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Measuring and Monitoring the Impact of Precision Land Levelling and Arable Cropping Systems on Aggregate Associated Carbon Fractions and Soil Carbon Stock in Sub-tropical Ecosystems

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Long term experiment (2009-10 to-2018-19) was conducted to study the effects of precision land levelled (PLL) versus traditional land levelled (TLL) systems on aggregate-associated soil organic carbon (SOC) in a farmers participatory fields under sub-tropical ecosystems (Western Uttar Pradesh) of Indian conditions. The significance of this study mainly focus to determine the suitability of various labile carbon fractions as indicators of soil quality and the stability of aggregates plays a vital role in preserving and long term storing of soil organic carbon by implementing Precision Land

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Levelling under various arable cropping system. The treatment comprised of sixteen alternative arable cropping systems strategies *viz*. R-W_{PLL}, R-W_{TLL}, S-W_{PLL}, S-W_{TLL}, R-P-Mb_{PLL}, R-P-Mb_{TLL}, R-P-O_{PLL}, R-P-O_{TLL}, R-C-O_{PLL}, R-C-O_{TLL}, O-W-Mb_{PLL}, O-W-Mb_{TLL}, M-W-Mb_{PLL}, M-W-Mb_{TLL}, M-P-Mb_{PLL}, and M-P-Mb_{TLL} etc were taken with recommended dose of fertilizers and various observations were recorded. The results indicated that the M-P-Mb_{PLL} produced 79.5 $kgha^{-1}day^{-1}$ productivity and used only 110 cm irrigation water which was 48.1 per cent less than irrigation water used for R-W_{PLL}. The land use efficiency under R-P-Mb_{PLL}, R-P-O_{PLL}, R-P-Mb_{PLL}, R-C-O_{PLL} and M-P-Mb_{PLL} were recorded as 86.2, 85.1, 84.8, 84.6 and 83.9%. However, energy value in terms total input energy and energy productivity were 39.9 and 218.5 GJ ha^{-1} over existing R-W system (32.9 & 105.7 GJ ha^{-1}). The quantity of water used in the R-C-O, M-W-Mb, M-P-Mb, and O-W-Mb were 46.1, 44.9, 40.1 and 36.3 per cent less than quantity of water used for R-W system. Aggregate-associated SOC contents in 0-15 cm depth were recorded highest SOC at 15-30 cm depth in PLL systems as 9.4% for both M-P-Mb_{PLL} and M-W-Mb_{PLL}. Highest PON change in arable cropping system (30.9 & 40.1%) was found in O-W-Mb with precision land levelling (T_{11}) plots followed by R-P-O with precision land levelling (T_7) plots (26.1 & 35.8%) as compared to R-W and S-W system. The values of LFOC in surface soil were 194.7, 187.9, 176.2, 170.9, 168.5, 150.6, 132.8 and 123.8 $mgkg^{-1}$ in R-P-O, R-C-O, M-W-Mb, O-W-Mb, M-P-Mb, R-P-Mb, R-W and S-W with precision land levelling treatments. Higher SOC sequestration was observed with precision land leveling along with alternative arable cropping systems with O-W-Mb_{PLL}, R-C-O_{PLL}, R-P-O_{PLL}, O-W-Mb_{PLL} and M-P-Mb_{PLL} respectively. Therefore, PLL systems had greater soil surface aggregation and carbon storage, land levelling did not affect SOC patterns across aggregates, but changed the distribution of aggregate size, reflecting that land levelling mainly influenced soil fertility by altering soil structure.

Keywords: Precision land leveling; microbial biomass carbon; soil organic carbon; energy use pattern.

1. INTRODUCTION

Conservation tillage method is a conservationist technique that can reduce losses and increase carbon from 0.35 Mg ha^{-1} per year in tropical soils [1] to 1.30 Mg ha^{-1} per year, With crop rotation, which can be amplified [2]. Soil aggregation and the content of carbon and nitrogen are attributes that are very sensitive to soil management and also influenced by the type of crop. Legumes are often used in conservationist soil management systems due to their capacity to biologically fix high quantities of nitrogen and can contribute to soil carbon addition at a pace of 0.88 Mg ha^{-1} annually [3]. These additions are typically linked to soil aggregation increases that protect soil carbon from microbial degradation [4]. Due to their high aboveground biomass production, with a higher C: N ratio [5] and their thick root system, which is correlated with intense microbial activity, grasses are predominantly used in conservationist systems. These crop type features can increase soil carbon at a rate of 0.71 Mg ha^{-1} per year [6].

Precision land levelling is a method that uses laser-equipped drag buckets to smooth the land surface (± 2 cm) from its average height, and this technique is well known for achieving higher levels of accuracy in land levelling and offers great potential for aggregate-associated SOC. The mean weight diameter (MWD) value increased in the PLL compared to the TLL practices at the rates of 137% and 204%, respectively at 0-15 cm soil depth. As was found by Kaur et al. [7] irrigation cost in laser levelled land got reduced by 44% over the conventional practice and water productivity improved by 39%. Studies has not been done earlier on laser land levelling for boosting aggregate associated carbon, microbial activities and reduced carbon footprints in sub-tropical region of India. Labile carbon is the SOC pool which is directly available for microbial activity and, hence, is considered to be the primary energy source for microorganisms [8]. Addition of organic matter as fertilizer [9] and precision leveled field reduced tillage will likely increase labile organic carbon [10]. In addition, these practices have the potential to enhance carbon and nitrogen cycling as well as soil aggregation, which are one of the primary mechanisms through which organic carbon is sequestered in soil [11]. Therefore, labile carbon has potential as an indicator of soil functions, in particular: nutrient cycling, soil aggregate formation and carbon sequestration.

Soil aggregate stability and diameter are closely related with soil carbon and nitrogen contents [4]. In addition, the physical fractionation of soil organic matter into particulate carbon and carbon associated with minerals can significantly contribute to understanding the dynamics of C and N and soil aggregation [3]. Carbon in particulate fraction represents the lowest carbon stock in Vertisols, although it is the most active fraction and is highly susceptible to soil management and cropping systems [4], whereas mineral-associated carbon fraction is the greatest and most stable carbon stock in the soil [12]. Furthermore, micro-aggregates are held together by roots, fungi hyphae, and polysaccharides to form macro-aggregates with diameter size greater than 250 μm, which are less stable and more sensible to changes in land use and soil management [13]. These macro-aggregates can also be formed around particulate carbon, protecting it against microbial degradation [12].

Although the highest and most stable carbon stock in the soil is the mineral-associated carbon fraction [12]. In addition, roots, fungi hyphae, and polysaccharides are kept together to form macro-aggregates with a diameter greater than 250 μm, which are less stable and more susceptible to changes in land use and conservation of soil [13]. It is also possible to form these macro-aggregates around particulate carbon to protect it from microbial degradation [12].

However, inside macro-aggregates, particulate carbon may be found fragmented into smaller particles, which bind themselves to soil mineral particles to form micro-aggregates [12].

Overall, the need for the hour in western Uttar Pradesh is the alternative cropping strategy in cereal-based production systems, both through location-specific cereal replacement and crop intensification as well as through crop intensification [14,15]. The general objective of this study was to facilitate the assessment of soil quality in agricultural systems by identifying a biochemical parameter that is sensitive to soil disturbance and linked with soil functions. Therefore, the present investigation aims at diversifying sustainable, resource-efficient and remunerative cereal-based production systems with adequate and promising vegetable and legume-based systems viz. rice-wheat (R-W),sorghum-wheat (S-W), rice-potato-mungbean (R-P-Mb),rice-potato-onion (R-P-O), rice-cabbage-onion (R-C-O), onion-wheat-mungbean (O-W-Mb), maize-wheat- mungbean (M-W-Mb), and maize-potato-mungbean (M-P-Mb) systems.

The basic objective of our research was to determine the suitability of various labile carbon fractions as indicators of soil quality across sub-tropical regions (western Uttar Pradesh) of India. To do so, we tested the sensitivity of the labile carbon fractions to precision land leveling and organic matter input in farmers participatory long-term field experiments. In addition to improving the production vulnerabilities that RWCS has brought so far, we evaluated the relationship of the various labile carbon fractions with physical, chemical and biological soil properties relevant to soil functions, in particular nutrient cycling, carbon sequestration, and decreased carbon footprints.

