Received: 2 May 2020 | Accepted: 26 October 2020

DOI: 10.1002/agj2.20534

Agronomy Journal

ARTICLE

Soil Tillage, Conservation, & Management

Effect of conservation agriculture practices on soil quality, productivity, and profitability of peanut-based system of Saurashtra, India

Ram A. Jat[1,2] | **Kiran K. Reddy**[1] | **Raja R. Choudhary**[1] | **Sachin Rawal**[1] | **Bhargava Thumber**[1] | **Nitin Misal**[1,3] | **P. V. Zala**[1] | **R. K. Mathukia**[4]

[1] ICAR-Directorate of Groundnut Research, Junagadh, Gujarat, 362 001, India

[2] ICAR- Indian Institute of Soil and Water Conservation, Research Centre, Vasad, Anand, Gujarat, 388 306, India

[3] School of Agriculture, Lovely Professional Univ., Phagwara, Jalandhar, Punjab 144 411, India

[4] College of Agriculture, Junagadh Agricultural Univ., Junagadh, Gujarat, 362 001, India

Correspondence
Ram A. Jat, ICAR-Directorate of Groundnut Research, Junagadh, Gujarat, 362 001 India
Email: rajatagron@gmail.com

Funding information
Science and Engineering Research Board; Department of Science and Technology, Government of India

Abstract

Moisture stress and low soil fertility are among the most important factors responsible for low productivity and profitability of peanut (*Arachis hypogaea* L.) in India. Conservation agriculture (CA) can delay or minimize moisture stress impacts on crop plants and improve the soil fertility. Hence, a field experiment was conducted at Research Farm of ICAR-Directorate of Groundnut Research, Junagadh, during 2015–2016 and 2016–2017 to evaluate the effects of different CA practices on soil moisture, soil fertility, yield, and profitability of peanut systems. Treatments consisted of four tillage practices in main plots (conventional tillage [CT], minimum tillage [MT], zero tillage [ZT], and rotary tillage [RT]); two residue management practices in sub-plots (residue removal [NR] and residue retention [RR]), and two intercropping systems in sub-sub plots using peanut, pigeonpea [*Cajanus cajan* (L.) Millsp.], and cotton (*Gossypium hirsutum* L.) (peanut+pigeonpea [PP] and peanut+cotton [PC]) systems and replicated thrice. Minimum tillage and residue management practice RR improved soil moisture content, soil porosity, soil organic C, nutrient status (mainly at 0–15 cm), and soil enzymatic activities and decreased soil temperature variation and soil penetration resistance. Minimum tillage and RR resulted in higher financial returns over CT and NR, respectively. Among the cropping systems, PP was found more productive and profitable as compared to PC. Thus, in the light black soils of Saurashtra, India, MT along with RR seems to be a suitable option particularly during the initial years of shifting to CA to retain soil moisture, improve soil fertility, and provide higher financial returns.

1 | INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an important oilseed crop of the world cultivated on over 28.2 M ha with production of 44.2 M t during 2015 (FAOSTAT, 2020). In India, peanut is the third most important oilseed crop, contributing nearly 26% to the total oilseed production in the country (average

Abbreviations: CA, conservation agriculture; CT, conventional tillage; DAS, days after sowing; MT, minimum tillage; NR, no residue; PC, peanut+cotton system; PP, peanut+pigeonpea system; RR, residue retention; RT, rotary tillage; SMBC, soil microbial biomass carbon; SOC, soil organic carbon; SOM, soil organic matter; TPF, triphenyl formazan; ZT, zero tillage.

of 2014–2015 to 2016–2017; NMOOP, 2020). Peanut is also rapidly emerging as a supplementary food crop due to its high nutritive value (Nigam, 2015). Peanut is a good source of high-quality edible oil; easily digestible protein; carbohydrates; and vitamins E, K, and B-complex (Settaluri, Kandala, Puppala, & Sundaram, 2012). However, the national average productivity of peanut in India was only 1.4 t ha^{-1} in 2015, as compared to 4.4 t ha^{-1} in the United States and 3.6 t ha^{-1} in China (FAOSTAT, 2020). Moisture stress under rainfed conditions (~80% area) and its cultivation on low-fertility soils are among the most important factors responsible for low peanut yields in India (Ramakrishna, Tam, Wani, & Long, 2006). Moisture stress not only adversely affects growth and yield of peanut but also causes pod losses in the soil during harvesting due to soil compaction in light black soils (Jain, Meena, & Bhaduri, 2017). Continuous cultivation in rainfed systems, particularly in the case of peanut, where almost all the biomass is removed from the field, decreases soil C content affecting long-term sustainability of the production systems (TojoSoler et al., 2011). Tillage not only exacerbates oxidation of soil organic matter (SOM) but also increases the cost of production (Jat, Sahrawat, Kassam, & Friedrich, 2014). Hence, production technologies that maintain high soil moisture content reduce soil compaction and increase soil SOM and fertility will be helpful to increase peanut yield in rainfed systems in the study region.

Core Ideas

- MT and RR maintain higher soil moisture content and moderates soil temperature variations.
- MT and RR improve soil quality and fertility.
- MT gives similar or higher crop yields but gives higher net returns over CT.
- PP system provides higher system yield and net returns over PC system.

Conservation agriculture (CA), based on minimum mechanical soil disturbance, soil cover with crop residues or cover crops, and diversified cropping systems, is well known to address the issues related to moisture stress and soil fertility constraints (Jat et al., 2014; Kassam, Friedrich, & Derpsch, 2018). Conservation agriculture protects crops by decreasing intensity and frequency of water stress (Hobbs & Govaerts, 2010). Under CA, surface-lying residues help maintain higher available soil moisture content by facilitating more water intake, increase water holding capacity, and decreasing evaporation loss (Scopel, Da Silva, Corbeels, Affholder, & Maraux, 2004; Shaxson, Kassam, Friedrich, Boddey, & Adekunle, 2008). Low soil temperatures due to mulching with residues further help decrease evaporation rate (Acharya, Kapur, & Dixit, 1998; Oliveira et al., 2001). Residue retention combined with minimum mechanical soil disturbance under CA builds up SOM, although the rate is climate, soil, and management dependent (Jat, Wani, & Sahrawat, 2012). Improved SOM and aggregation at the soil surface also leads to increased nutrient use efficiency (Franzluebbers, 2002). Conservation agriculture sustains soil fertility as a result of reduced runoff and leaching losses of nutrients (Scopel et al., 2004), release of nutrients from residues (Carpenter-Boggs, Stahl, Lindstrom, & Schumacher, 2003), and increased activity of soil microorganisms (Nurbekov, 2008). Supply of CA machinery, availability of crop residues, weed management, and lack of experience are the major limitations to adoption of CA in rainfed systems in the country (Bhan & Behera, 2014).

Intercropping of pigeonpea [*Cajanus cajan* (L.) Millsp.] and cotton (*Gossypium hirsutum* L.) with peanut are popular systems in several parts of India, including in the study region (Jain, Jat, Meena, & Chakraborty, 2018; Singh, Ahlawat, & Kumar, 2013; Singh, Ahlawat, & Sharma, 2015). Farmers prefer intercropping in rainfed systems because it provides succor against risk of crop failure, as drought is a common feature in the region, and gives higher productivity, financial returns, and resource use efficiency in normal years (Jain et al., 2017; Tiwari, Sharma, & Singh, 2011). Burning of pigeonpea and cotton residues is a common practice among farmers, which otherwise may be retained as mulching material and soil conditioners. This provides good opportunity to promote CA because otherwise low biomass production in rainfed systems is one of the major constraints to adoption of CA. To date, no previous attempts have evaluated the effects of CA-based practices in peanut-based cropping systems in the country. Therefore, the objectives of the present study were to evaluate the effects of CA-based practices on soil moisture content, soil quality, yield, and profits.

2 | MATERIALS AND METHODS

2.1 | Experimental site and weather

The experiment was conducted at the Research Farm of ICAR-Directorate of Groundnut Research, Junagadh, Gujarat, India (70°36' E, 21°31' N; 60 m asl) during two consecutive seasons of 2015–2016 and 2016–2017. Mean maximum and minimum temperatures were 36.4 and 36.8 ˚C and 22.2 and 20.6 ˚C during the growing seasons of 2015–2016 and 2016–2017, respectively. Total rainfall was 734 and 1,125 mm during 2015–2016 and 2016–2017, respectively. Detailed weather information is given in Figure 1.

