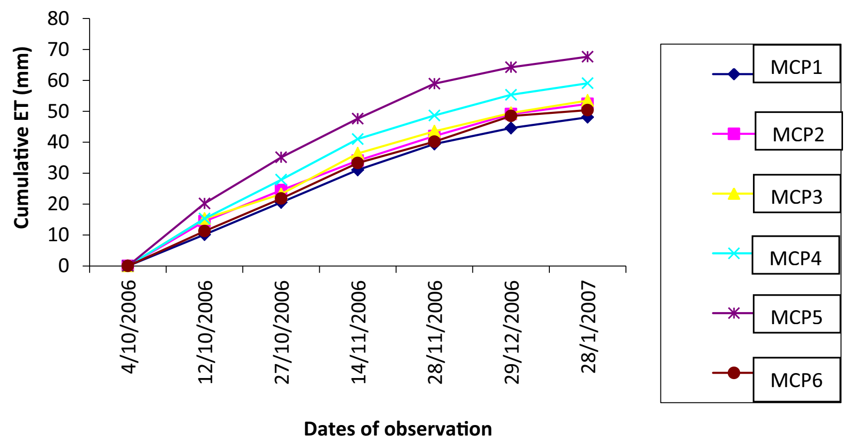
Fig. 3 Soil moisture (%, v/v) under moisture conservation practices during experimentation period **a** 2002–03, **b** 2003–04, **c** 2004–05, **d** 2005–06, **e** 2006–07. MCP_1: Control, MCP_2: *Gliricidia* cover in the standing maize, MCP_3: *Gliricidia* cover in the standing maize + maize stover, MCP_4: Interculture + *Gliricidia* cover + maize stover, MCP_5: *Gliricidia* cover +pre-sowing irrigation, MCP_6: *Gliricidia* cover in the standing maize + no-tillage

increase in phosphorus doses from 0 to 40 kg P_2O_5 kg^{-1}, the RLD values at 0–15 cm were recorded highest under P40 doses followed by P20 and minimum (0.7–1.2 cm cm^{-3}) under P0 (Fig. 5b). Similar pattern of RLD was observed at 15-30 cm soil depth; however, values were lower than at surface.

Soil Aggregation and Water Stable Aggregates

Soil aggregation was measured through parameters like water stable aggregates (WSA) and mean weight diameter (MWD) after five crop cycles. Results indicated that higher MWD was recorded under MCP4 and MCP5 (0.74 and 0.76 mm, respectively) coupled with higher dose of phosphorus application as compared to other treatments (Table 2). This indicates that application of *Gliricidia* cover followed by maize stover cover has favoured the soil aggregation in rainfed Vertisols. Similar trends were observed for water stable aggregates (WSA) after five crop cycles. In general, increase in mean weight diameter and water stable aggregates is observed with increase in P fertilizer application as it increases the crop growth (both

Fig. 4 Cumulative ET (mm) during chickpea growth period 2006–07



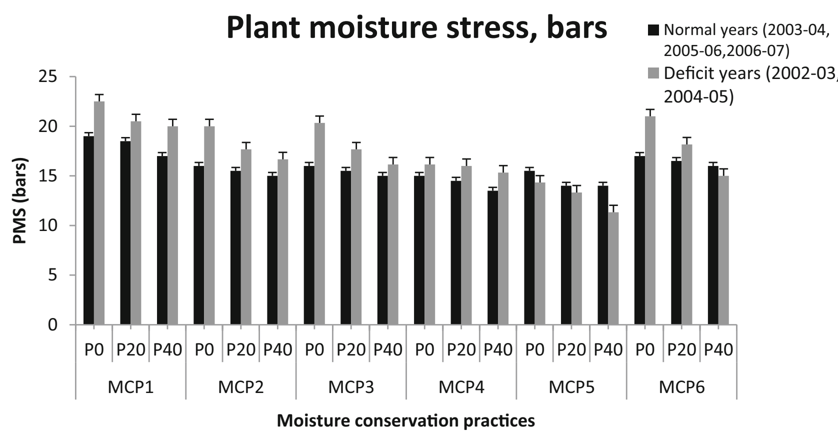


Fig. 5 Effect of moisture conservation practices on plant moisture stress (PMS) at flowering stage of chickpea. MCP_1: Control, MCP_2: *Gliricidia* cover in the standing maize, MCP_3: *Gliricidia* cover in the standing maize + maize stover, MCP_4: Interculture + *Gliricidia* cover + maize stover, MCP_5: *Gliricidia* cover +pre-sowing irrigation, MCP_6: *Gliricidia* cover in the standing maize + no-tillage; *phosphorus doses were applied only for chickpea crop

aboveground biomass and belowground biomass). Moreover, roots may promote better soil aggregation and its stability by supporting soil microbial communities through root exudation of organic cementing agents. Our results corroborated with the findings of Wilhelm et al. [32], who have reported that retaining crop residue on the soil surface is often considered to maintain physical, chemical and biological properties in agricultural soils.