2. MATERIALS AND METHODS

2.1 Details of Field Experiment

The experiment was conducted with major arable cropping system during ten successive *Kharif, rabi* and *spring* seasons of 2009-10 to 2018-19 on sandy loam soils of sub-tropical, India at eight different randomly selected farmers' sites in each District (A-H) at Meerut and Muzaffarnager District of western Uttar Pradesh which falls under the agro-climatic region, Western Uttar Pradesh Zone (UP-6), U.P., India. All experimental sites were divided into two plots (i.e. precision levelled and adjoining unlevelled plot or traditional levelled) each of size about 0.40 ha. Thus, total sixteen experimental plots were formed consisting of eight precision lasers levelled (0-0.1% grade) and adjoining eight unlevelled plots (0.5-2% slope), which were presumed as control. The average land slopes of 2, 1.8, 1.2, 0.8, 0.6, 0.5, 1 and 1.5% were observed for unlevelled plots located at A, B, C, D, E, F, G and H site, respectively. Unlevelled or traditional levelled field plots adjacent to respective precisely laser levelled plots were selected for comparison to reduce the effect of inherent soil variability. Irrigation water was applied as per the requirement of laser levelled plots and the same amount of water was applied to adjoining unlevelled/traditional levelled fields and consequent soil moisture and water stress were monitored. As the crop suffered from extreme water stress conditions in unlevelled fields at the stage of production, additional 7.o cm of irrigation water was applied only as life-saving irrigation to unlevelled plots. The average crop water requirement (ETc) during crop period was estimated using CROPWAT 8.0 (FAO, Rome) based on ten years weather data collected from nearest agro-meteorological observatory at Sardar Vallabhbhai Patel

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The benchmark of this study mainly focus to determine the suitability of various labile carbon fractions as indicators of soil quality because there was low SOC content in the western Uttar Pradesh of India, the long-term used of precision land levelling and arable cropping systems increased the content of SOC and the stability of aggregates plays a vital role in preserving and long term storing of soil organic carbon. Treatments comprised of sixteen alternative arable cropping strategies *viz*. T_1 Rice-Wheat with Precision land levelling (R-W_{PLL}), T_2 Rice-Wheat with Traditional land levelling (R-W_{TLL}),T_3 Sorghum-Wheat with Precision land levelling (S-W_{PLL}), T_4 Sorghum-Wheat with traditional land levelling (S-WTLL), T_5 Rice-Potato-Mungbean with Precision land levelling (R-P-Mb_{PLL}), T_6 Rice-Potato- Mungbean with Traditional land levelling (R-P-Mb_{TLL}), T_7 Rice-Potato-Onion with Precision land levelling (R-P-O_{PLL}), T_8 Rice-Potato-Onion with Traditional land levelling (R-P-O_{TLL}), T_9 Rice-Cabbage-Onion with Precision land levelling (R-C-O_{PLL}), T_{10} Rice-Cabbage-Onion with Traditional land levelling (R-C-O_{TLL}), T_{11} Onion-Wheat-Mungbean Precision land levelling (O-W-Mb_{PLL}), T_{12} Onion-Wheat-Mungbean with traditional land levelling (O-W-Mb_{TLL}), T_{13} Maize-Wheat-Mungbean with Precision land levelling (M-W-Mb_{PLL}), T_{14} Maize-Wheat-Mungbean with traditional land levelling (M-W.Mb_{TLL}),T_{15} Maize-Potao-Mungbean with Precision land levelling (M-P-Mb_{PLL}), and T_{16} Maize –Potato-Mungbean with traditional levelling (M-P-Mb_{TLL}) cropping systems were taken with recommended dose of fertilizers. The details of crops and field cultural operations followed in cropping systems etc. are given in Table 2. A common dose of nutrients amounting 150 kg N + 60 kg P_2O_5 + 40 kg K_2O + 25 kg $ZnSO_4$ ha^{-1} were applied in all treatments during first year of study (2009-10). The 1/3rd N and whole P_2O_5, K_2O and $ZnSO_4$ was applied as basal, while remaining 2/3rd N was top dressed as urea in two equal splits at two vegetative growth phases. At the time of top dressing, fertilizer was broadcasted and care was taken so that the fertilizers were mainly applied on targeted crop rows only. Proper agronomic practices were followed during crop growth periods. At maturity, the crop was harvested manually and estimates the grain yield. Grain moisture was determined using a grain moisture meter. The crop grain yield was balanced to a moisture content of 14 percent.

2.2 Soil Chemical and Physical Analysis

The soil samples were drawn after drying for chemical analysis. The available N, P and K were determined using standard procedures mentioned in Table 1. Bulk density of surface (0–15 cm) and sub-surface (15–30 cm) soil was determined by the core sampler method from three randomly chosen spots from each plot [16]. The soil porosity was computed from the relationship between bulk density and particle density using (1):

$$\text{Porosity (\%)} = 1 - \frac{BD}{PD} x\ 100 \qquad (1)$$

Where

BD is bulk density (g cm^{-3}) and
PD is particle density (g cm^{-3})

2.2.1 Soil sampling for soil quality parameters

Soil samples were taken from the experimental field randomly from each plot after the end of cropping system cycles during five years. Each plot was taken from ten soil cores (5 cm diameter, 0-15 cm depth). The soil samples were put in polythene bags and allowed to dry and transported to the laboratory where they were thoroughly mixed and sieved (2 mm mesh). The soil samples were then placed in the dark overnight at 5 °C, and were balanced to 22-25°C before biological analyses [17].

Soil sampling was done after ten years from the experiment establishment, in spring 2009, before sowing the summer crops of the next growing season. Three undisturbed soil samples (5.0-cm diameter x 5.0-cm height) were collected on the 0.00-0.10-m soil layer in each plot. From the sample portion, 30 g were used for a particle-size fractionation. This sample was placed in a 200-mL plastic bottle with a sodium hexametaphosphate solution (5 g L^{-1}), and three agate balls (5-mm diameter) were used to improve soil mechanical dispersion. The material was shaken overnight, in a horizontal shaker for 16 hours, at a frequency of 50 rpm. The sample was passed through a 250-μm sieve placed above another one of 53 μm. Fractions were selected as in Koutika et al. [18] from 2,000 to 250 μm, medium particulate carbon; from 250 to 53 μm, fine particulate carbon; and <53 μm, mineral-associated carbon. The remaining material in each class was washed, oven dried at 50ºC, weighed, and grounded to pass a 105‐μm mesh sieve, for carbon and nitrogen determination. Another 4 g of the bulk soil were oven-dried at 50ºC and ground to pass the same 105-µm mesh sieve. Portions between 0.275 to 0.300 g, from each sample, were weighed to determine total carbon.

2.2.2 Soil organic carbon

Soil organic carbon was determined by wet digestion with potassium dichromate along with 3:2 H_2SO_4: 85% H_3PO_4 digestion mixture in a digestion block set at 120°C for 2h [19-21]. A pre-treatment with 3 ml of 1 NHCl g^{-1} of soil was used for removal of carbonate and bicarbonate. By using the bulk density value the SOC for each soil layer was calculated and expressed as Mg ha^{-1}.

2.3 Light Fractions Organic C and N

PMN in soil was determined by the method described by Keeney [22,23] where 10 g air-dry soil was taken in a test tube with distilled water (1:2) and incubated for 7 days under waterlogged conditions at 40°C. The mineralized NH_4^+ N was determined by the Kjeldahl's distillation method. The amount of PMN (mg NH_4^+ N kg^{-1} d^{-1}) was determined by subtracting the concentration of NH_4^+ N at the beginning of incubation.

2.3.1 Particulate organic carbon

Particulate organic matter (POM) was separated from 2 mm soil following the method described by Camberdella and Elliott [24]. Briefly a 10 g sub-sample of soil was dispersed in 100 ml 0.5% sodium hexa-metaphosphate solution by shaking for 15h on a reciprocal shaker. The soil suspension was poured over a 0.05 mm screen. All material remaining on the screen, defined as the particulate organic fraction within a sand matrix, was transferred to a glass beaker and weighed after oven-drying at 60°C for 24 h. The particulate organic carbon in POM was determined following the method of Snyder and Trofymow [19].

2.3.2 Dissolved organic carbon

Dissolved organic C (DOC) was extracted from 10 g of moist soil with 1:2.5 ratio of soil to water at 25.8°C [25]. After shaking for 1 h and centrifuging for 10 min at 4500 r min^{-1}, the supernatant was filtered with a 0.45 mm membrane filter. The filtrate was measured by oxidation with potassium dichromate and titration with ferrous ammonium sulphate.

2.3.3 Economic analysis, production indices and monetary efficiencies

In order to determine the cost of cultivation, cost of each input and output were calculated accordingly as per prevailing prices during each year. Gross and net returns per ha were calculated based on the crop productivity and prevailing market prices of different crops during respective crop years/seasons. The system productivity and profitability was calculated by dividing the crop equivalent yield and net returns by 365. The irrigation system productivity was calculated by dividing the crop equivalent yield by the total amount of irrigation water was used to grow the crop [26]. Similarly, nutrient use productivity was calculated by dividing the crop equivalent yield by the total quantity of nutrients used in the cropping system. Total system energy input and output was measured based on energy input/output of each crop in respective system. Physical energy of each input and output was converted into energy equivalents viz. Mega Joules (MJ) and Giga Joules (GJ) by using conversion coefficient values given by Mandal [27]. Energy input–output relationship with respect to energy efficiency, energy productivity and net energy in different cropping systems vary with the component crops knitted in a cropping sequence, soil type, agronomic operations and fertilizers used, plant protection measures and economic produce levels [27].

2.4 Statistical Analysis

All the field and laboratory data on various plant parameters on component crops of different cropping systems was statistically analyzed using the F test as per the procedure given by Gomez and Gomez [28]. Least significance difference (LSD) values at P = 0.05 were used to determine the significant differences between treatment.