Soil at the experimental site was a Typic haplustepts (sand 29%, silt 15%, clay 56%), moderately calcareous (28.9% $CaCO_3$), moderately alkaline (pH 8.4) with electrical

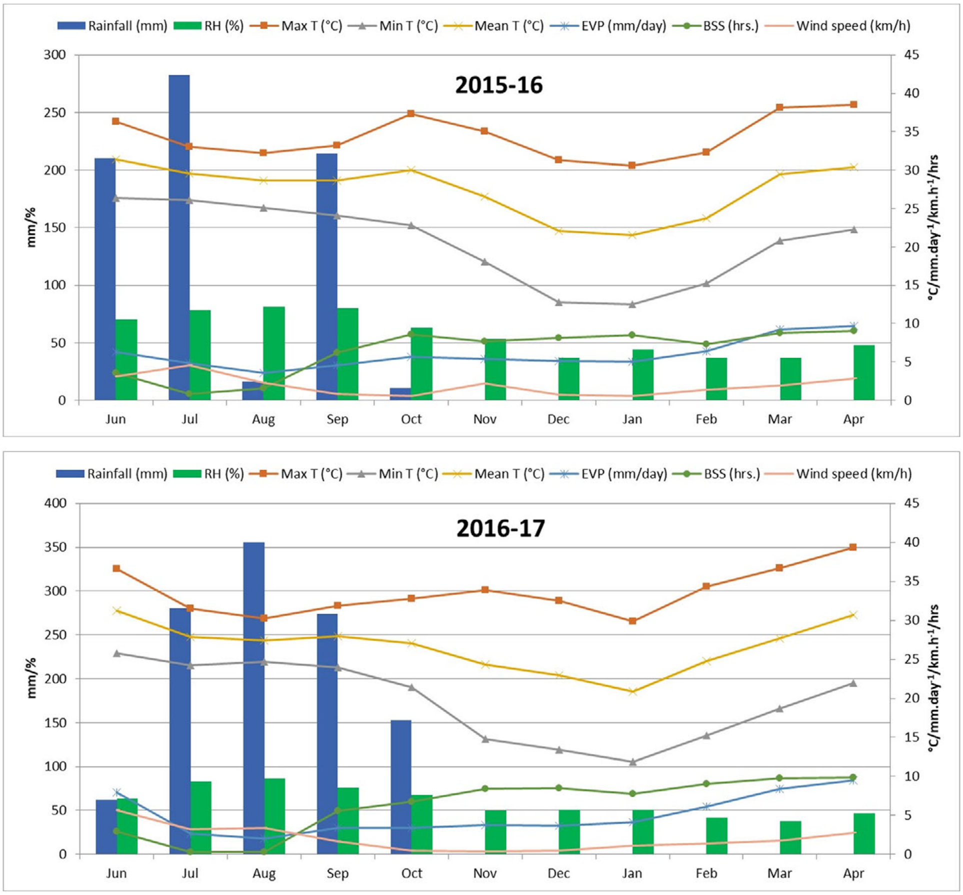

FIGURE 1 (a) Rainfall, relative humidity (RH), maximum temperature, minimum temperature, mean temperature (mean T), evapotranspiration (EVP), bright sunshine (BSS), and wind speed during 2015–2016. (b) Rainfall, RH, maximum temperature, minimum temperature, mean T, EVP, BSS, and wind speed during 2016–2017.

conductivity of 0.44 dS m^{-1}, medium in organic C (6.6 g kg^{-1}), low in available N (190 kg ha^{-1}) and P_2O_5 (13.7 kg ha^{-1}), and medium in K_2O (280 kg ha^{-1}). The experimental field was maintained as fallow for 5 yr preceding our study. Additional details of soil properties are given in Table 1.

2.2 | Experimental design and crop management

The treatments were four tillage practices in main plots (conventional tillage [CT], minimum tillage [MT], zero tillage [ZT], and rotary tillage [RT]) and two residue management practices in sub-plots (residues removed [no residue, NR] and residues retained [RR], and two intercropping systems in sub-sub plots (peanut+pigeonpea [PP] and peanut+cotton [PC]). The experiment was laid out in split-split plot design with three replications. Crops were grown based on recommended practices in the region (JAU, 2020), except for the treatments in the study (Table 2). The experimental field was prepared in January 2015 for the study, and a crop of vegetable clusterbean (*Cyamopsis tetragonoloba* L.) was grown during summer 2015 before commencement of the study. This allowed us to execute tillage treatments from the very first year of the study. The CT plots were prepared using a cultivator twice followed by planking and leveling. In MT, a cultivator was only used once. In RT, a cultivator was used once, followed by one pass of a rotavator to prepare the plots. No tillage operation was done before sowing of crops in ZT. In the second year of the study, tillage operations were done as per treatments just after the harvesting of pigeonpea/cotton crop when some residual soil moisture was available in the soil to facilitate tillage operations. Sowing of crops was done manually in rows opened at 30-cm spacing. Peanut and cotton were sown on 18 June, and pigeonpea was relay intercropped on 18 July in both years of study. Peanut and intercrops of pigeonpea and cotton were established at a 3:1 ratio (i.e., after every three rows of peanut, one row of pigeonpea/cotton was sown). Spacing of peanut, pigeonpea, and cotton was 30 × 10 cm, 120 × 15 cm, and 120 × 30 cm, respectively. Weeds were controlled by pre-emergence application of pendimethalin (800 g a.i. ha^{-1}) followed by manual weeding at 25 and 45 d after sowing (DAS) of peanut. In pigeonpea and cotton, one manual weeding was done 30 d after harvesting of peanut.

TABLE 1 Soil physicochemical properties of experimental site prior to experimentation

Soil properties	Value	Methodology
Soil pH	8.4	pH meter (Richards, 1954)
EC, dS m^{-1}	0.44	EC meter (Jackson, 1974)
Organic C, g kg^{-1}	6.6	Walkley–Black method Jackson (1974)
Total N, kg ha^{-1}	1,486.0	AOAC (1995), Kjeldahl method
Available N, kg ha^{-1}	190.0	alkaline $KMnO_4$ method (Subbaiah & Asija, 1956)
Available P, kg ha^{-1}	13.7	Olsen's method (Olsen et al., 1954)
Available K, kg ha^{-1}	280.0	flame photometric method (Jackson, 1974)
Ca and Mg, meq L^{-1}	360.0	Richards (1954)
S, kg ha^{-1}	32.4	terbidometric method (Chaudhary & Cornfield, 1966)
EDTA extracted Fe, mg kg^{-1}	1.9	Lindsay & Norvell (1978)
EDTA extracted Mn, mg kg^{-1}	1.4	
EDTA extracted Zn, mg kg^{-1}	0.3	
EDTA extracted Cu, mg kg^{-1}	0.7	
Water soluble B, mg kg^{-1}	0.7	Page (1982)

Note. EC, electrical conductivity; EDTA, ethylenediamine tetraacetic acid.

TABLE 2 Cost of key inputs and outputs used for economic analysis in peanut-based cropping systems

Particulars	Peanut, 2015	Pigeonpea, 2015–2016	Cotton, 2015–2016	Peanut, 2016	Pigeonpea, 2016–2017	Cotton, 2016–2017
MSP, INR kg $grain^{-1}$	40.3	46.2	38.0	45.0	50.5	41.0
Haulm, INR kg $grain^{-1}$	4.0	–	–	4.0	–	–
Seed, INR kg^{-1}	65	150	800	65	150	800
Urea, INR kg^{-1}	6.3	6.3	6.3	6.3	6.3	6.3
SSP, INR kg^{-1}	8.0	8.0	8.0	8.0	8.0	8.0
MoP, INR kg^{-1}	18.0	18.0	18.0	18.0	18.0	18.0
Electricity, INR kWh^{-1}	3.13	3.13	3.13	3.27	3.27	3.27
Diesel, INR L^{-1}	45.2	45.2	45.2	46.4	46.4	46.4
Labor, INR $person^{-1}$ d^{-1}	200	200	200	240	240	240

Note. INR, Indian rupees; MoP, muriate of potash; MSP, minimum support price; SSP, single super phosphate.

In NR, all the crop residues were removed from the field after harvesting of economic produce. In the first year of the study, pigeonpea and cotton residues were outsourced from the farmers' field. Residues (5 t ha^{-1} of each) were spread on the soil surface before tillage operations after manually cutting into smaller pieces of ~5.0 cm size. However, as mechanical shredding of cotton stalks is prevalent in the region, the labour price on manual cutting of residues was adjusted accordingly. In CT, MT, and RT, residues were incorporated in the soil but remained on the surface in ZT. In the second year, pigeonpea and cotton residues were retained in the field in RR. Peanut haulm was removed for use as fodder in all the treatments. Pigeonpea was relay sown 30 DAS of peanut, and cotton was sown at the same time that peanut was sown. The entire recommended dose of N, P_2O_5, and K_2O of peanut (25–50–30 kg ha^{-1}) and pigeonpea (25–50–40 kg ha^{-1}) was applied at the time of sowing. In cotton (240–50–150 kg ha^{-1}), all P and K and half of the N requirement was applied at the time of sowing, and the remaining N requirement was applied in two equal splits (i.e., 60 kg ha^{-1} each) at 30 and 60 DAS. Sources of N, P_2O_5, and K_2O were urea, single super phosphate, and muriate of potash, respectively. Peanut was mainly rainfed, but supplemental irrigation was applied as needed during dry spells. Pigeonpea and cotton were given four irrigations after harvesting of peanut.

2.3 | Sampling and measurement

2.3.1 | Soil moisture

To determine soil moisture content, soil samples were taken from the 0-to-15- and 15-to-30-cm depths at different times coinciding with pod formation, seed formation, and harvest stages of peanut in 2015 and 2016. The soil moisture content was estimated by gravimetric method following the standard procedure laid out by Wani et al. (1999), expressed in percent, and pooled for the two seasons.

2.3.2 | Soil temperature

Soil temperature was measured using mercury-in-glass soil thermometer (R-tek) at 7.5 cm soil depth. Observations were taken twice a day at 10:30 a.m and 2:30 p.m. at different dates at around 20% soil moisture content during the growing season of peanut in 2016.