Crop Yield

Maize Yield

Yield data indicated that grain yield of maize was around 2.5 t ha^{-1}, which was not significantly different among soil moisture storage treatments. The maize grain yield was higher, i.e., in the range of 3411–4402 kg ha^{-1} in one of the deficit rainfall years (i.e., 2004–05) probably due to least problem of water stagnation (Table 3). In good rainfall year 2005–06, it was in the range of 2125–3015 kg ha^{-1}. It was also observed that maize yields were higher under *Gliricidia* mulch applied plots compared to control. It can be explained by the fact that moisture storage was higher in mulched plots that led to prolonged water availability, adequate ET and thus higher yield in these treatments. In fact, *Gliricidia* mulch was applied in the standing maize, after recession of the monsoonal rains. But, before its application, the water stagnation during the rainy season that was observed in good monsoon years had affected the crop. But after recession of rainfall, as the moisture depletion started in standing maize, toward crop maturity stage, the *Gliricidia* mulch might have moderated soil moisture loss and facilitated better nutrient availability under mulched plots. Our results corroborated with findings of Kumar et al. [16] who have reported that application of mulches at 10 t ha^{-1} conserved more moisture and increased yield of turmeric by 12%. Similarly, application of paddy straw mulch resulted in 18% increase in yield over *Gliricidia* mulch. Moreover, quality of mulch was