3. RESULTS AND DISCUSSION

3.1 Production Efficiency and Land Use Efficiency

Present experiment revealed that among sixteen precision lasers levelling/ traditional land levelling and alternative arable cropping systems viz. R-P-Mb_{PLL}, R-P-O_{PLL}, R-C-O_{PLL}, M-W-Mb_{PLL} and M-P-Mb_{PLL} recorded highest production efficiency followed by O-W-Mb_{PLL}, R-W_{PLL}, R-P-Mb_{TLL}, M-P-Mb_{TLL} and M-W-Mb_{TLL}, respectively (Fig. 1). High production potential of potato, onion, cabbage, maize and higher pod yield in mungbean, were the possible reasons for getting highest efficiency in this system. Potato/Onion/Cabbage based systems are also more productive and profitable than cereal-based systems due to higher productivity resulting in better remuneration. This discussion holds true in the current study, when highest production efficiency in R-P-Mb_{PLL} was reflected due to residual fertility of legumes tailored in this system [14], better water and nutrient availability due to precision land levelling [29] besides higher supply of macro and micronutrients and soil physical health, due to better activities by incorporating the SMB biomass [30]. The land use efficiency under R-P-Mb_{PLL}, R-P-O_{PLL}, R-P-Mb_{PLL}, R-C-O_{PLL} and M-P-Mb_{PLL} were recorded as 86.2, 85.1, 84.8, 84.6 and 83.9%, respectively which were at par with M-W-Mb_{PLL} (82.8%), R-C-O_{TLL} (82.3%), O-W-Mb_{PLL} (81.5%) and M-W-Mb_{TLL} (80.7%). However, energy value in terms total input energy and energy productivity were 39.9 and 218.5 GJ ha^{-1} over existing R-W system (32.9 & 105.7 GJ ha^{-1}), respectively.

3.2 Energy Dynamics and Energy Use Efficiencies

Keeping in view current energy crisis, studies on energy dynamics and energy use efficiency in agricultural production systems also assume great importance to identify promising production systems which have less dependency on non-renewable energy sources. In the current study, the estimation of energy use in different cropping systems revealed that M–P– Mb_{TLL} utilized highest energy (38.2 GJ ha^{-1}) followed by M-W-Mb_{TLL} (37.2 GJ ha^{-1}), O-W-Mb_{TLL} R-P-Mb_{TLL} and O-W-Mb_{TLL}, respectively. M–P– Mb_{TLL} system used highest energy input because potato consumes higher energy with respect to fertilizer, seed as well as human labour for earthing-up and digging operations in potato; besides more energy input in pod picking operation in mungbean legumes. R-C-O_{TLL} and O-W-Mb_{TLL} sequence also consumed more energy owing to regular spraying of pesticides in cabbage crop being prone to wet season diseases besides relatively higher fertilizer and irrigation requirements in cabbage [14]. M-W_{TLL} and S-W_{TLL} systems again exhibited higher energy efficiency because in spite of better energy output by these systems, their energy use per unit energy output was quite lower as compared to other systems. R-P-O_{PLL}, R-C-O_{PLL} system also produced higher energy equivalents which resulted in greater net energy returns quite close to O-W-Mb_{PLL} system was primarily due to higher yield of this system.

3.3 Production, Monetary and Employ ment Efficiencies

Production and monetary efficiencies are the performance indicators of various cropping systems in terms of productivity and monetary gains day^{-1} ha^{-1}, respectively. In current study, highest production efficiency (89.7 kg ha^{-1} day^{-1}) and monetary efficiency (Rs. 351.6 $ha^{-1}day^{-1}$) were observed in R-P-O_{PLL} precision land leveling which proved significantly superior over rest of the cropping systems (Table 3). R-C-O_{PLL} system ranked second and showed superiority over O-W-Mb_{PLL} and R-P-Mb_{PLL}. Overall, R-P-O_{PLL} cropping system utilized land more efficiently which led to higher production and monetary advantages in the present experimentation. The efficiency of production referred to as the day-to-day productivity of the system under specific treatment depends on the production capacity of the crops obtained in that system. Thus, highest production efficiency was observed in R-P-O_{PLL} sequence because of highest production and gross returns obviously with considerable contributions of potato and onion crops. High value crops viz. onion, potato, cabbage, mungbean and maize producing quick returns, are perfect option for small holders to utilize surplus labour and augment their income. The remunerative price from onion resulted in higher net returns in O–W–Mb_{PLL} sequence but higher cost of cultivation is the major drawback for lower benefit: ratio than R-C-O_{PLL} rotation.

The data given in Table 3 and Fig. 1 revealed that there is sufficient scope to replace rice-wheat cropping system with other cropping systems without any decline in economic yield rather it improved substantially. The R-P-O_{PLL}, R-C-O_{PLL}, O-W-Mb_{PLL} and R-P-Mb_{PLL} gave 1.56, 1.54, 1.47 and 1.45 times more productivity over R-W_{PLL} system which clearly elucidated the superiority of these systems over R-W system. These systems also helped to save 40- 110 cm of irrigation water (Fig. 1). The R-P-O_{PLL} system gave the highest productivity (89.7 $kgha^{-1}day^{-1}$) and used 77 cm less water than R-W_{PLL} system with a productivity margin of 32.3 $kgha^{-1}day^{-1}$. The summer R-C-O_{PLL} system gave 88.6$kgha^{-1}day^{-1}$ productivity with 112 cm irrigation water (Table 3 and Fig. 1) leading to 100 cm saving of water. O-W-Mb$_{PLL}$ cropping system gave 84.2kgha^{-1}day^{-1}productivity with total irrigation water used as 132 cm, thereby indicating the net saving of irrigation water to the extent of 80 cm.

The M-P-Mb$_{PLL}$ produced 79.5kgha^{-1}day^{-1} productivity and used only 110 cm irrigation water which was 48.1 per cent less than irrigation water used for R-W$_{PLL}$ system (Table 3 & Fig. 1). It might be due to the reason that mungbean pulse crop have improved the soil physicochemical properties which might have reduced the water loss due to evaporation, percolation and seepage as compared to R-W system [31-33]. The net returns were maximum Rs. 1, 47,898 ha^{-1} annum^{-1} in R-P-O system and it was 2.32 times more over R-W system (Table 3). The net returns in the other cropping systems like R-C-O, O-W-Mb, and M-P-Mb were Rs. 134,925, 121,863, and 113,651, respectively. The quantity of water used in the R-C-O, M-W-Mb, M-P-Mb, and O-W-Mb were 46.1, 44.9, 40.1 and 36.3 per cent less than quantity of water used for R-W system. The corresponding value in terms of saving of electricity consumption (per ha basis) was 233, 284, 382 and 570 electricity units with electricity bill amounting Rs 1173, 1425, 1915 and 2858 per ha over R-W system, respectively (Table 3). Similar kinds of reports have also been reported by Bohra et al. [34]; Rathore et al. [35].

3.4 Resource Use Efficiency

In the present context of degradation of natural resources and the productivity of crops, the resources efficiency and sustainability of cropping systems are attracting the attention of scientists all over the world. The resources efficiency is a paramount character for the establishment of new cropping system. The cropping system which utilize the farmer's available resources effectively and provide him employment throughout that will be acceptable to the farmers readily. Resource use efficiency of different cropping systems was evaluated through different approaches proposed by Singh et al. [36]; Sharma [37]. In order to evaluate the efficiency of different cropping systems, two components were calculated, i.e. monetary return usage efficiency (MRUE) Rs ha^{-1} day^{-1} and system profitability (Rs ha^{-1} day^{-1}). The monetary return use efficiency (MRUE) values ranged between 135.3 and 339.2 among alternative arable cropping systems; being lowest in S-W and highest in R-P-O (Table 3). The system profitability among different cropping systems ranged between Rs. 169.1 and 382.6 ha^{-1}day^{-1}. The system profitability efficiency like production efficiency was highest in R-P-O and it was distinctly higher than all other cropping systems. The system profitability efficiency was around Rs.290 ha^{-1} day^{-1} in R-C-O, O-W-Mb, M-W-Mb, and M-P-Mb cropping systems (Table 3).

Different cropping systems paid opportunities to the farmers to work for different number of days in a year, in agriculture there is a major problem of under employment and therefore, employment generation efficiency (EGE) cope with the cropping system which employs farmers for more number of days is a boon to the farmers. R-P-O engages farmers almost throughout the year i.e.1.84 man day ha^{-1} day^{-1}, while M-P-Mb, R-C-O and M-W-Mb employs farmers for only 1.65, 1.49 and 1.4 man day ha^{-1} day^{-1}. For more than 0.64 man day ha-1 day-1, almost all cropping systems do not engage farmers and this reflects underemployment in agriculture (Table 3). These data indicate that farmers must go along with growing crops for agri-business. These results corroborate the findings of Gangwar and Baldev [38], Chandrappa et al. [39], Bastia et al. [40], Sharma et al. [41].

3.5 Cation Exchange Capacity

Cation exchange capacity (CEC) was also increased due to alternative arable cropping systems. The highest CEC increase under alternative arable cropping systems (30.8%) was found in M-W-Mb followed by O-W-Mb (30.4%) and M-P-Mb (28.6%). R-W and S-W cropping systems showed the lowest increase of CEC from the experimentation (Fig. 2). The large loss of aggregate stability for the R-W and S-W systems are of particular concern, as it suggests that the increased aggregate stability of surface soil under R-W is due to puddling rather than an intrinsic property of R-W cropping system. This observation is consistent with that of [42].