2.3.3 | Soil porosity

Soil porosity was determined mathematically using soil bulk density and particle density at the 0-to-15-cm and the 15-to-30-cm depths after harvest of pigeonpea and cotton in 2016–2017. Bulk density and particle density of soil was determined using a core sampler and a pycnometer, respectively.

$$\text{Porosity}\,(\%) = \left[1 - \frac{\text{Bulk density of soil}}{\text{Particle density of soil}}\right] \times 100$$

2.3.4 | Soil penetration resistance

Soil penetration resistance was measured following Bengough (1991) after harvest of intercrops of pigeonpea and cotton in 2016–2017. A soil penetration resistance meter (cpII 40, Rimik) was inserted into the soil up to the depth of 22 cm at 1 wk after irrigation. Surface-lying residues and crop stubbles were removed around the point of insertion.

2.3.5 | Soil organic C

A modified Walkley and Black (1934) protocol was used for estimation of soil organic C (SOC) in soil samples taken from the 0-to-15-cm and the 15-to-30-cm depths after harvest of pigeonpea and cotton in 2016–2017. Briefly, 1 g of soil sample was placed in a 500-ml conical flask, and 10 ml of 1 N $K_2Cr_2O_7$ and 20 ml of concentrated H_2SO_4 was added. The mixture was left aside for 30 min. Subsequently, 200 ml of water was added along with 10 ml of 70% H_3PO_4, 10 ml of 2% NaF, and 2 ml of diphenylamine (dissolved 0.5 g in 20 ml of water, to which 100 ml of concentration H_2SO_4 was added). Titration was done with 0.5 N ferrous ammonium sulfate. A blank without soil was run simultaneously.

$$\text{SOC}\,(\%) = (10/\text{blank}) \times (\text{blank} - \text{reading}) \times (0.003 \times 100/\text{wt. of soil})$$

2.3.6 | Available N, P_2O_5, and K_2O in soil

To estimate available N, P_2O_5, and K_2O, soil samples were taken from the 0-to-15-cm and 15-to-30-cm depths after harvest of pigeonpea and cotton in 2016–2017. The soil samples were dried, ground, and passed through a 2-mm sieve. Available N was estimated following Subbaiah and Asija (1956), P_2O_5 as per Olsen, Cole, Watanabe, and Dean (1954), and K_2O as per Hanway and Heidal (1952).

2.3.7 | Soil microbial biomass C

Soil microbial biomass C (SMBC) was determined as per the procedure given by Vance, Brookes, and Jenkinson (1987). Soil samples were taken 30 DAS of peanut at the 0-to-15-cm and the 15-to-30-cm depths in both years of the study. Air-dried soil (20 g) was fumigated with 50 ml of ethanol-free chloroform in a desiccator. Ethanol-free chloroform was prepared by passing 100 ml chloroform through a glass column containing 75 g basic aluminum oxide. After 24 h of fumigation at 25 ˚C, chloroform was removed by repeated evacuations. The fumigated soil samples were extracted with 80 ml of 0.5 M K_2SO_4 for 30 min on a rotary shaker at 160 rpm and filtered. Then 8 ml of filtrate was refluxed with 2 ml of $K_2Cr_2O_7$ and 15 ml of diacid mixture (H_2SO_4:H_3PO_4::2:1) for 30 min on a hot plate at 150 ˚C with three drops of phenanthroline indicator solution. After cooling, the mixture was titrated with ferrous ammonium solution. A similar procedure was followed for non-fumigated soil samples except that these samples were not fumigated.

2.3.8 | Soil enzymatic activities

Soil enzymatic activities were determined at 30 DAS of peanut in both years of the study. Moist soil samples were taken from the 0-to-15-cm depth, passed through a 2-mm sieve, and analyzed for enzymatic activities. Dehydrogenase activity in soil was determined by the colorimetric procedure of Tabatabai (1994). During this procedure, formation of triphenyl formazan (TPF) takes place from reduction of 2,3,5-triphenyltetrazolium chloride. A 1.0-g sample of moist soil was placed in a screw-cap tube to which 0.2 ml of 3% 2,3,5-triphenyltetrazolium chloride and 0.5 ml of 1.0% glucose were added. The content was mixed well, followed by incubation for 24 h at 35 ˚C. After 24 h, the tubes were removed, and 10 ml of methanol was added, mixed, and placed in a refrigerator for 3 h to allow settling down of soil particles and better extraction of TPF. The red color of TPF was determined at 485 nm and expressed as µg triphenyl formazon g^{-1} soil h^{-1}.

The procedure of Tabatabai (1994), with modifications from Schinner, Ohlinger, Kandeler, and Margensin (1996), was used to determine alkaline phosphatase activities in soil. A 1.0-g sample was taken to which 4 ml of 0.25% p-nitrophenyl phosphate in a borax-NaOH buffer (pH 9.4) were added. Flasks swirled for a few minutes to thoroughly mix the contents, followed by incubation for 1 h at 37 °C. The suspension was filtered through Whatman No. 42 filter paper, followed by the addition of 1 ml of $CaCl_2$ followed by 4 ml of NaOH. The volume was made up to 50 ml with distilled water, and intensity of yellow color was measured on a ultraviolet/visible spectrophotometer at 420 nm. Results were expressed as µg p-nitrophenol g^{-1} soil h^{-1}.

2.3.9 | Yield and system productivity

Peanut was harvested from a 2.0 × 8.0 m^2 area in each plot and sun-dried for 4–5 d, and total biomass was recorded. The pods were stripped, gleaned, and weighed after drying to 12% moisture content. To get haulm yield, pod yield was subtracted from the total dry biomass weight of each net plot. Pigeonpea and cotton were harvested from a 3.0 × 9.0 m^2 area. Pigeonpea harvested from 3.0 × 9.0 m^2 area excluding the border rows was sun-dried for 5 d in the field, and total dry biomass yield was recorded. The seeds were threshed manually and weighed separately from each plot after oven drying to 10% moisture to get grain yield. Grain yield was deducted from the total dry biomass yield to obtain the stover yield. Likewise, seed cotton was hand picked from a 3 × 9 m^2 area excluding the border rows four or five times during the season, dried to 8% moisture content, and weighed to get seed cotton yield from each individual plot. After last picking of seed cotton, plants were harvested and sun-dried in the field for 1 wk, and their dry biomass was recorded to obtain the stalk yield of cotton. System productivity was calculated as peanut pod equivalent yield using following formula:

$$\text{Peanut pod equivalent yield} = \frac{(\text{Seed cotton yield OR Pigeonpea grain yield} \times \text{Price of seed cotton OR Pigeonpea grain})}{\text{Price of peanut pod}}$$

2.3.10 | Net returns and benefit cost ratio

Net returns were calculated by subtracting the cost of cultivation from the gross returns. The cost of cultivation included expenditure incurred toward inputs (e.g., seed, fertilizers, pesticides, and herbicides) and field operations (e.g., field preparation, sowing, irrigation, weeding, interculturing, pesticide application, harvesting, stripping [peanut], hand picking of cotton bolls, threshing of pigeonpea grains, and other miscellaneous expenses). The gross returns were calculated using price of pods and haulm in peanut, seed cotton, and pigeonpea grains at minimum support price. Details of prices of major inputs and outputs used are provided in Table 2.

2.3.11 | Statistical analysis

SAS version 9.3 (SAS Institute Inc.) was used to conduct ANOVA (Gomez & Gomez, 1984) for split-split plot design. Data were statistically analyzed using F-test. If significant differences were found, the Duncan's multiple range test at the 5% level was performed to compare differences between the treatment means (Duncan, 1955).

3 | RESULTS AND DISCUSSION

3.1 | Weather

Total rainfall received in 2015 was 734 mm, which was sufficient for groundnut. However, rainfall distribution was not uniform, and as a result severe water stress was experienced in the month of August. In 2016 the total rainfall was 1,125 mm, which was higher than the average annual rainfall of the study site (953.5 mm), but monsoon arrived late, and therefore very low rainfall was received in the month of June.

3.2 | Soil moisture

Soil moisture content was significantly affected by the tillage and residue management practices and cropping systems (Figure 2). Both ZT and MT, being at par, had higher soil moisture content at podding, seed formation and at harvest compared with CT and RT at the 0-to-15-cm and 15-to-30-cm depths ($p < .05$). This was likely a result of retention of crop residues on the soil surface and reduced trafficking under ZT and MT. The reduced trafficking minimized soil