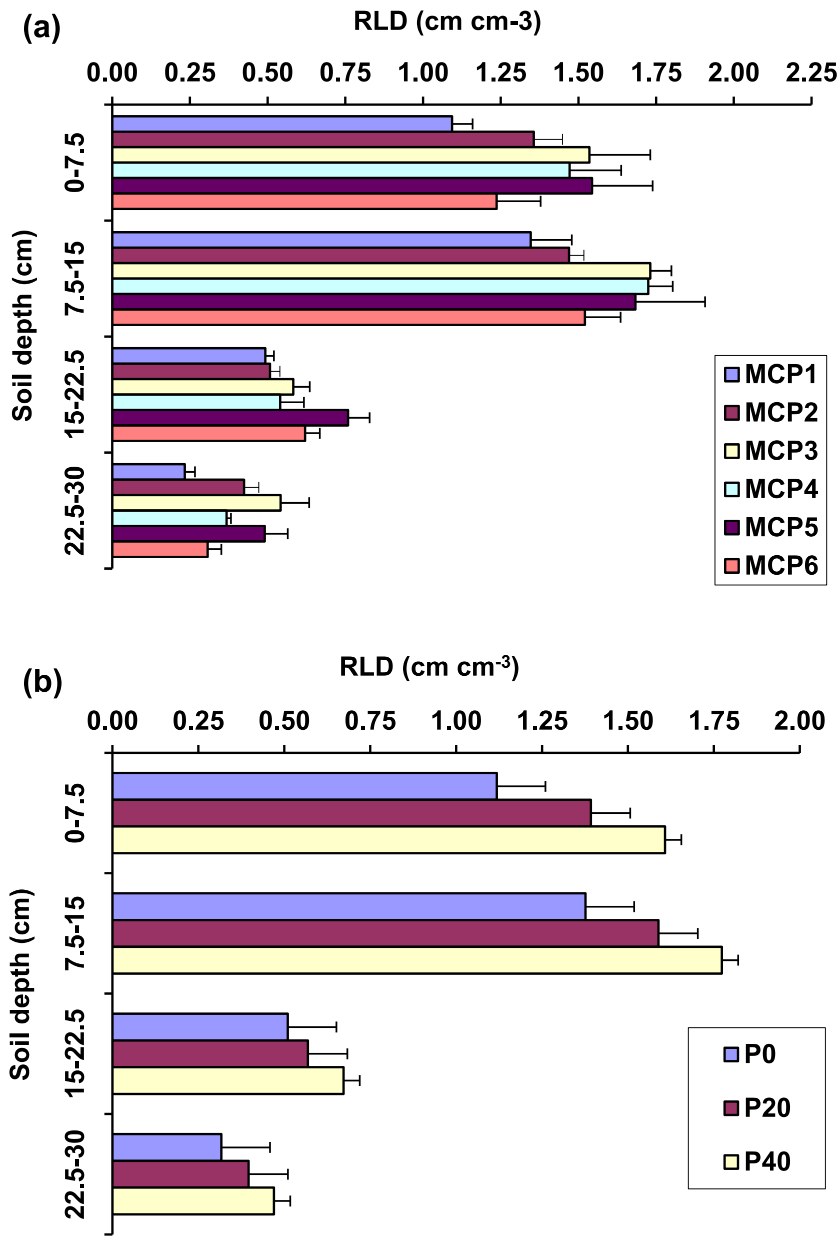


Fig. 6 **a** Root length density (RLD) of chickpea as affected by soil moisture conservation treatments at pod filling stage during 2006–07. MCP_1: Control, MCP_2: *Gliricidia* cover in the standing maize, MCP_3: *Gliricidia* cover in the standing maize + maize stover, MCP_4: Interculture + *Gliricidia* cover + maize stover, MCP_5: *Gliricidia* cover +pre-sowing irrigation, MCP_6: *Gliricidia* cover in the standing maize + no-tillage. **b** Root length density (RLD) of chickpea as affected by doses of phosphorus at pod filling stage during 2006-07. MCP_1: Control, MCP_2: *Gliricidia* cover in the standing maize, MCP_3: *Gliricidia* cover in the standing maize + maize stover, MCP_4: Interculture + *Gliricidia* cover + maize stover, MCP_5: *Gliricidia* cover +pre-sowing irrigation, MCP_6: *Gliricidia* cover in the standing maize + no-tillage

more effective in conserving soil moisture and increasing crop growth. The cumulative ET was higher in treated plots compared to control; highest being in *Gliricidia* cover + pre-sowing irrigation (MCP5) followed by late interculture+ *Gliricidia* cover+ maize stover (MCP4). In the normal monsoon years, the yield advantage in maize due to best treatments (MCP4) was to the tune of 16% when compared to control, whereas the same in deficit years was 19.5%.

Chickpea Yield

Under normal monsoon conditions such as normal onset time, distribution and cessation time (Year 2003–04, 2005–06 and 2006–07), the soil moisture conservation practices proved useful in producing higher chickpea yields in the range of 734–1157 kg ha^{-1}, in comparison with control that ranged from 569 to 817 kg ha^{-1} (Table 4). The grain yield of chickpea in deficit years (year 2002–03 and 2004–05) in treated plots was low in the range of 212–767 kg ha^{-1}, whereas the same in control plots was recorded to be only 125–190 kg ha^{-1}. Among treated plots, the grain yield was the highest in *Gliricidia* cover + pre-sowing irrigation treatment (MCP5) and late interculture + *Gliricidia* cover + maize stover (MCP4). Under normal monsoon years, the best treatments (MCP4 and MCP5) recorded around 46% higher chickpea yield as compared to control. In deficit monsoon years, though the overall yield levels were low, still the best treatments

Table 2 Soil aggregation and water stable aggregates as influenced by moisture conservation practices and phosphorus application after five crop cycles at 0–15 cm depth

Moisture conservation practices/*P* levels (kg P_2O_5 /ha)	MWD (mm)				WSA (%)			
	P0	P20	P40	Mean	P0	P20	P40	Mean
MCP_1	0.59	0.63	0.75	0.66 ± 0.05^{cd}	62.97	68.44	72.34	67.91 ± 2.72^{bc}
MCP_2	0.67	0.67	0.70	0.68 ± 0.01^{cd}	63.89	68.41	71.50	67.93 ± 2.21^{bc}
MCP_3	0.66	0.71	0.73	0.70 ± 0.02^{bc}	67.91	68.49	73.00	69.80 ± 1.61^{ab}
MCP_4	0.70	0.71	0.80	0.74 ± 0.03^{ab}	70.68	71.34	73.01	71.68 ± 0.69^{a}
MCP_5	0.75	0.75	0.78	0.76 ± 0.01^{ab}	70.75	71.54	72.33	71.54 ± 0.45^{a}
MCP_6	0.60	0.74	0.84	0.72 ± 0.07^{bc}	66.52	70.11	70.65	69.09 ± 1.30^{ab}
Mean	0.68^{bc}	0.70^{b}	0.77^{a}		67.24^{b}	69.64^{b}	72.43^{a}	