3.6 Total Porosity and Hydraulic Con ductivity

Soil porosity results showed that alternative arable cropping systems plots could increased the total porosity of soil, while R-W cropping system would decrease the soil porosity for aeration; as a consequence, it improves the soil's water holding ability along with poor soil aeration.

Table 1. Physico-chemical properties of experimental soil at initiation of field experiment

Soil parameters	Status/value	Methods employed
Mechanical separates		
I. sand	63.0	Modified hydrometer Bouyoucos [43]
II. Silt	16.2	
III. Clay	20.4	
Textural class	Sandy loam	
Bulk density (Mg m^{-3})	1.40 (0-15 cm) 1.46 (15-30 cm)	Core sampler
Water stable aggregates (>0.25mm)	48.5	Wet sieving Haynes [44]
Moisture at field capacity (%)	15.5	
Soil chemical properties		
I. Soil reaction (P^H)	7.5	1:2.5 soil & water suspension Jackson [45]
II. Organic carbon (%)	0.36	Rapid titration method Walkley and Black [46]
III. Available nutrients (kg ha^{-1})		
N	165.8	Alkaline permanganate method Subbiah and Asija, [47]
P	12.5	0.5 M $NaHCO_3$, P^H 8.5 Olsen et al. [48]
K	193.2	Ammonium acetate Hanway and Heidel [49]

Table 2. Details of agronomic practices followed for different crops in field experimentation during 2009-10 to 2018–19

Crop in rotation	Seed rate $kgha^{-1}$	Date of sowing/ transplanting	Date of harvesting
Rice (*Oryza sativa* L)	25	3rd week of June	3rd week of October
Wheat (*Triticum aestivum* L.)	100	2nd week of November	2nd week of April
Sorghum	5-6	2nd Week of June	4th week of September
Maize (*Zea mays* L.)	20	1st week of July	2nd week of October
Kharif Onion (*Allium cepa* L.)	4-5	1st week of July	1st week of November
Potato (*Solanum tuberosum* L.)	2000	3rd week of October	1st week of March
Cabbage (*Brassica oleracea*)	750-1000gm	3rd week of Sept. to 1st week of Oct.	3rd and 4th week of October
Mungbean (*Phaseolus radiatus* L.)	25	3rd week of April	3rd week of June

Table 3. Efficiency of various crop sequences (mean of 10 cropping cycles)

Crop Sequences	WUE (kg grain/ m^3 water used)	Electric consumption	Cost of electricity consumption	MRUE (Rs/ha/day)	EGE (man day/ha/day)	Productivity (kg/ ha/day)	Net return (Rs/ha)	System Profitability (Rs/ha/day)
T_1 R-W_{PLL}	0.986	1782	8925	163.9	0.58	57.4	68,600	188.7
T_2 R-W_{TLL}	0.635	1963	9815	152.6	0.64	55.9	59,091	176.8
T_3 S-W_{PLL}	0.875	875	4375	137.9	0.96	49.8	55,520	174.2
T_4 S-W_{TLL}	0.784	917	4585	132.6	1.21	45.1	48,410	163.9
T_5 R-P-Mb_{PLL}	1.378	1235	6175	315.6	1.65	83.3	126,689	328.6
T_6 R-P-Mb_{TLL}	0.963	1370	6850	270.1	1.25	71.8	102,142	288.8
T_7 R-P-O_{PLL}	2.892	1415	7075	351.6	1.73	89.7	154,030	388.9
T_8 R-P-O_{TLL}	2.149	1567	7835	326.8	1.95	81.2	141,765	376.2
T_9 R-C-O_{PLL}	1.678	1496	7480	343.5	1.41	88.6	138,050	361.4
T_{10} R-C-O_{TLL}	1.058	1682	8410	312.6	1.56	80.3	131,800	346.2
T_{11} O-W-Mb_{PLL}	2.216	1590	7950	317.6	1.38	84.2	123,933	359.3
T_{12} O-W-Mb_{TLL}	1.883	1689	8445	291.7	1.52	79.3	119,793	346.8
T_{13} M-W-Mb_{PLL}	1.953	1586	7930	173.0	1.28	78.6	108,262	229.2
T_{14} M-W-Mb_{TLL}	1.856	1735	8675	232.4	1.68	67.4	93,721	216.9
T_{15}-M-P-Mb_{PLL}	1.876	1680	8400	193.0	1.57	79.5	118,027	254.3
T_{16}- M-P-Mb_{TLL}	1.264	1830	9150	165.2	1.72	72.1	109,275	214.6

WUE = Water use efficiency, MRUE = Monetary return use efficiency, EGE = Employment generation efficiency

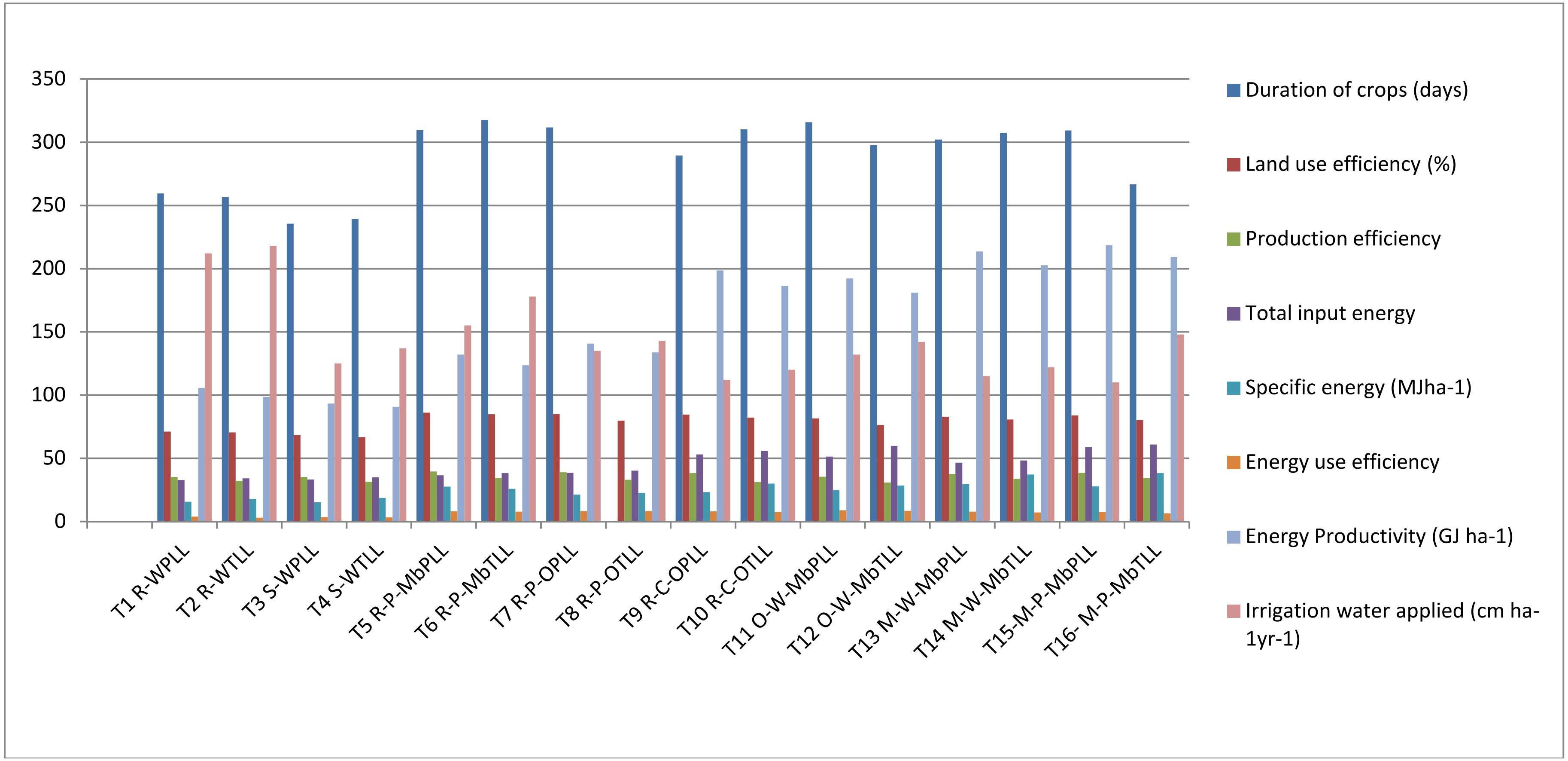

Fig. 1. Performance and energy consumption pattern under alternative cropping systems

However, the effects of alternative arable cropping systems on the total porosity were significant. Alternative arable cropping systems plots shown an improvement in the soil porosity and was most probably related to the beneficial effects of soil organic matter caused by residue cover (Fig. 2). Oliveira and Merwin, 2001 found that the increased porosity was especially important for the crop development since it may have a direct effect on the soil aeration and enhances the root growth. Therefore, increased root growth will enhance plant water as well as nutrient uptake. Within the alternative arable cropping systems, M-P-Mb, O-W-Mb, M-W-Mb, R-C-O and R-P-Mb produced more porosity than R-W cropping system. Husnjak and Kosutic [50]; Naresh et al. [32] stated that higher BD decreased total porosity and modified the ratio of capacity of water holding to air capacity in favour of capacity of water holding.