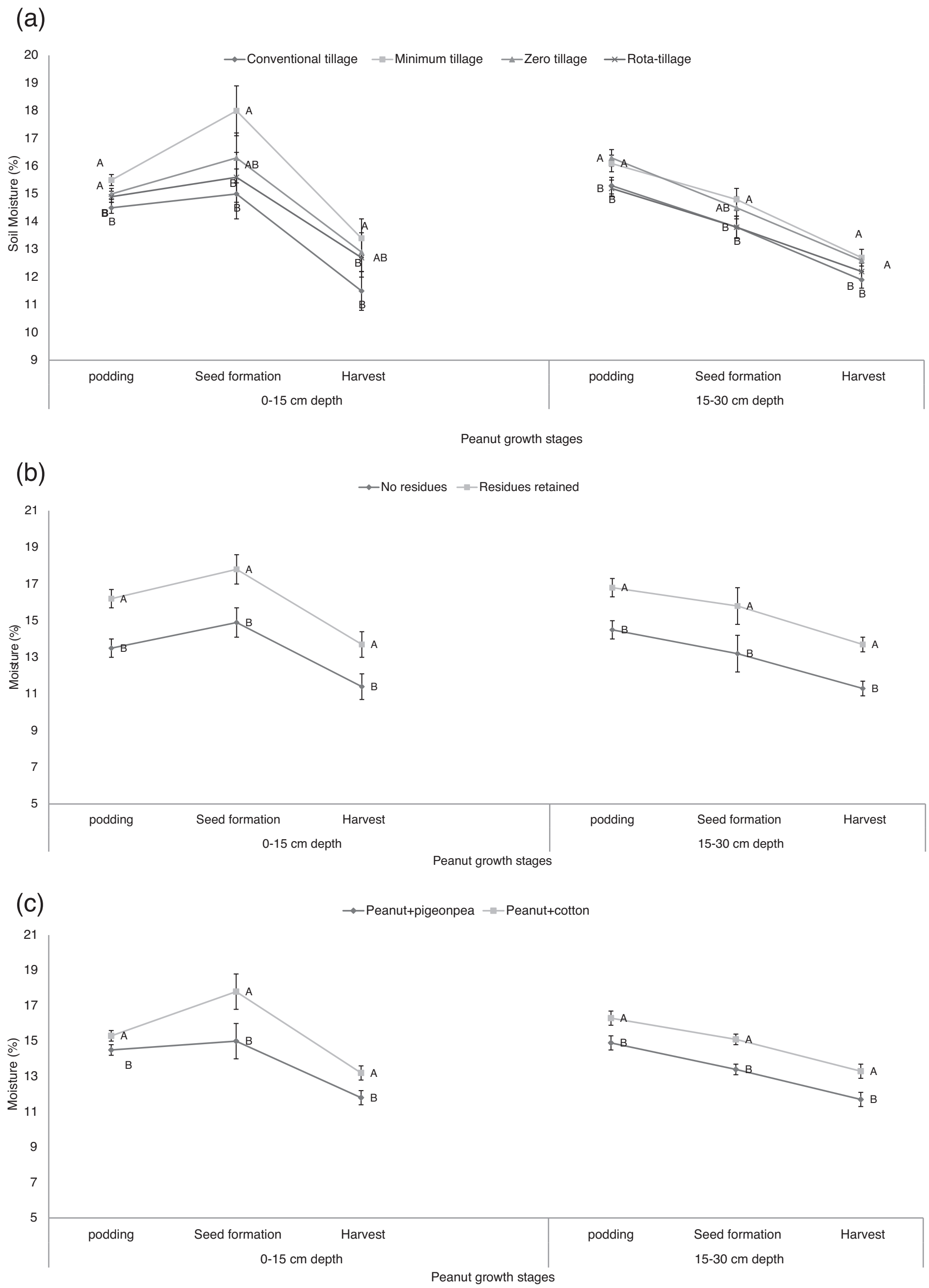

FIGURE 2 (a) Effect of tillage practices on soil moisture content in peanut (mean of 2015 and 2016). (b) Effect of residue management practices on soil moisture content in peanut (mean of 2015 and 2016). (c) Effect of cropping systems on soil moisture content in peanut (mean of 2015 and 2016). Similar letters (at same growth stage) indicate no statistically significant difference; different letters (at same growth stage) indicate statistically significant differences ($P < .05$ DMRT)

compaction and increased the soil porosity, especially in the lower layer, which facilitated greater water infiltration into the soil. Bhatt (2017) and Jat et al. (2015) also found higher soil moisture content under ZT and MT, respectively, over CT. Residue retention improved soil moisture content at both the depths at podding, seed formation and at harvest as compared to NR ($p < .05$). These results corroborate the findings of Salahin et al. (2017), who reported higher soil moisture content with residue retention. Greater surface cover by crop residues has been shown to enhance soil moisture content by increasing infiltration and reducing evaporation (Thierfelder & Wall, 2009). Scopel et al. (2004) and Shaxson et al. (2008) reported that retention of crop residues improves not only water infiltration but also soil water holding capacity.

Among the cropping systems, higher soil moisture content was found with PC as compared to PP at podding, seed formation and at harvest at depths of 0–15 and 15–30 cm ($p < .05$). The greater stomatal conductance, higher biomass, and deeper and extensive root system of pigeonpea removed more soil water content as compared to cotton (Balde et al., 2011). Soil moisture was low at lower depth (15–30 cm) across the stages due to the presence of porous calcareous material, which has poor water holding capacity.

3.3 | Soil temperature

Data presented in Table 3 reveal that MT resulted in higher soil temperatures at 10:30 a.m.; the lowest temperature was recorded with CT across all the dates ($p < .05$). However, at 2:30 p.m. the lowest soil temperature was recorded with MT, and highest was recorded with CT on all the dates except 29 September ($p < .05$). A similar trend was observed with respect to mean soil temperature. Further, less variation in soil temperature was found with MT, whereas highest was with CT. The greater amount of surface-lying crop residues and the higher soil moisture content were responsible for less soil temperature variation under MT. Soil moisture governs soil temperature behavior by influencing soil heat dissipation down the profile (Ochsnor, Horton, & Ren, 2001). Romero, Bellido, and Bellido (2015) have also reported lower soil temperature with reduced tillage in a rainfed system in vertisols.

Residue retention was found to have higher soil temperature at 10:30 a.m. but lower soil temperature at 2:30 p.m. over NR across all the measurement dates ($p < .05$). Residue retention also had lower soil temperature variation as compared to NR ($p < .05$). This is attributed to the higher soil moisture content (Rengasamy & Churchman, 2009) and mulching effect (Horton, Bristow, Kluitenberg, & Sauer, 1996) of RR. Among the cropping systems, PC had a higher soil temperature at 10:30 a.m. but a lower soil temperature at 2:30 p.m., in addition to having less soil temperature variation, as compared to PP ($p < .05$). This is due to higher soil moisture content under PC and the shading effect of a larger canopy of cotton plants during measurement dates. These results support the findings of Onwuka and Mang (2018). Because pigeonpea was relay sown 30 DAS of peanut, its canopy development was slower as compared to cotton. Soil temperature affects other soil properties, such as biological activities (Conant, Drijber, & Haddix, 2008), organic matter decomposition (Allison, Wallenstein, & Bradford, 2010), CEC (Ubeda, Pereira, & Outeiro, 2009), moisture content (Rengasamy & Churchman, 2009), and aeration (Allison et al., 2010). Further, soil temperature has a profound effect on plant growth by influencing water and nutrient uptake (Onwuka & Mang, 2018) as well as root and shoot growth (Weih & Karlson, 1999).

TABLE 3 Effect of tillage practices, residue management, and cropping systems on soil temperature (7.5 cm depth) in peanut-based cropping systems

Treatments	10:30 a.m.						2:30 p.m.						Variation in mean values
	9 Sept.	15 Sept.	22 Sept.	29 Sept.	10 Oct.	Mean	9 Sept.	15 Sept.	22 Sept.	29 Sept.	10 Oct.	Mean	
Tillage practices													
Conventional tillage	28.2A	28.5B	28.0B	28.6B	28.5B	28.4B	31.7A	31.9A	31.6A	32.0A	30.8A	31.6A	3.3A
Minimum tillage	28.7A	29.7A	29.8A	29.8A	29.7A	29.6A	30.5B	30.8B	30.1B	31.2A	29.0B	30.3B	0.8C
Zero tillage	28.7A	29.5AB	29.7A	29.0A	28.5B	29.1A	30.7A	31.0B	30.5A	30.8A	30.2A	30.6B	1.6B
Rota-tillage	28.5A	29.0AB	26.8B	29.2AB	27.8B	28.3B	31.2A	31.6A	31.6A	31.4A	30.8A	31.3A	3.0A
Residue management practices													
Residues removed	28.2B	28.8B	28.9A	28.5B	27.6B	28.4B	31.8A	31.6A	31.6A	32.0A	31.0A	31.6A	3.2A
Residues retained	28.7A	29.6A	28.6A	29.8A	28.1A	29.0A	30.2B	31.0B	30.4B	30.7B	30.1B	30.5B	1.5B
Cropping system													
Peanut + pigeonpea	28.2B	28.8B	28.1B	28.7B	27.2B	28.2B	31.7A	31.8A	31.8A	31.9A	31.0A	31.6A	3.4A
Peanut + cotton	28.8A	29.6A	29.4A	29.7A	28.6A	29.2A	30.3B	30.8B	30.1B	30.9B	29.4A	30.3B	1.1B

Note. Values followed by the same letters indicate no statistically significant difference; values followed by different letters in the same column indicate statistically significant differences ($P < .05$, DMRT).