MCP1: Control, MCP2: Gliricidia cover in the standing maize, MCP3: Gliricidia cover in the standing maize + maize stover, MCP4: Interculture + Gliricidia cover + maize stover, MCP5: Gliricidia cover + pre-sowing irrigation, MCP6: Gliricidia cover in the standing maize + no-tillage

Table 3 Maize grain yield (kg ha^{-1}) as affected by moisture conservation practices (MCPs)

	Year 1 (2002–03)	Year 2 (2003–04)	Year 3 (2004–05)	Year 4 (2005–06)	Year 5 (2006–07)
Moisture conservation practices (MCPs)					
MCP_1	2103^{e}	2480^{c}	3411^{de}	2165^{d}	2125^{c}
MCP_2	2325^{cd}	2876^{ab}	4113^{a}	2307^{bc}	2345^{ab}
MCP_3	2545^{b}	2968^{ab}	4108^{ab}	2329^{bc}	2402^{ab}
MCP_4	2602^{a}	3015^{a}	3986^{ab}	2386^{bc}	2455^{ab}
MCP_5	2455^{c}	2812^{ab}	3808^{bc}	2416^{ab}	2479^{a}
MCP_6	2479^{cd}	2907^{ab}	3429^{d}	2422^{a}	2431^{ab}
CD ($P = 0.05$)	165	287	210	170	185

MCP1: Control, MCP2: Gliricidia cover in the standing maize, MCP3: Gliricidia cover in the standing maize + maize stover, MCP4: Interculture + Gliricidia cover + maize stover, MCP5: Gliricidia cover + pre-sowing irrigation, MCP6: Gliricidia cover in the standing maize + no-tillage

*Phosphorus doses were applied only for chickpea crop; MCPs within a column value followed by the same alphabet are not significantly different $P < 0.05$

(MCP4 and MCP5) recorded 3.2 and 4.7 times higher chickpea yields, respectively, in comparison with control. This may be due to exceptionally low yields under control. Among P treatments, grain yield was significantly higher in 40 kg P_2O_5 ha^{-1}, compared to 20 kg P_2O_5 ha^{-1} and no P application.

Water Use Efficiency (WUE)

The mean values of WUE of chickpea (Table 5) were higher (7.64 kg ha^{-1} mm^{-1}) under MCP4, which was on par with MCP5 (7.41 kg ha^{-1} mm^{-1}). Minimum value of WUE (5.68 kg ha^{-1} mm^{-1}) was recorded under control (MCP1). When compared for various P doses, the highest WUE was recorded under P40 (7.59 kg ha^{-1} mm^{-1}) followed by P20 (6.78 kg ha^{-1} mm^{-1}) and minimum under P0 (5.93 kg ha^{-1} mm^{-1}) (Table 5). Results indicated that different moisture conservation practices in conjunction with variable phosphorus doses enhanced WUE of chick pea grown after maize, which was higher under 40 kg ha^{-1} P_2O_5 followed by 20 kg ha^{-1} P_2O_5. The cumulative ET was higher in treated plots as compared to control, highest being observed under MCP4 and MCP5. Our results corroborated with the findings of Zhang et al. [33] and Zhao et al. [34]. More WUE was recorded under the mulches compared to no-mulch which demonstrates the effectiveness of mulch in reducing soil evaporation and increased plant transpiration. Similarly, Chakraborty et al [6] reported that rice husk showed higher yields, lower water use, thereby recording the highest water use efficiency compared to other mulches. Indeed, increase in biomass and grain yield in the mulched plots was also reported by others [5, 20, 31].