3.6.1 Soil organic carbon (SOC)

Results of alternative arable cropping systems after ten years significantly influenced the total organic carbon (TOC), and soil organic carbon (SOC) content of the surface soil is depicted in (Fig. 2). Data indicate that R-W cropping system have a resulted in highly significant losses of SOC ranging from 6.2 to 7.35% for both the 0–5 and 5–15 cm depths. In surface soil (0-5 cm layer) highest soil organic carbon change (9.3%) was found in R-P-O cropping system plots followed by O-W-Mb and R-C-O cropping system plots (8.65 & 8.25%).The adoption of alternative arable cropping systems of R-P-O, O-W-Mb and R-C-O for ten crop cycles increased soil organic carbon by 51.12; 39.6% and 33.1% more than that of R-W cropping systems, respectively.

These treatments were statistically similar and superior from all rest of other treatments. Irrespective of alternative arable cropping systems in 0– 5 cm soil layer enhanced 23.4, 26.1% and 15.1, 19.8% TOC in precision land levelling and traditional land levelling plots in surface soil as compared to R-W and S-W cropping systems. However, SOC enhanced 13.9, 26.8% and 14.7, 23.8% in precision land levelling and traditional land levelling plots in surface soil as compared to R-W and S-W cropping systems. Similar increasing trends were observed in 5 -15 cm soil layer, however, the magnitude was relatively lower (Fig. 2). The higher content of SOC in the surface soil is because the organic matter is usually incorporated in the surface layer and left over residues of shallow-rooted crops like mungbean and onion also gets accumulated in the top few centimetres of the soil [20,21].

3.6.2 Particulate organic carbon (POC)

Particulate organic carbon was found stratified along the soil depth. A higher POC was found in surface soil decreasing with depth (Fig. 3). At the 0–15 and 15-30 cm, POC content under R-P-O with precision land leveling and traditional land leveling was greater than under R-W and S-W precision and traditional land leveling practices sown plots, respectively. The decrease in soil macro-aggregate disturbance under unpuddled precision land levelling plots allowed a greater accumulation of SOC between and within the aggregates. Thus, less soil disturbance is the major cause of higher POC in the precision land leveling with alternative cropping systems plots compared with the R-W and S-W or cereals based cropping plots in the 0-15cm and 15-30 cm soil layers. This phenomenon could lead to the creation of micro-aggregates within macro-aggregates built around fine intra-aggregate POC and to the stabilisation of SOC within these micro-aggregates over the long term. Because increased POC is regarded as a potential indicator of increased C accumulation (Six et al., 1999), the results of this study indicate that precision land leveling with alternate cropping systems had a significant effect on the formation and stabilization of SOM within the 0-15cm soil layer and the soil amended organic matter by residue decomposition contained significantly higher POC in the 0–15 cm than that in the traditional land leveling with cereal based cropping systems treatments after ten crop cycles in sub-tropical ecosystems of Northwest India. Results in these respects are consistent with those of Yan et al. [51], Jat et al. [52].

3.6.3 Particulate organic nitrogen (PON)

Particulate organic nitrogen (PON) content over R-W and S-W cropping system of the field after 10-year crop cycles is presented on Fig. 3. Upper and lower depth (0-15 cm and 15-30 cm) had significantly different in PON change. Highest PON change in arable cropping system (30.9 & 40.1%) was found in O-W-Mb with precision land leveling (T_{11}) plots followed by R-P-O with precision land leveling (T_7) plots (26.1 & 35.8%) as compared to R-W and S-W precision land leveling (T_1 & T_3). The use of arable cropping system with traditional land leveling (T_8 & T_{12}) plots for ten crop cycles increased PON by 31.3 & 33.1% and 37.6 & 48.2% more than that of cereal based traditional land leveling T_2 and T_4, respectively. In lower depth (15-30 cm), similar increasing trends were observed, however, the magnitude was relatively lower (Fig. 3).

3.6.4 Labile fraction organic carbon (LFOC)

The labile fraction organic carbon (LFOC) is considered as a useful approach for the characterization of SOC resulting from different soil management practices including cropping systems and use of land leveling practices. The values of LFOC in surface soil were 194.7, 187.9, 176.2, 170.9, 168.5, 150.6, 132.8 and 123.8 $mgkg^{-1}$ in R-P-O, R-C-O, M-W-Mb, O-W-Mb, M-P-Mb, R-P-Mb, R-W and S-W with precision land leveling RT treatments, respectively (Fig. 3). However, 180.9, 177.2, 167.2, 162.5, 143.8, 120.5, 107.1 and 90.8 $mgkg^{-1}$ in R-P-O, R-C-O, M-W-Mb, O-W-Mb, M-P-Mb, R-P-Mb, R-W and S-W with traditional land leveling treatments (Fig. 3). In 15- 30 cm layer, the increasing trends in LFOC content due to use of land leveling practices and arable cropping systems were similar to those observed in 0-15cm layer, however, the magnitude was relatively lower (Fig. 3).

Chen et al. [53] also found that single effect of cropping system was not significant but its significance became apparent after its interaction with land leveling system. Similar results were obtained in our study. Li et al. [54] explained that land leveling might enter the labile C pool, provide substrate for the soil microorganisms, and contribute to the accumulation of labile C.

3.6.5 Labile fraction organic nitrogen (LFON)

Results on LFON content in 10-year experiment showed that in 0 - 15 cm soil layer of land levelling system, T_1, T_3, T_7, T_9, T_{11}, and T_{15} treatments increased LFON content from 9.7, 9.3 $mg{\cdot}kg^{-1}$ in R-W and S-W to 14.8, 13.9, 13.7 and 12.8 $mgkg^{-1}$ with precision land levelling in arable cropping systems under R-P-O, R-C-O, O-W-Mb, and M-P-Mb, respectively (Fig. 3). In 15 -30 cm layer, the increasing trends in LFON content due to the use of land levelling and arable cropping systems were similar to those observed in 0 -15 cm layer, however, the magnitude was relatively lower (Fig. 3).

3.6.6 Potentially mineralizable nitrogen (PMN)

After 10 years of the experiment, potentially mineralizable nitrogen (PMN) content showed that in 0-15 cm soil layer T_7, T_9 and T_{11} treatments increased from 7.6 $mgkg^{-1}$ in R-W_{PLL} plots (T_1) to 14.8, 16.3 and 12.8 $mgkg^{-1}$ in R-P-O, R-C-O and O-W-Mb with precision land levelling and 11.6, and 10.6 mg kg^{-1} under precision land levelling in M-P-Mb and M-W-Mb, respectively (Fig. 4). In 15 -30 cm layer, the increasing trends due to the use of land levelling and arable cropping systems were similar to those observed in 0 -15 cm layer however, the magnitude was relatively lower (Fig. 4).Continuous precision land levelling and diversified cropping systems resulted in considerable accumulation of PMN in 0–15 cm soil layer than cereal crops as mono-cropping plots (Fig. 4).

3.6.7 Microbial biomass carbon (MBC)

The level of MBC was indistinguishable between the R-W and S-W ZT in traditional land leveling regimes and was markedly lower under these regimes than under precision land leveling and pulses or vegetables cropping systems (Fig. 4). Changes in MBC can indicate the effects of management practices on soil biological and biochemical properties. The higher MBC was observed in the precision land leveling plots than the traditional land leveling plot under the rice-wheat and sorghum-wheat crops suggests that abandonment of the cropland had substantial beneficial effects on the activity of microbial organisms probably caused by the accumulation of organic C compounds at the soil surface. A possible reason for this difference is that in the absence of growing plants other labile C fractions may provide food for microbes, and thus maintain MBC. Another possible reason could be related to the soil moisture status. Under the traditional land leveling treatment, in which biomass production would inevitably deplete much more soil moisture, the microbes in the plot would be stressed at the time of sampling (wheat maturity). The microbial biomass carbon (MBC) is an important component of the SOM that regulates the transformation and storage of nutrients. All SOM transformations are governed by Soil MBC and are considered to be the principal component of the active SOM pool.

Similar to our results in several studies have reported that precision land levelling practices increased MBC in the surface soils [55]; Naresh et al. [56]. Lack of soil disturbance under precision land levelling provides steady source of organic C substrates for soil microorganisms, which enhances their activity and accounts for higher soil MBC as compared with traditional land levelling – where a temporary flush of microbial activity with levelling events results in large losses of C as CO_2. It has commonly been thought that soil microbial biomass is restricted by energy substrates rather than mineral nutrients. However, studies have demonstrated that soil microbial growth can be constrained by N availability [57]. Bolinder et al. [58] found that the MBC showed higher sensitivity to crop management practices as compared to SOC. Due to the complex existence of the MBC, early change in the status of soil organic matter due to management practises can be encouraged [59,60].