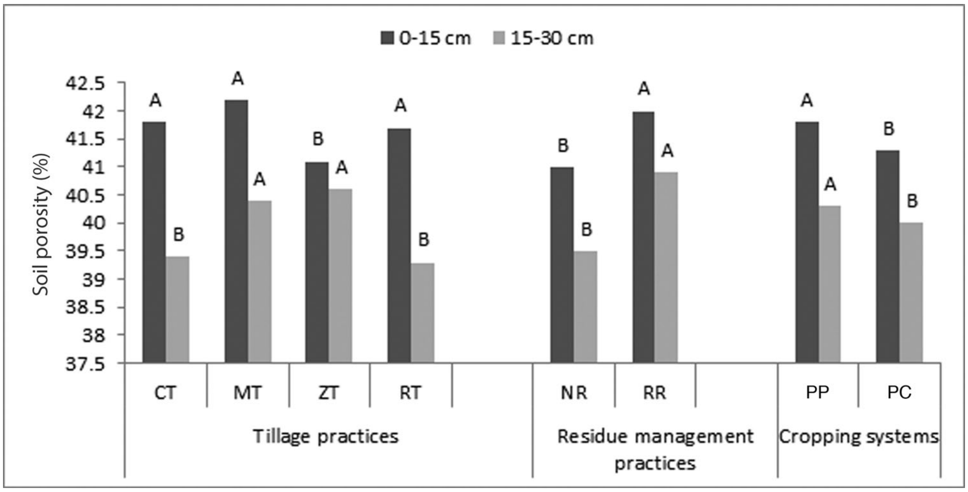

FIGURE 3 Effect of tillage practices, residue management, and cropping systems on soil porosity in peanut-based cropping systems. CN, conventional tillage; PC, peanut+cotton intercropping system; PP, peanut+pigeonpea intercropping system; MT, minimum tillage; NR, residue removal; RR, residue retention; RT, rotary tillage; ZT, zero tillage. Bars with same letters (at same depth) indicate no statistically significant difference; bars with different letters (at same depth) indicate statistically significant differences ($P < .05$ DMRT)

3.4 | Soil porosity

Figure 3 shows that tillage practices, residue management, and cropping systems had significant effects on soil porosity. Soil porosity rates with MT, CT, and RT were similar, but ZT had lower porosity at the 0-to-15-cm depth ($p < .05$). Pulverization due to tillage operations kept the surface layer of soil porous under MT, CT, and RT. In rainfed situations, dry soil conditions may reduce the activity of soil-inhabiting organisms involved in mixing of crop residues. Mixing of crop residues is important to increase the porosity of soil under ZT management (Jat et al., 2012). Due to this fact, lower soil porosity was observed under ZT in the surface layer. However, at the 15-to-30-cm layer, MT and ZT had similar porosity but were higher than both CT and RT. Greater trafficking under CT and RT was the reason for compaction and reduced porosity in lower layer in these tillage systems. Decreased bulk density, due to higher soil organic C content, better aggregation, and increased root growth and biomass, could also be a cause for this (Unger & Jones, 1998). Residue retention improved porosity over NR in both the depths, which is attributed to higher SOM ($p < .05$). Among the cropping systems, PP improved porosity over PC ($p < .05$), which was due to higher root and aboveground biomass of pigeonpea retained in the field.

3.5 | Soil penetration resistance

Soil penetration resistance was lower with MT than CT throughout the various depths ($p < .05$) (Figure 4). This is attributed to higher moisture content and less trafficking under MT. Soil water content is an important factor affecting penetration resistance (Quang, Jansson, & Khoa, 2012). Decreased trafficking reduced the soil compaction. Zero tillage had greater penetration resistance in the upper depths (20–80 mm) compared to CT. However, at lower depths (120–220 mm) lower penetration resistance was found with ZT, which was similar to MT. A lack of pulverization in the absence of tillage caused soil compactness in surface layers under ZT. Martınez, Fuentes, Silva, Valle, and Acevedo (2008) also reported greater soil surface compactness under ZT. Data also revealed that MT and RT had similar penetration resistance values in the upper depths (20–80 mm), but in the lower depths (120–220 mm) RT had greater penetration resistance over all tillage practices. Higher soil compaction with rotary tillage has also been reported by Polat, Saglam, Aydemir, and Qikman (2006) and Mukesh, Rani, and Kumar (2013).

Residue retention had lower soil penetration resistance as compared to NR up to 180 mm depth ($p < .05$) as a consequence of biomass retention, higher moisture content, and improved chemical and biological activities under RR (Thierfelder, Amet́zquita, & Stahra, 2005). No significant difference was found at depths of 200–220 mm. Soil penetration resistance was lower in PP at lower depths (120–220 mm) as compared to PC ($p < .05$), which is attributed to more porous space created by decaying of the deep and extensive root system of pigeonpea.

3.6 | SOC and available NPK

Data given in Table 4 show that SOC of ZT was similar to MT and was higher than CT and RT at both depths, but significant differences were observed at the 0-to-15-cm depth

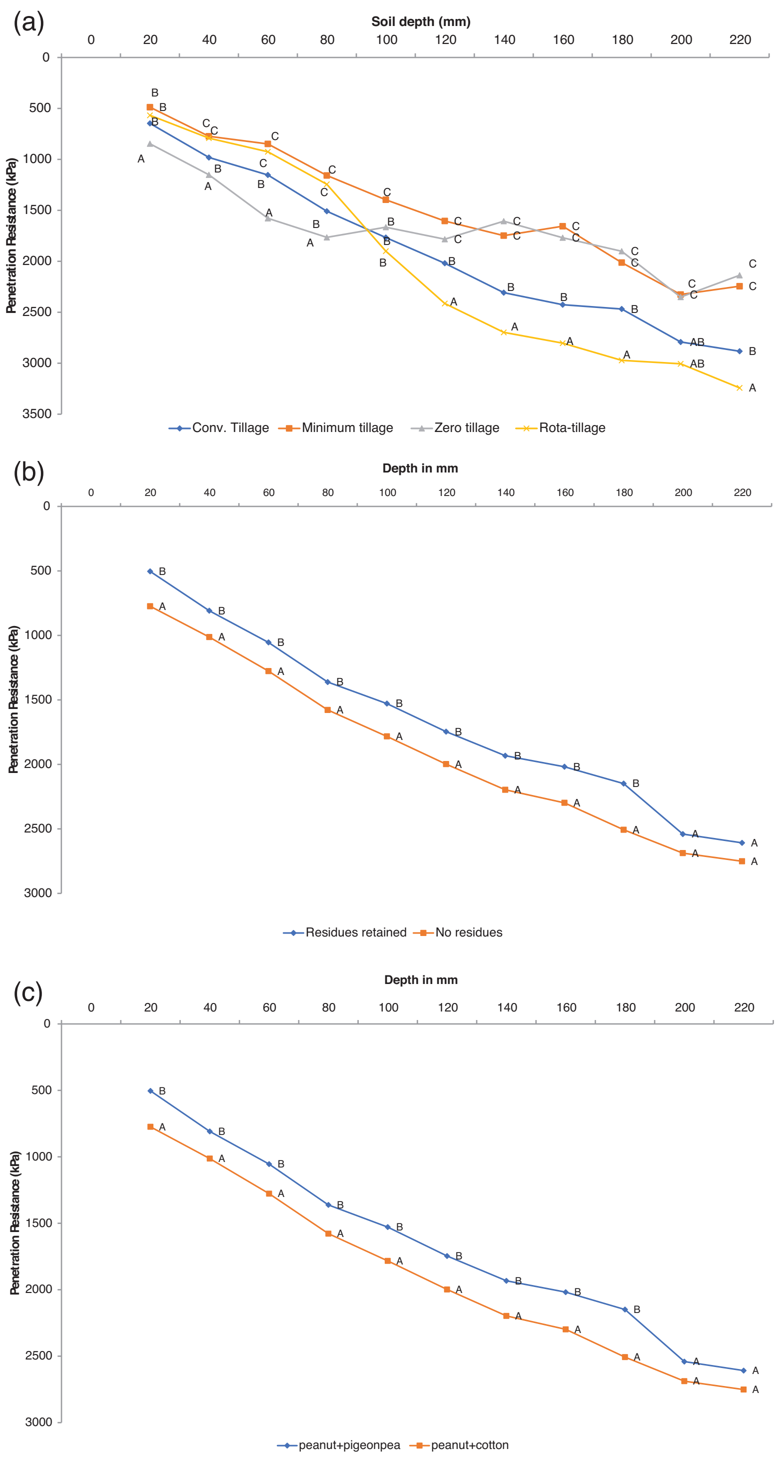

FIGURE 4 (Top) Effect of tillage practices on soil penetration resistance in peanut-based cropping systems. (Middle) Effect of residue management practices on soil penetration resistance in peanut-based cropping systems. (Bottom) Effect of cropping systems on soil penetration resistance in peanut-based cropping systems. Similar letters (at same depth) indicate no statistically significant difference; different letters (at same depth) indicate statistically significant differences ($P < .05$ DMRT)

only. The lowest SOC was found under RT at the 0-to-15-cm depth ($p < .05$). These results are attributed to relatively more soil disruption under CT and RT, intensifying oxidation of SOM (Follet, 2001). On the other hand, ZT and MT increased SOC due to a reduced rate of decomposition of crop residues and plant roots and the continued accumulation of organic matter in the soil by the fauna and flora (Lal, 2010). Available N, P, and K were higher under MT at both depths ($p < .05$) (Table 4). Available N and K were lowest with CT at the 0-to-15-cm depth and with RT at the 15-to-30-cm depth, whereas the lowest available P was recorded with CT in both depths. Improved SOC at the 0-to-15-cm depth and available N in both depths and available potash at the 0-to-15-cm depth was observed with RR over NR, but differences in available P were not significant among the two residue management systems. Conservation agriculture–based practices lead to greater availability of both native and applied nutrients to the crops due to reduced runoff loss of nutrients and release

TABLE 4 Effect of tillage practices, residue management, and cropping systems on soil organic C and available N, P, and K in soil in peanut-based cropping systems