Table 4 Chickpea grain yield (kg ha^{-1}) as affected by MCPs

	Effect of moisture conservation practices (MCPs)				
	2002–03	2003–04	2004–05	2005–06	2006–07
Moisture conservation practices (MCPs)					
MCP1	190^{f}	637^{d}	125^{e}	569^{cd}	817^{cd}
MCP2	297^{e}	776^{cd}	212^{cd}	734^{ab}	931^{c}
MCP3	488^{c}	914^{ab}	276^{c}	769^{ab}	1097^{ab}
MCP4	605^{b}	932^{ab}	407^{b}	863^{ab}	1157^{a}
MCP5	730^{a}	933^{a}	767^{a}	869^{a}	1156^{a}
MCP6	322^{d}	836^{ab}	238^{cd}	665^{cd}	881^{cd}
CD ($P = 0.05$)	35	169	75	181	114
P levels (kg P_2O_5 /ha)*					
P0 P_2O_5 /ha	403^{C}	693^{C}	312^{C}	557^{C}	903^{C}
P20	492^{B}	836^{B}	334^{B}	756^{B}	1012^{B}
P40	672^{A}	997^{A}	366^{A}	921^{A}	1104^{A}
CD ($P = 0.05$)	28	51	13	55	65
MCP X P ($P = 0.05$)	NS	NS	NS	NS	NS

MCP1: Control, MCP2: Gliricidia cover in the standing maize, MCP3: Gliricidia cover in the standing maize + maize stover, MCP4: Interculture + Gliricidia cover + maize stover, MCP5: Gliricidia cover +pre-sowing irrigation, MCP6: Gliricidia cover in the standing maize + no-tillage

*Phosphorus doses were applied only for chickpea crop; MCPs within a column value followed by the same lowercase alphabet are not significantly different $P < 0.05$; P levels within a column value followed by the same uppercase alphabet are not significantly different $P < 0.05$

Table 5 WUE of chickpea (kg mm^{-1}) and PUE (kg kg^{-1} P_2O_5 applied) under different moisture conservation practices

	Water use efficiency (WUE)					Phosphorus use efficiency (PUE)			
MCP	2003–04	2004–05**	2005–06	2006–07	Mean	2004–05**	2005–06	2006–07	Mean
MCP1	5.75	2.86	8.46	5.64	5.68	0.90	7.14	3.97	4.00
MCP2	4.98	3.35	10.83	6.95	6.53	1.12	9.06	5.59	5.26
MCP3	6.00	4.36	10.72	6.85	6.98	1.62	9.09	6.71	5.21
MCP4	5.79	5.64	11.21	7.91	7.64	1.46	13.25	6.92	7.21
MCP5	5.73	6.88	10.34	6.70	7.41	1.40	8.35	6.91	5.55
MCP6	5.79	4.17	9.15	6.37	6.37	0.87	10.18	3.11	4.72
P levels (kg P_2O_5 /ha)*									
P0	5.19	4.43	7.56	6.55	5.93	0	0	0	0
P20	5.62	4.59	10.27	6.66	6.78	1.11	9.94	5.60	5.55
P40	6.21	4.62	12.53	6.99	7.59	1.35	9.08	5.48	5.30

MCP1: Control, MCP2: Gliricidia cover in the standing maize, MCP3: Gliricidia cover in the standing maize + maize stover, MCP4: Interculture + Gliricidia cover + maize stover, MCP5: Gliricidia cover +pre-sowing irrigation, MCP6: Gliricidia cover in the standing maize + no-tillage; *phosphorus doses were applied only for chickpea crop; **2004–05 was deficit monsoon year

Phosphorus Use Efficiency (PUE)

Phosphorus use efficiency over the period under study revealed that maximum PUE value of 7.21 kg kg^{-1} P_2O_5 applied was recorded under MCP4 (Table 5). Similar results were reported by Kushwah et al. [15] in soybean–wheat system under Vertisols of Central India. Minimum value was recorded under MCP1 (control) being 4.0 kg kg^{-1} P_2O_5 applied. A comparison of PUE across various MCPs for different P doses revealed that P20 recorded higher PUE of 5.55 kg kg^{-1} P_2O_5 applied, which was at par with PUE under P40 doses (5.30 kg kg^{-1} P_2O_5) applied.

Conclusions

We conclude that the moisture conservation practices integrated with proper root augmenting P nutrition helpes in growing chickpea crop under rainfed maize–chickpea system. Under normal monsoon conditions, the soil moisture conservation practices are useful in obtaining optimum chickpea yields. Even in abnormal monsoon trends, such as drought spells within the season and early cessation of the monsoon, the moisture conservation practices can help in obtaining higher chickpea yield.

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