3.6.8 Microbial biomass nitrogen (MBN)

Results on MBN content after 10 years showed that in surface soil were 30.4, 24.1, 22.7, 19.4, 25.2, 23.3, 19.4 and 18.2 mgkg^{-1} in R-C-O, O-W-Mb, M-P-Mb and M-W-Mb with precision land leveling and traditional land leveling and 14.9, 13.8 in R-W and S-W with precision land leveling treatments, respectively (Fig. 4). In 15-30 cm layer, the increasing trends in MBN content due to use of land leveling practices and arable cropping systems were similar to those observed in 0-15cm layer, however, the magnitude was relatively lower (Fig. 4). Our results are in accordance with earlier studies, which reported greater MBN under tillage practices [55,56].

3.6.9 Dissolved organic carbon (DOC)

Dissolved organic carbon (DOC) content over R-W and S-W (T_1 & T_3) of the field after 10 -year crop cycle is presented on Fig. 4. There were considerably different DOC variations in the surface and subsurface soil layers (0-15 and 15-30 cm). Highest DOC change (26.4 & 19.8%) was found in O-W-Mb and M-W-Mb with precision land leveling (T_{11} & T_{13}) plots followed by M-P-Mb with precision land leveling (T_{15}) plots (15.1%).The use of precision land leveling and alternative arable cropping system (T_1 and T_3) plots for two wheat crop cycle increased DOC by 13.5 and 4.7% more than that of R-W and S-W with precision land leveling (T_9, and T_5), respectively. In subsurface soil layer similar increasing trends were observed, however, the magnitude was relatively lower (Fig. 4). Several field studies have shown that concentration and fluxes of DOC in soil solution decrease significantly with soil depth [61]. The results obtained in the present study are in agreement with earlier investigations reporting higher levels of DOC under precision land leveling practices [53]. According to Lewis et al. [62] increasing precision land leveling and alternative arable cropping systems intensity could reduce DOC levels in soils as a result of destruction of soil macro-aggregates and elevated respiration. Lower amount of DOC, hence is likely under R-W and S-W due to increased soil disturbances subjecting aggregated protected SOC fraction to rapid decomposition via oxidation. Our results suggest that DOC fraction is sensitive to land leveling practices.

3.6.10 Soil contents of carbon and nitrogen, in different carbon fractions

Rice-Potato-Mungbean with Precision land levelling (R-P-Mb_{PLL}) [T_5] increased soil carbon (C) and nitrogen (N) contents in the medium particulate carbon fraction, when compared with rice-wheat and sorghum- wheat cropping system (Fig. 5). However, the carbon and nitrogen content in fine particulate and mineral-associated fractions was not affected by either summer crops or second crops. The increases in carbon and nitrogen by Rice-Potato-Mungbean with Precision land levelling may be attributed to the low C: N ratio of it residues in comparison with those of rice, wheat and sorghum crops with precision and traditional land levelling which contributes to quickly adding carbon and nitrogen into the medium particulate fraction. The continuous input of alternative arable cropping systems on the soil, under precision land levelling is essential to carbon addition in particulate carbon fraction, which is composed of fresh residues.

Within rice crop, carbon and nitrogen (C & N) contents showed the lowest values with the second crops wheat and sorghum (Fig. 5). This may be explained by the greater recalcitrance of mungbean residues and by the fact that the former crops are commonly cultivated for grain yield, exporting, respectively.

Besides, mungbean fix, annually 19.5 g kg^{-1} N which may contribute to the accumulation of soil carbon and nitrogen. According to Seo et al. [63], crops recover 15% of the total N from labeled legume residue, in the first year; and another 55% are recovered from the soil organic N fraction.

Mineral-associated carbon fraction, followed by fine particulate and medium particulate fractions, had higher total carbon and nitrogen (Fig. 5). The highest carbon and nitrogen content verified in the more stable fraction, i.e., mineral-associated carbon, indicates a strong organo-mineral relationship [64], which is important for soil carbon sequestration. The benefits of mungbean and onion in the accumulation of soil carbon may be attributed to its low C: N ratio, which favors increasing nitrogen availability, necessary for rapid residue processing into the particulate soil carbon fractions. The C: N ratio of mungbean residues is equal to 14.1, with the following amounts of nitrogen accumulated, released, and remaining: 58.79, 29.53, and 14.57 g kg^{-1}, respectively.

3.6.11 Soil carbon changes in relation to carbon input

Addition of stubble, root and rhizodeposition in general and alternative arable cropping systems in case of R-C-O_{PLL} and O-W-Mb_{PLL} treatments over 10 years resulted in a substantial amount of organic C input to the soil (Table 4). Despite addition of 2.98 & 3.21 Mg $ha^{−1}$ $year^{−1}$ C for 10years in S-W_{PLL} and R-W_{PLL} 5.7 and 6.7 Mg $ha^{−1}$ of initial total SOC were lost from the surface soil layer under the above treatments, respectively (Table 4). The mechanical disturbances in these plots might have promoted breaking of C-rich macro-aggregates, and accumulation of C-poor micro-aggregates [65], thus resulting in oxidation of intra-aggregate SOC owing to the absence of physical protection [66,67]. In these CT plots, the moderate residue load could have been completely decomposed and used by the native microbes for the respiration process. On the other hand, precision land was levelling and alternative arable cropping system restricted SOC loss from soil, owing to improved soil structure and greater protection of SOC. The fresh crop residue turned to SOM, and the C was entrapped as intra-aggregate SOC inside 'micro-aggregates within macro-aggregates' [65]. The treatment R-C-O_{PLL} resulted in sequestration of 2.9 Mg SOC $ha^{−1}$ over the period of 10 years (Table 4), whereas all other treatments had a loss of SOC during this period. In this treatment, addition of crop residue C over the years often exceeded the capability of native microbes to decompose, degrade and/or assimilate SOM to meet their cell nourishment or respiration needs [66,67]. This continuous supply of fresh organic matter encouraged formation of C-rich macro-aggregates and also entrapment as intra-aggregate SOC.

3.6.12 Carbon buildup, stabilization and sequestration

There were significant differences in the carbon built-up among treatments (Table 4). A higher percentage of C buildup was observed in R-C-O_{PLL} treatment (43.6%) followed by R-P-O_{PLL} treatment (441.1%), which was reflected in the profile SOC concentration of respective treatments. With the exception of the precision land leveling and used of alternative arable cropping systems, the magnitude of SOC sequestration in other treatments was 5.3–9.4 Mg ha^{-1}. Higher SOC sequestration was observed with precision land leveling along with alternative arable cropping systems with O-W-Mb_{PLL}, R-C-O_{PLL}, R-P-O_{PLL}, O-W-Mb_{PLL} and M-P-Mb_{PLL}. Cultivation of a rice-wheat and sorghum-wheat mono-cropping caused a net depletion of SOC pool by 5.83 Mg C ha^{-1}. Though adoption of precision land leveling decreased the bulk density of the soil particularly at surface and subsurface layer due to higher SOC and increased root biomass it improves the SOC concentration significantly and ultimately increased SOC stock of the profile. SOC concentrations and stocks increased considerably with precision land leveling and alternative arable cropping systems which are possibly attributed to a larger proportion of recalcitrant organic compounds in root biomass [68]. Use of mungbean, and onion crop can result in an increase in lignin and lignin-like products, which are major components of the resistant C pool in the soil [69]. Crop production was also enhanced by the pulse crop inputs, which lead to higher total C inputs from rhizodeposition, root biomass and stubble return (Table 4).

Table 4. An estimate of total organic inputs to soil under different treatments over 10 years (2009–10 to 2018–19)

Crop Sequences	Stubble biomass C (Mg ha^{-1})	Root biomass C (Mg ha^{-1})	Rhizodeposition biomass C (Mg ha^{-1})	C build-up %	C build-up rate Mg C ha^{-1} y^{-1}	C Sequestrated Mg C ha^{-1}
T_1 R-W_{PLL}	3.21	8.79	14.68	27.9±0.7	1.06±0.08	6.7±0.2
T_2 R-W_{TLL}	2.15	8.16	13.76	29.8±0.06	1.28±0.007	5.6±0.8
T_3 S-W_{PLL}	2.98	7.93	13.56	25.9±1.6	0.96±0.08	5.7±0.2
T_4 S-W_{TLL}	2.18	7.35	12.82	22.4±1.2	0.89±0.06	5.3±0.5
T_5 R-P-Mb_{PLL}	3.97	8.92	15.12	39.3±1.8	1.13±0.021	6.8±0.5
T_6 R-P-Mb_{TLL}	2.85	8.25	14.68	37.5±3.1	1.02±0.006	6.3±0.8
T_7 R-P-O_{PLL}	4.45	9.15	15.53	41.0±2.2	1.63±0.09	9.3±0.2
T_8 R-P-O_{TLL}	3.36	8.76	14.93	40.7±2.4	1.82±0.006	8.7±0.8
T_9 R-C-O_{PLL}	4.89	9.65	16.25	43.6±0.09	1.88±0.001	9.6±0.7
T_{10} R-C-O_{TLL}	3.86	8.99	15.09	40.2±2.3	1.64±0.10	9.1±0.2
T_{11} O-W-Mb_{PLL}	4.87	9.45	13.68	39.3±1.8	1.96±0.09	9.4±0.8
T_{12} O-W-Mb_{TLL}	3.49	8.75	12.85	37.3±0.06	1.73±0.021	8.5±0.5
T_{13} M-W-Mb_{PLL}	3.86	8.96	15.46	34.2±1.8	1.36±0.07	8.2±0.1
T_{14} M-W-Mb_{TLL}	2.62	8.63	14.53	31.8±0.6	1.33±0.04	7.6±0.8
T_{15}-M-P-Mb_{PLL}	3.79	8.51	15.66	36.6±0.6	1.46±0.09	8.6±0.8
T_{16}- M-P-Mb_{TLL}	2.27	8.28	14.73	34.2±1.8	1.46±0.07	7.9±0.3