Treatments	Soil organic C		Available N		Available P		Available K	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
	–g kg^{-1}–		–kg ha^{-1}–					
Tillage practices								
Conventional tillage	6.9B	9.8A	178.0B	357.5A	14.6B	12.8B	301.1B	283.7B
Minimum tillage	7.9A	10.0A	227.0A	371.6A	16.7A	18.0A	326.7A	315.0A
Zero tillage	8.0A	10.1A	205.1AB	355.7A	16.7A	14.4B	315.0A	283.4B
Rota-tillage	6.0C	9.7A	214.0AB	314.9B	14.9B	13.7B	309.7B	276.2B
Residue management practices								
Residues removed	6.0B	10.0A	198.9B	333.8B	15.1A	14.6A	305.6B	289.0A
Residues retained	8.9A	11.0A	218.6A	366.0A	15.6A	15.1A	320.7A	290.2A
Cropping systems								
Peanut + pigeonpea	8.6A	11.0A	206.4A	344.2A	15.6A	15.6A	315.3A	285.3A
Peanut + cotton	6.4B	10.0A	211.0A	355.7A	15.3A	14.2A	311.0A	293.9A

Note. Initial values at the 0-to-15-cm depth: soil organic C, 6.6 g kg^{-1}; available N, 190.0 kg ha^{-1}; available P, 13.7 kg ha^{-1}; available K, 280.0 kg ha^{-1}. Values are given for two soil depths (0–15 and 15–30 cm). Values followed by the same letters indicate no statistically significant difference; values followed by different letters in the same column indicate statistically significant differences ($P < .05$, DMRT).

of nutrients from decomposing crop residues (FAO, 2001). Higher SOC was found with PP over PC at the 0-to-15-cm depth due to higher biomass addition through pigeonpea as compared to cotton. However, cropping systems did not significantly affect the available NPK in soil despite higher doses of N and K in cotton compared with pigeonpea. The high amount of N applied to cotton is mostly utilized by cotton, and some is lost into environment through leaching and denitrification (Flis, 2019). On the other hand, biological N fixation is key to the N supply of pigeonpea and enrichment of soil N status (Mhango, Snapp, & Kanyama-Phiri, 2017). Similarly, cotton has a high K requirement for fiber and seed development, leaving very low residual K in soil (Reddy, Hodges, & Varco, 2000).

3.7 | Soil enzymatic activities and SMBC

The mean data indicated that activities of dehydrogenase and alkali phosphatase in soil were higher with MT followed by ZT, and the least were with CT ($p < .05$) (Table 5). Residue retention improved mean activities of dehydrogenase and alkali phosphatase in soil as compared to NR ($p < .05$). Higher activities of enzymes under CA components are attributed to higher SOM and consequent increased microbial activities in soil, as suggested by the higher SMBC content of the soil. Similar results were reported by Madejon, Moreno, Murillo, and Pelegrin (2007) and Tao et al. (2009). Mean activities of alkali phosphatase in soil were higher in PP than PC ($p < .05$).

Mean SMBC was higher with MT and ZT over both RT and CT ($p < .05$) (Table 5). Soil microbial biomass C was improved with RR as compared to NR ($p < .05$). No or reduced tillage and residue retention improves SOC, leading to higher microbial population and hence higher SMBC. Kandeler et al. (2006); Singh, Marwaha, and Kumar (2009) and Mullen, Melhorn, Tyler, and Duck (1998) also observed higher SMBC at higher SOC content. Govaerts et al. (2007) also found higher SMBC with crop residue retention. Further, SMBC was higher with PP than PC ($p < .05$). Higher biomass production, differential lignin composition, and the different C/N ratio of pigeonpea than cotton resulted in significantly varied microbial activities (Zita, Rimantas, & Steponas, 2012).

3.8 | Crop yield and system productivity

Peanut pod yields with RT, CT, and MT were similar and provided higher pod yield and system productivity over ZT ($p < .05$). The highest haulm yield was produced with MT, which was 18.2% higher than CT (Table 6). However, pigeonpea grain yield and seed cotton yields were similar in all the tillage practices. Pigeonpea stalk yield was higher with CT

TABLE 5 Effect of tillage practices, residue management, and cropping systems on soil enzymatic activities and soil microbial biomass C (SMBC) in peanut-based cropping systems

Treatments	Dehydrogenase			Alkaline phosphatase			SMBC		
	2015	2016	Mean	2015	2016	Mean	2015	2016	Mean
	μmol TPF kg^{-1} d^{-1}			μmol PNP g fw^{-1} h^{-1}			μg g^{-1} soil		
Tillage practices									
Conventional tillage	15.8B	15.4A	15.6C	155.3C	176.7C	166.0C	176.9B	119.1B	148.0B
Minimum tillage	22.5A	18.8A	20.7A	162.8A	182.6A	172.7A	243.4A	139.7A	191.6A
Zero tillage	18.2B	16.9A	17.6B	158.7B	179.6A	169.2B	210.1A	116.1B	163.1A
Rota-tillage	16.6B	15.0A	15.8C	159.0B	179.2B	169.1B	188.4B	125.1A	157.0B
Residue management practices									
Residues removed	16.0B	15.0B	15.5B	157.7B	177.9B	167.8B	187.2B	110.0B	148.6B
Residues retained	20.5A	18.1A	19.3A	160.2A	181.1A	170.65A	222.2A	140.0A	181.1A
Cropping systems									
Peanut + pigeonpea	18.1A	16.4A	17.2A	160.0A	181.9A	170.9A	208.7A	149.3A	179.0A
Peanut + cotton	18.5A	16.6A	17.5A	157.9B	177.1B	167.5B	200.8A	100.7B	150.7B

Note. FW, fresh weight; PNP, paranitrophenol; TPF, triphenyl formzan. Values are given for 0–15 cm depth. Values followed by the same letters indicate no statistically significant difference; values followed by different letters in the same column indicate statistically significant differences ($P < .05$, DMRT).

and RT compared with MT and ZT ($p < .05$). The results revealed that overall MT produced similar or higher crop yields as compared to CT. This suggests that CT, which represents an energy-intensive excessive tillage approach, is not essential to achieve higher yield levels of peanut and intercrops of pigeonpea and cotton in the light black soils of Saurashtra. Constable, Rochesrer, and Daniells (1992) and Blaise, Majumdar, and Tekale (2005) have also reported equal or greater yields in other crops with reduced tillage than CT in Vertisols. Minimum tillage has been reported to promote root growth, which favors higher nutrient and water uptake by plants (Basuri & Salako, 2015). The higher system productivity with RT was because peanut and cotton responded well to rotary tillage. Significantly lower yield under ZT is attributed to lower plant stand and kernel weight and to more pod losses (data not given here) in soil during harvesting due to hardening of surface layer.

Pod and haulm yield of peanut, grain yield of pigeonpea, seed cotton yield, stalk yield of cotton, and system productivity (expressed as peanut pod equivalent yield) were not significantly affected by residue management practices. Retention of cotton residues had a more favorable effect on productivity as compared to pigeonpea residues. Increase in crop yield with residue retention generally become visible with long-term management when positive effects of residue retention on soil health become more pronounced (Lumpkin & Sayre, 2009). Erenstein (2002) have also reported that the short-term yield effects of CA components are variable over space and time; the productive benefits accumulate over time because mulching prevents or minimizes soil degradation and gradually improves the soil in physical, chemical, and biological properties. Further, pod yield of peanut was not affected by cropping system. However, haulm yield was significantly higher (14.6%) with PC over PP ($p < .05$). System productivity was also significantly higher (15.6%) with PP compared with PC. The lower system productivity with PC was due to lesser seed cotton yield in 2015–2016 due to an attack of whitefly (*Bemisia tabaci*, Gennadius) and pink boll worm (*Pectinophora gossypiella*).

3.9 | Economics

Minimum tillage and RT gave higher financial returns than CT and ZT ($p < .05$). Higher system productivity under RT resulted in higher financial returns compared with ZT. Although system productivity was less than CT, the lower cost of production and the higher haulm yield resulted in better financial returns with MT compared with CT (Table 6). Dogra, Joshi, and Sharma (2002) also reported higher net returns with minimum tillage. Residue retention increased net returns by 13.9% over NR ($p < .05$) due to higher crop yields and lower cost with mechanical residue shred-

TABLE 6 Effect of tillage practices, residue management, and cropping systems on pod and haulm yield of peanut, grain and stalk yield of pigeonpea, seed cotton yield and stalk yield, system productivity, and system net returns (mean data of 2015–2016 and 2016–2017)

Treatment	Peanut		Pigeonpea		Cotton		System productivity	System net returns
	Pod yield	Haulm yield	Grain yield	Stalk yield	Seed cotton yield	Stalk yield		
	kg ha^{-1}							Returns ha^{-1}
Tillage practices								
Conventional tillage	1,448A	1,457B	1,038A	7,257A	1,145A	3,009A	2,828A	52,747B
Minimum tillage	1,336A	1,723A	1,127A	5,344B	1,242A	3,074A	2,741A	55,772A
Zero tillage	1,175B	1,656A	1,163A	5,577B	1,207A	3,024A	2,491B	46,620C
Rota-tillage	1,465A	1,533A	1,031A	6,130A	1,211A	3,112A	2,826A	57,340A
Residue management practices								
Residues removed	1,328A	1,512A	1,038A	6,254A	1,163A	3,014A	2,692A	51,655B
Residues retained	1,384A	1,674A	1,147A	5,900A	1,240A	3,095A	2,759A	54,584A
Cropping system								
Peanut + pigeonpea	1,373A	1,484B	–	–	–	–	2,924A	60,902A
Peanut + cotton	1,339A	1,701A	–	–	–	–	2,526B	45,337B

Note. Values followed by the same letters indicate no statistically significant difference; values followed by different letters in the same column indicate statistically significant differences ($P < .05$, DMRT).

ding over manual cutting and transportation of cotton and pigeonpea stalks under NR. Among the cropping systems, PP gave 34.3% higher net returns over PC ($p < .05$), which is attributed to higher and stable yields of pigeonpea and to the lower cost of intercropping of pigeonpea as compared to cotton.

4 | CONCLUSIONS

Our results indicate that CA-based practices of minimum tillage and residue retention have good potential to improve soil characteristics and to improve yield and financial returns in peanut-based intercropping systems in light black soils of the Saurashtra region of India. Minimum tillage and retention of pigeonpea/cotton residues were more profitable as compared to CT and NR, respectively. Minimum tillage and RR maintained higher soil moisture content and insulated the soil from temperature variations effectively compared to CT and NR, respectively. Further, MT and RR had higher soil organic C content and superior nutrient status in the soil, particularly in surface layers compared with conventional practices. Among the cropping systems, PP was more productive and profitable as compared to the PC.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGMENTS

This work was funded by The Science & Engineering Research Board (SERB), Department of Science & Technology, Government of India and same is highly acknowledged. The authors are thankful to ICAR-DGR, Junagadh for providing the required facilities to complete this study.

AUTHOR CONTRIBUTIONS

Ram A. Jat: Conceived, planned and carried out the field experimets, analysed and interpreted the results and drafted the paper; Kiran K. Reddy: Analyzed the soil samples and contributed in drafting the materials and methods part; Raja R. Choudhary: Contributed in reviewing the literature and paper drafting ; Sachin Raval: Assisted in soil sample analysis; Bhargava Thumber: Assisted in field observations, sample analysis and data entry; Nitin Misal: Assisted in field observations; P.V. Zala: Managed the field trials; R.K. Mathukia: Assisted in statistical analysis of the data.

ORCID

Ram A. Jat https://orcid.org/0000-0003-3611-3624

REFERENCES

AOAC. (1995). *Official methods of analysis of AOAC International*. Arlington, VA: AOAC.

Acharya, C. L., Kapur, O. C., & Dixit, S. P. (1998). Moisture conservation for rainfed wheat production with alternative mulches and conservation tillage in the hills of north-west India. *Soil and Tillage Research*, *46*, 153–163.

Allison, D., Wallenstein, M. D., & Bradford, M. A. (2010). Soil carbon response to warming dependent on microbial physiology. *Nature Geoscience*, *3*, 336–340.

Balde, A. B., Scopel, E., Affholder, F., Corbeels, M., Macena Da Silva, F. A., Xavier, J. H. V., & Wery, J. (2011). Agronomic performance of no-tillage relay intercropping with maize under smallholder conditions in Central Brazil. *Field Crops Research*, *124*, 240–251.

Basuri, M. A., & Salako, F. K. (2015). Soil hydraulic properties and maize root growth after application of poultry manure under different tillage systems in Abeokuta, southwestern Nigeria. *Archives of Agronomy and Soil Science*, *61*, 235–237.

Bengough, A. G. (1991). The penetrometer in relation to mechanical resistance to root growth. In K. A. Smith & C. E. Mullins (Eds.), *Soil analysis: Physical methods* (pp. 431–445). New York: Marcel Dekker.

Bhan, S., & Behera, U. K. (2014). Conservation agriculture in India: Problems, prospects and policy issues. *International Soil and Water Conservation Research*, *2*(4), 1–12. https://doi.org/10.1016/S2095-6339(15)_30053-8

Bhatt, R. (2017). Zero tillage impacts on soil environment and properties. *Journal of Environmental & Agricultural Sciences*, *10*, 1–19.

Blaise, D., Majumdar, G., & Tekale, K. U. (2005). On-farm evaluation of fertilizer application and conservation tillage on productivity of cotton + pigeonpea strip intercropping on rainfed Vertisols of central India. *Soil and Tillage Research*, *84*, 108–117.

Carpenter-Boggs, L., Stahl, P. D., Lindstrom, M. J., & Schumacher, T.E. (2003). Soil microbial properties under permanent grass, conventional tillage, and no-till management in south Dakota. *Soil and Tillage Research*, *71*, 15–23.

Chaudhary, I. A., & Cornfield, A. H. (1966). The determination of total sulphur in soil and plant materials. *Analyst*, *91*, 528.

Conant, R. T., Drijber, R. A., & Haddix, M. C. (2008). Sensitivity of organic matter decomposition to warming varies with its quality. *Global Change Biology*, *14*(4), 868–877.

Constable, G. A., Rochesrer, I. J., & Daniells, I. G. (1992). Cotton yield and nitrogen requirement as modified by crop rotation and tillage method. *Soil and Tillage Research*, *23*, 41–59.

Dogra, P., Joshi, B. P., & Sharma, N. K. (2002). Economic analysis of tillage practices for maize cultivation in the Himalayan humid subtropics. *Indian Journal of Soil Conservation*, *30*(2), 172–178.

Duncan, D. B. (1955). Multiple-range and multiple-F tests. *Biometrics*, *11*, 1–42.

Erenstein, O. (2002). Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. *Soil and Tillage Research*, *67*, 115–133.

FAO. (2001). *Conservation agriculture case studies in Latin America and Africa* (FAO Soils Bulletin No. 78). Rome: FAO.

FAOSTAT. (2020). Crops. Retrieved from http://www.fao.org/faostat/en/#data/QC

Fliss, S. (2019). 4R nitrogen fertilizer management in cotton production. *Crops & Soils Magazine*, *52*, 22–24. https://doi.org/10.2134/cs2019.52.0303

Follet, R. F. (2001). Soil management concepts and carbon sequestration in cropland soils. *Soil and Tillage Research*, *61*, 77–92.

Franzluebbers, A. J. (2002). Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil and Tillage Research*, *66*, 197–205.

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research*. New York: John Wiley & Sons.

Govaerts, B., Mezzalama, M., Unno, Y., Sayre, K.D., Guido, M.L., Vanherck, K., … Deckers, J. (2007). Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. *Applied Soil Ecology*, *37*, 18–30.

Hanway, J., & Heidal, H. S. (1952). Soil analysis methods as used in Iowa State College Soil Testing Laboratory. *Iowa State College of Agriculture Bulletin*, *57*, 1–13.

Hobbs, P. R., & Govaerts, B. (2010). How conservation agriculture can contribute to buffering climate change. In M. P. Reynolds (Ed)., *Climate change and crop production* (pp. 177–199). Wallingford, U.K.: CAB International.

Horton, R., Bristow, R. I., Kluitenberg, G. J., & Sauer, T. J. (1996). Crop residue effects on surface radiation and energy–balance review. *Theoretical and Applied Climatology*, *54*(1–2), 27–37.

Jackson, M. L. (1974). *Soil chemical analysis*. New Delhi: Prentice Hall of India.

Jain, N. K., Meena, H. N., & Bhaduri, D. (2017). Improvement in productivity, water-use efficiency, and soil nutrient dynamics of summer peanut (*Arachis hypogaea* L.) through use of polythene mulch, hydrogel, and nutrient management. *Communications in Soil Science and Plant Analysis*, *48*(5), 549–564. https://doi.org/10.1080/00103624.2016

Jain, N. K., Jat, R. S., Meena, H. S., & Chakraborty, K. (2018). Productivity, nutrient, and soil enzymes influenced with conservation agriculture practices in peanut. *Agronomy Journal*, *110*, 1–8. https://doi.org/10.2134/agronj2017.08.0467

Jat, R. A., Sahrawat, K. L., Kassam, A. H., & Friedrich, T. (2014). Conservation agriculture for sustainable and resilient agriculture: Global status, prospects and challenges. In R. A. Jat, K. L. Sahrawat, & A. Kassam (Eds.), *Conservation agriculture: Global prospects and challenges* (pp. 1–25). Wallingford, U.K.: CAB International.

Jat, R. A., Wani, S. P., Pathak, P., Singh, P., Sahrawat, K. L., … Sudi, R.S. (2015). Evaluating climate change mitigation and adaptation potential of conservation agriculture in semi-arid tropics of southern India. *British Journal of Environment and Climate Change*, *5*(4), 324–338.

Jat, R. A., Wani, S. P., & Sahrawat, K. L. (2012). Conservation agriculture in the semi-arid tropics: Prospects and problems. *Advances in Agronomy*. *117*, 191–273.

JAU. (2020). Recommendations/technology for farmers' community developed by the University during last 15 years (2004-05 to 2018-19). Retrieved from http://www.jau.in/index.php/resources/research-recommendations

Kandeler, E., Mosier, A. R., Morgan, J. A., Milchunas, D. G., King, J. A., Rudolph, S., & Tscherko, D. (2006). Response of soil microbial biomass and enzyme activities to the transient elevation of carbon dioxide in semi-arid grassland. *Soil Biology and Biochemistry*, *38*, 2448–2460.

Kassam, A., Friedrich T., & Derpsch, R. (2018). Global spread of conservation agriculture. *International Journal of Environmental Studies*, *76*, 29–51.

Lal, R. (2010). A dual response of conservation agriculture to climate change: Reducing CO2 emissions and improving the soil carbon sink. Retrieved from http://www.marm.gob.es/es/ministerio/servicios-generales/publicaciones/Opening_address_tcm7-158494.pdf

Lindsay, W. L., & Norvell, W. A. (1978). Development of a DTPA soil test for zinc, iron, manganese and copper. *Soil Science Society of American Journal*, *42*, 421–428. https://doi.org/10.2136/sssaj1978.03615995004200030009x

Lumpkin, T. A., & Sayre, K. (2009). Enhancing resource productivity and efficiency through conservation agriculture. In *Proceedings of the Fourth World Congress on Conservation Agriculture "Innovations for Improving Efficiency, Equity and Environment"* (pp. 3–9). New Delhi, ICAR.