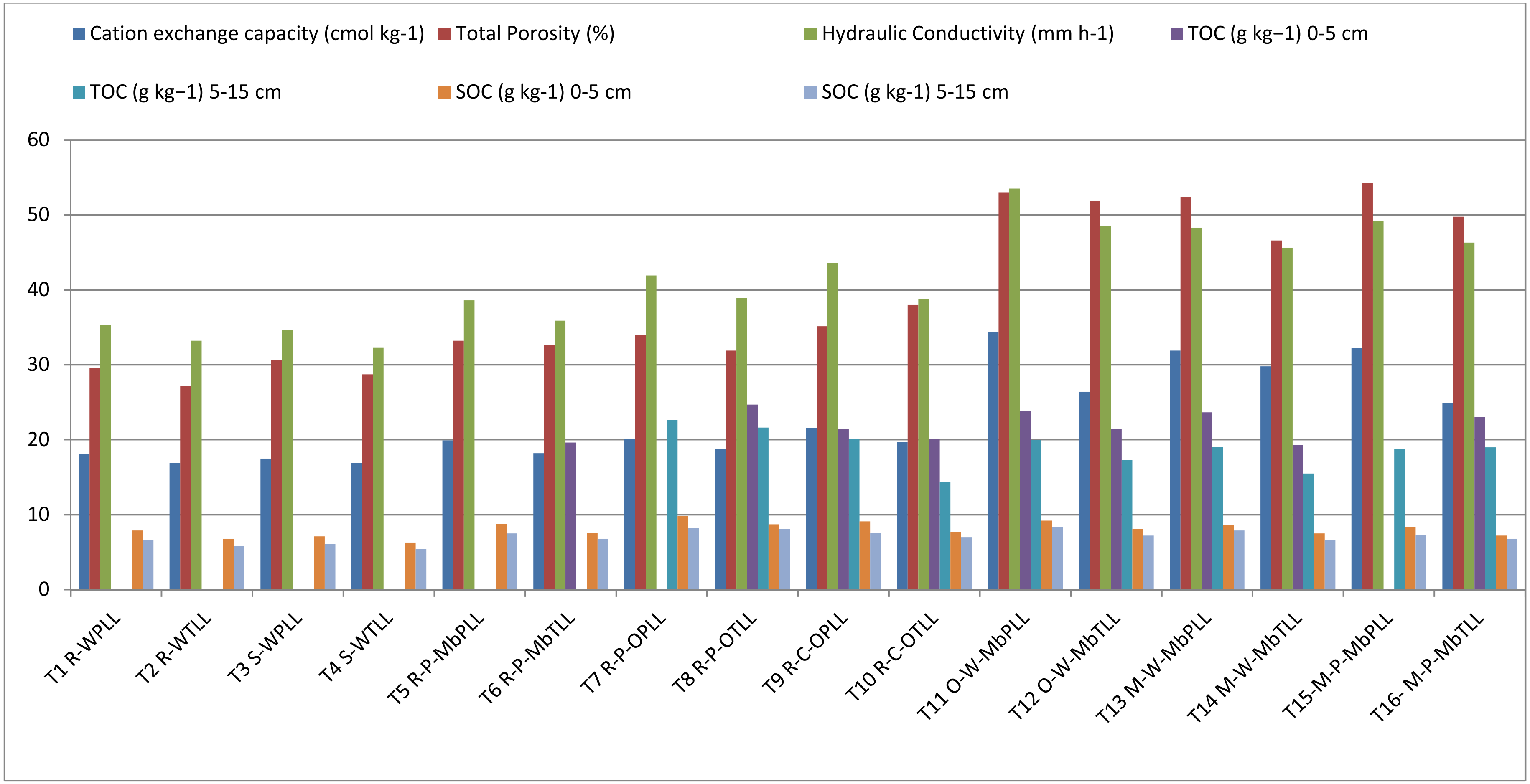

Fig. 2. Impact of 10 years of treatments application on soil physical properties and total organic carbon (TOC) and organic carbon of the soil (SOC)

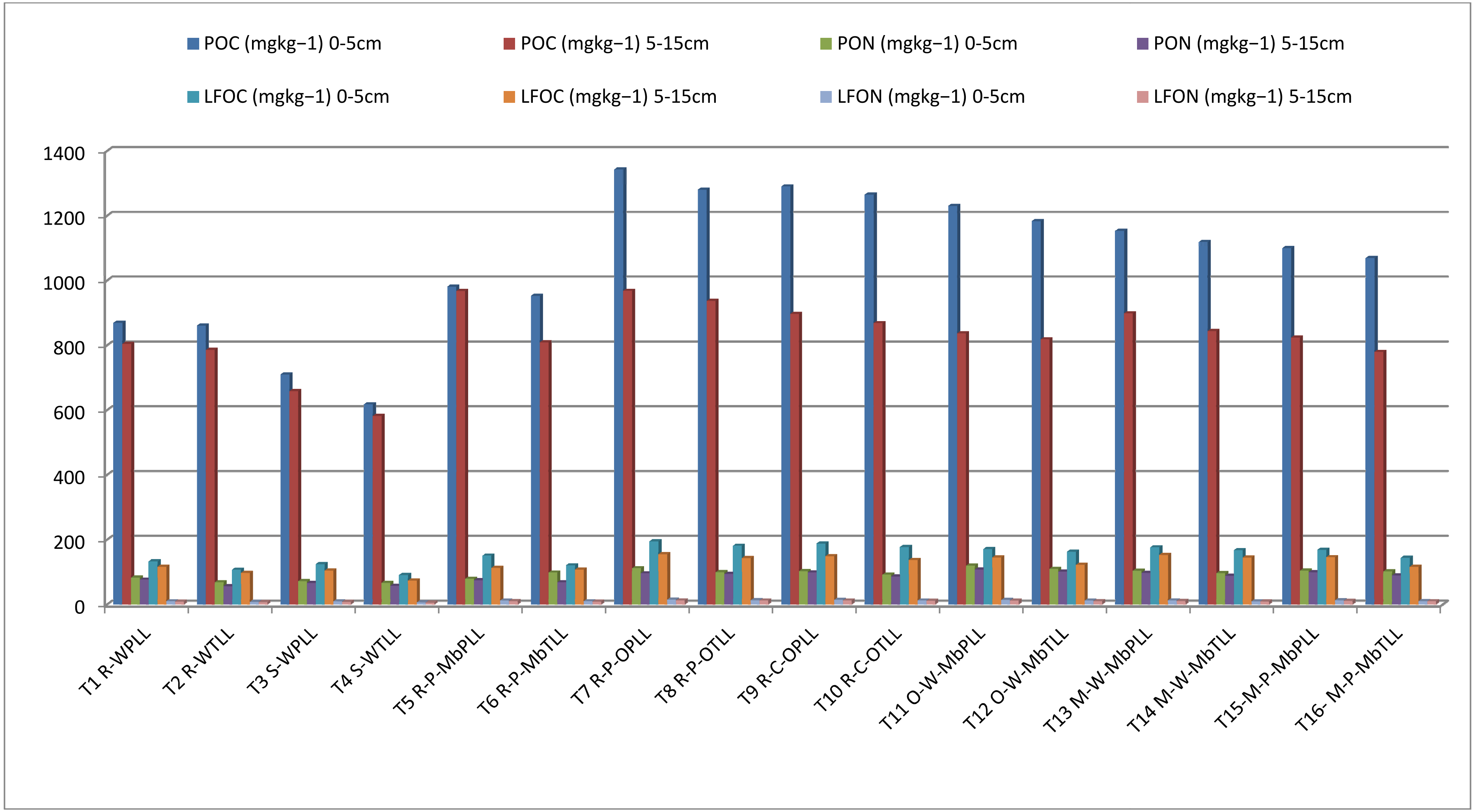

Fig. 3. Labile carbon fractions of soil as influenced by continuous arable cropping systems conventional vis-a-vis precision land levelling practices