Madejon, E., Moreno, F., Murillo, J. M., & Pelegrin, F. (2007). Soil biochemical response to long-term conservation tillage under semi-arid Mediterranean conditions. *Soil and Tillage Research*, *94*, 346–352.

Martınez, E., Fuentes, J., Silva, P., Valle, S., & Acevedo, E. (2008). Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile. *Soil and Tillage Research*, *99*, 232–244.

Mhango, W. G., Snapp, S., & Kanyama-Phiri, G.Y. (2017). Biological nitrogen fixation and yield of pigeonpea and groundnut: Quantifying response on smallholder farms in northern Malawi. *African Journal of Agricultural Research*, *12*(16), 1385–1394. https://doi.org/10.5897/AJAR2017.12232

Mukesh, S., Rani, V., & Kumar, A. (2013). Effect of using rotavator on soil properties and crop: A review. *Annals of Agri Bio Research*, *18*, 356–359.

Mullen, M., Melhorn, C., Tyler, C., & Duck, D. (1998). Biological and biochemical soil properties in no-till corn with different cover crops. *Journal of Soil and Water Conservation*, *5*, 219–224.

Nigam, S. N. (2015). Groundnut at a glance. Retrieved from http://oar.icrisat.org/8455/1/Groundnut%20at%20a%20Glance.pdf

National Mission on Oilseeds and Oil Palm (NMOOP). (2020). Statistics. Retrieved from http://nmoop.gov.in/Statistics.aspx

Nurbekov, A. (2008). *Manual on conservation agriculture practices in Uzbekistan*. Rome: FAO.

Ochsnor, T. E., Horton, R., & Ren, T. (2001). A new perspective on soil thermal properties. *Soil Science Society of American Journal*, *65*(6), 1641–1647. https://doi.org/10.2136/sssaj2001.1641

Oliveira, J. C. M., Timm, L. C., Tominaga, T. T., Cassaro, F. A. M., Reichardt, K., Bacchi, O. O. S., … Camara, G.M.D. (2001). Soil temperature in a sugarcane crop as a function of the management system. *Plant and Soil*, *230*, 61–66.

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with $NaHCO_3$. *USDA Circular*, *939*, 1–19.

Onwuka, B., & Mang, B. (2018). Effects of soil temperature on some soil properties and plant growth. *Advances in Plants & Agriculture Research*, *8*(1), 34–37. https://doi.org/10.15406/apar.2018.08.00288

Page, A. L. (1982). *Methods of soil analysis. Part II. Chemical and microbiological properties*. Madison, WI: ASA.

Polat, R., Saglam, R., Aydemir, S., & Qikman, A. (2006). Effects of different tillage methods on soil physical properties under second crop sesame in the Harran Plain, Southeast Turkey. *Asian Journal of Plant Sciences*, *5*(4), 613–618.

Quang, P. V., Jansson, P., & Khoa, L. V. (2012). Soil penetration resistance and its dependence on soil moisture and age of the raised-beds in the Mekong delta, Vietnam. *International Journal of Engineering Research and Development*, *4*(8), 84–93.

Ramakrishna, A., Tam, H. M., Wani, S. P., & Long, T. D. (2006). Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. *Field Crops Research*, *95*, 115–125.

Reddy, K. R., Hodges, H. F., & Varco, J. J. (2000). *Potassium nutrition of cotton* (vol. 1094). Mississippi State, MS: Mississippi Agricultural & Forestry Experiment Station.

Rengasamy, P., & Churchman, G. J. (2009). Cation exchange capacity, exchangeable cations and solidity. In K. I. Peverrilli, L. A. Sparrow, & D. J. Reuter (Eds.), *Soil analysis: An interpretation manual* (pp. 147–155). Canberra, Australia: CSIRO.

Richards, L. A. (1954). *Diagnosis and improvement of saline and alkali soils* (Vol. 78). Washington, DC: USDA.

Romero, V. M., Bellido, L. L., & Bellido, J.L. (2015). Effect of tillage system on soil temperature in a rainfed Mediterranean Vertisol. *International Agrophysics*, *29*, 467–473.

Salahin, N., Alam, K., Mondol, A. T. M. A. I., Islam, M. S., Rashid, M. H., & Hoque, M. A. (2017). Effect of tillage and residue retention on soil properties and crop yields in wheat-mungbean-rice crop rotation under subtropical humid climate. *Open Journal of Soil Science*, *7*(1), 1–17.

Schinner, F., Ohlinger, R., Kandeler, E., & Margensin, R. (1996). *Methods in soil biology*. Berlin: Springer.

Scopel, E., Da Silva, F. A. M., Corbeels, M., Affholder, F. O., & Maraux, F. (2004). Modelling crop residue mulching effects on water use and production of maize under semi-arid and humid tropical conditions. *Agronomie*, *24*, 383–395.

Settaluri, V. S., Kandala, C. V. K., Puppala, N., & Sundaram, J. (2012). Peanut and their nutritional aspects: A review. *Food and Nutrition Science*, *3*, 1644–1650. https://doi.org/10.4236/fns.2012.312215

Shaxson, F., Kassam, A., Friedrich, T., Boddey, B., & Adekunle, A. (2008). *Underpinning conservation agriculture's benefits: The roots of soil health and function*. Rome: FAO.

Singh, G., Marwaha, T. S., & Kumar, D. (2009). Effect of resource-conserving techniques on soil microbiological parameters under long-term maize-wheat crop rotation, *Indian Journal of Agriculture Sciences*, *79*(2), 94–100.

Singh, R. J., Ahlawat, I. P. S., & Sharma, N. K. (2015). Resource use efficiency of transgenic cotton and peanut intercropping system using modified fertilization technique. *International Journal of Plant Production*, *9*(4), 523–540.

Singh, R. J., Ahlawat, I. P. S., & Kumar, K. (2013). Productivity and profitability of the transgenic cotton–wheat production system through peanut intercropping and FYM addition. *Experimental Agriculture*, *49*(3), 321–335. https://doi.org/10.1017/S0014479713000197

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, *25*(8), 259–260.

Subbiah, B. V., & Asija, G. L. (1956). A rapid method for the estimation of nitrogen in soil. *Current Science*, *26*, 259–260.

Tabatabai, M. A. (1994). Soil enzymes. In R. W. Weaver, J. S. Angle, & P. Bottomley, (Eds.), *Methods of soil analysis: Microbiological and biochemical properties* (pp. 775–833). Madison, WI: SSSA.

Tao, J., Griffiths, B., Zhang, S., Chen, X., Liu, M., Hu, F., & Li, H. (2009). Effects of earthworms on soil enzyme activity in an organic residue amended rice–wheat rotation agro-ecosystem. *Applied Soil Ecology*, *42*, 221–226.

Thierfelder, C., & Wall, P. C. (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil and Tillage Research*, *105*, 217–227.

Thierfelder, C, Amet́zquita C. E., & Stahra, K. (2005). Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate. *Soil and Tillage Research*, *82*, 211–226.

Tiwari, D., Sharma, B. B., & Singh, V. K. (2011). Effect of integrated nutrient management in pigeonpea based intercropping system. *Journal of Food Legumes*, *24*(4), 304–309.

TojoSoler, C. M., Bado, V.B., Traore, K., McNair Bostick, W., Jones, J.W., & Hoogenboom, G. (2011). Soil organic carbon dynamics and crop yield for different crop rotations in a degraded ferruginous tropical soil in a semi-arid region: A simulation approach. *Journal of Agricultural Sciences*, *149*, 579–593. https://doi.org/10.1017/S0021859611000050

Ubeda, X., Pereira, P., & Outeiro, L. (2009). Effects of fire temperature on the physical and chemical characteristics of the ash from two plot of cork oak (*Quercus suber*). *Land Degradation Development*, *20*(6), 589–608.

Unger, P. W., & Jones, O. R. (1998). Long-term tillage and cropping systems affect bulk density and penetration resistance of soil cropped to dryland wheat and grain sorghum. *Soil and Tillage Research*, *45*, 39–57.

Vance, E. D., Brookes, P. C., & Jenkinson, D. S. (1987). An extraction method for measuring soil microbial biomass. *Soil Biology and Biochemistry*, *19*, 703–707.

Walkley, A., & Black, I. A. (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, *37*, 29–37.

Wani, S. P., Singh, P., & Pathak, P. 1999. *Methods and management of data for watershed research: Technical manual for the training workshop*. Patancheru, India. ICRISAT.

Weih, M., & Karlson, S. (1999). The nitrogen economy of mountain birch seedlings: Implication for winter survival. *Journal of Ecology*, *87*(2), 211–219.

Zita, K., Rimantas, V., Steponas, R. (2012). The influence of crop residues type on their decomposition rate in the soil: A litterbag study. *Zemdirbyste Agriculture*, *99*(3), 227–236.

How to cite this article: Jat RA, Reddy KK, Choudhary RR, et al. Effect of conservation agriculture practices on soil quality, productivity, and profitability of peanut-based system of Saurashtra, India. *Agronomy Journal*. 2021;1–16. https://doi.org/10.1002/agj2.20534