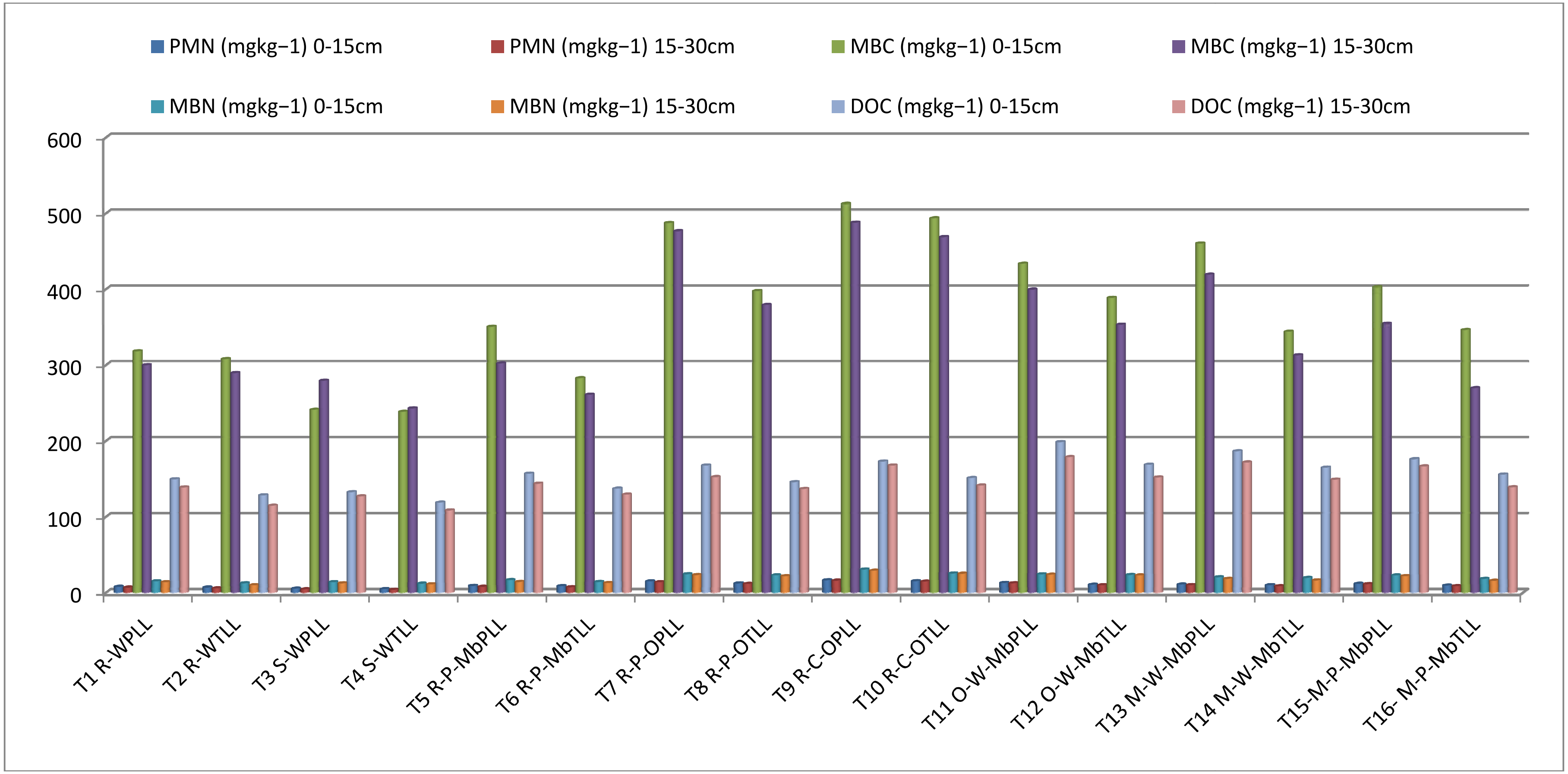

Fig. 4. Impact of treatments on soil contents of various biological fractions of carbon.

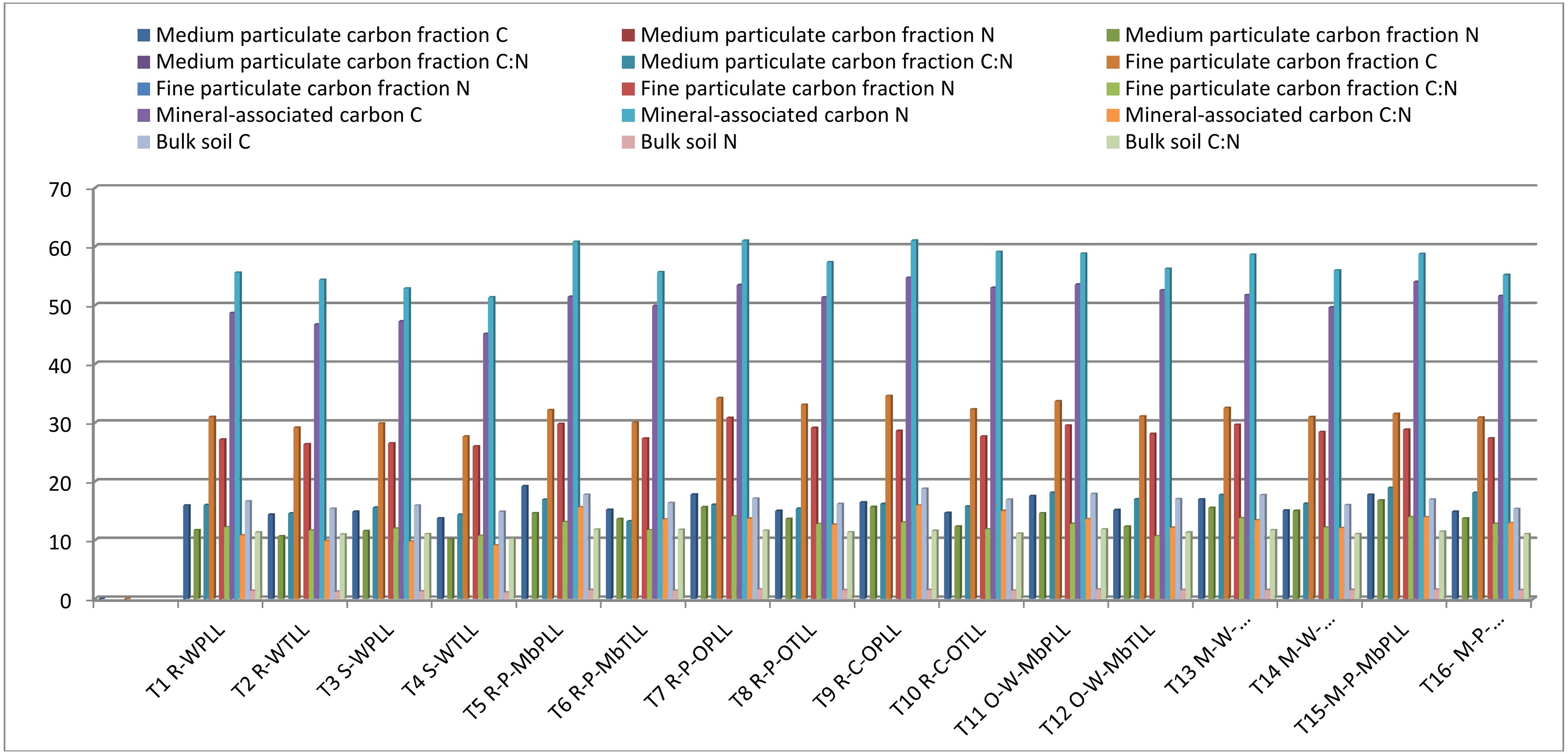

Fig. 5. Soil carbon and nitrogen contents, as well as the C: N ratio, calculated by precise land levelling and arable cropping Systems in various carbon fractions and bulk soil

4. CONCLUSIONS

Precision land levelling practices has played an important role in improving the total SOC and labile C pools content in the soil after 10 years. The long-term use of precision land levelling and arable cropping systems increased the content of SOC because there was low SOC content in the western Uttar Pradesh of India. Under R-C-O_{PLL}, O-W-Mb_{PLL} and M-P-Mb_{PL}, SOC concentrations and storage were maximum at surface soil and depth intervals down to 30 cm, below which concentrations did not improve with depth. At the same time, on average the estimate of soil C storage to 30 cm depth was higher than that for soil C accumulated to 15 cm depth. These findings suggest that the estimate of soil C accumulation to 30 cm depth was more effective than that for soil C accumulated to 15 cm depth. These labile pools were closely associated with each other and SOC, meaning that they were vulnerable to SOC changes. The labile SOC, which is often considered as the storehouse of soil nutrients, was improved under precision land levelling. Enhanced lability of surface SOC under precision land levelling practices indicates improved C quality in terms of the nutrient supply and buffering capacity. The present investigation clearly shows the superiority of precision land levelling practices over traditional land leveling for enhancing soil C, both in terms of quantity and quality.

Precision land levelling with alternative arable cropping systems resulted in markedly higher soil labile organic carbon pools than the Rice-Wheat and Sorghum- Wheat cropping system with traditional land levelling, and it could be a suitable management strategy to improve or restore soil quality. The surface soil layer had substantially higher levels of all soil health parameters than subsurface layer, presumably due to higher retention of crop stubbles, fallen leaves and root biomass. The enhanced proportions of POC, LFOC, MBC in SOC and that of PON, LFON, and DOC with the adoption of precision land levelling and alternative arable cropping systems indicate that the improvement in labile forms of both C and N was relatively rapid than Rice- Wheat or cereal based mono-cropping with traditional land levelling practices suggesting that active C and N pools reflect changes due to land levelling practices. Thus, used of precision land levelling and inclusion suitable cropping pattern could maintain the soil health under intensive agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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