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Can Cowpea Intercropped Maize-Based System with Inclusion of Short Cycle Winter Crop through Soil Moisture Conservation Practices Enhance Crop, Water, Energy Productivity and Soil Health under Long Term Organic Management?

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Abstract: Organic farming has positive, impact on environment, soil health, and healthy food quality. Worldwide demand for organic foods is increasing by leaps and bounds in recent years. The present investigation was undertaken during 2014 to 2018 to evaluate the effect of cowpea (*Vigna unguiculata*) co-culture with maize (*Zea mays* L.) on productivity enhancement over prevailing maize-fallow system, and to assess the feasibility of inclusion of short duration winter crops after maize with appropriate residue management practices on productivity and soil health. The experiment comprised of six cropping systems in main plot and three soil moisture conservation (SMC) measures options in sub plot. Results indicated that the inclusion of second crop in place of fallow and cowpea co-culture with maize increased average maize grain yield by 6.2 to 23.5% as compared to that of maize-fallow (MF). Use of maize stover mulch (MSM) + weed biomass mulch (WBM) increases maize grain yield by 19.1 and 6.5% over those of MSM and no mulch (NM), respectively. Various soil moisture conservation (SMC) measures had significant (p=0.05) effect on crop yields and water productivity. Double cropping system had significantly (p=0.05) higher amount of soil available NPK, soil organic carbon (SOC), microbial biomass carbon (MBC) and dehydrogenase activity (DHA) at 0-15 cm and at 15-30 cm depth than those under MF. The SWC measures of MSM+WBM had significantly higher available N, SOC, and MBC by 5.5, 4.8 and 8.1% than those under NM, respectively. Correspondingly, soils under MSM and MSM+WBM had 2.24 and 2.99% lower bulk density (ρb) in 0-15 cm and 2.21 and 2.94% lower ρb in 15-30 cm than that of NM. The energy use efficiency (EUE) was significantly higher under MCV (7.90%) over rest of the cropping sequences. MSM+WBM and MSM recorded 25.1 and 16.6% higher net energy over NM, respectively. The net return (INR 159.99×10^3/ha) and B:C ratio (2.86) were significantly higher with MCV system followed by MCR cropping sequence. MSM+WBM had significantly higher net return (INR 109.44×10^3/h), B:C ratio (2.46) over those under MSM (INR 97.6×10^3/h) and NM (INR 78.61×10^3/h). Overall the cowpea co-culture with maize and inclusion of short cycle winter crops along with MSM+WBM in maize-based cropping systems was found productive in terms of crop and water, profitable, energy efficient and sustained the soil health.

Key words: Crop intensification, energy balance, North East Hill Region, organic farming, soil health, water productivity

1. Introduction

The conventional crop production systems largely relies on synthetic agrochemicals, high yielding cultivars, and crop land expansion, all of which have a strong negative impact on human, animal, plant and environmental health. The major concern is that agriculture must meet the twin challenges of feeding burgeoning population, with rising demand for organic food, while simultaneously minimizing its global environmental impacts. Therefore, despite the high production capabilities, conventional production systems need to shift towards eco-friendly agriculture systems which combine low footprint of ecology to produce the crops/commodity to ensure food, nutritional, soil and environmental security. Substantial evidence indicates that organic farming has positive, however, dependent impact on environment, soil health, energy consumption and food safety. As a result the worldwide demand of organic foods has increased many folds in recent years. Presently, organic agriculture is practiced on ~69.8 million hectares (Mha) covering ~1.4% of total agricultural land of 181 countries (1). The organic farming has the potential to provide quality and safe food (2) with premium price of produce (3) compared to conventional farming. Although the productivity of crops under organic agriculture is reported lower than the conventional agriculture from many eco-regions (4,5,6) but it has the potential to contribute to sustainable agriculture (7) through enhanced soil microbial biodiversity (8,9) and build-up of soil organic matter (SOM) (10). However, low crop and biomass productivity in organic farming as has been reported by many (11,12,13) may be attributed to limiting factors, such as nutrient, water and environmental limitations. This is especially important as organic farming are mostly practiced in rainfed areas which are dependent on rainfall, low success rates of second crop on residual moisture, non-inclusion of legumes in the system and uncertain decomposition pattern of SOM. Additionally, most of the available reports on organic farming are based on single crop and not in systems approach. Thus, the overall land productivity is mostly lower than those under conventional production systems supported by inorganic nutrient management and assured irrigation. Hence, inclusion of suitable short duration crop(s) with appropriate location specific SMC practices may increase the land, water and nutrient productivity. Thus, there is an urgent need for re-designing the cropping systems for matching their water requirements including both legumes and manures as realistic approach to organic farming systems (8).

Hilly regions of eight north eastern Indian states (Arunachal Pradesh, Assam, Meghalaya, Sikkim, Manipur, Nagaland, Mizoram and Tripura) spread over 26.2 M ha and supports 49 million populations is popularly known as North Eastern Region (NER) of India. The NER without Assam which is mostly a valley land is called as North Eastern Hill (NEH) region. The NER has ~4.0 M ha net cultivated area (14) and dominated by two major cropping systems *i.e.*, rice and maize-based systems. The region is blessed with high rainfall (2450 per annum) >80% of which is received during pre-rainy and rainy season (March to October) while very scanty and/ or no rainfall is received during winter season from November to March. Therefore, region is mostly dominated by mono-cropping of rice and/or maize. Further, low use of synthetic fertilizers and chemicals (< 12.0 kg ha^{-1}), plentiful availability of biomass and animal excreta is the specialty of the region which provides ample opportunities for organic food production (15,10). Thus, Government of India has identified NER as potential hub for promoting organic farming and Sikkim was declared the first organic state of country in 2016. Organic farming-a system has the capability to produce food with minimal harm to ecosystems, animals or humans-is often proposed as an option in the region. However, critics argue that organic agriculture may have lower yields and would, therefore, need more land to produce the same amount of food as conventional farms, resulting in more widespread deforestation and biodiversity loss, and thus, undermining the environmental benefits of organic practices. But a systematic and credible research for enhancing the productivity of organic farming is lacking specially from hilly ecosystems. However, credible evidence is available that crop and land intensification with site specific best management practices enhances the crop as well as system productivity both in rainfed and irrigated areas. Thus, it is pertinent to evaluate the crop intensification/diversification, moisture conservation and fertility restorative practices under organic management system for sustainable agriculture. In the NEH region of India, maize is the predominant cereal crop in rainy season (16). Maize is the dominant crop in Sikkim as well. Maize crop has very wider adaptability, can be grown under rainfed condition and a suitable crop for organic system during rainy season. Owing to its growth pattern, and wider planting space (17) there lies opportunities for inclusion of a leguminous cover crop as intercrop with maize. Cowpea is suitable and tested intercrop in the region (18) in maize to utilize ground cover with concurrent acquisition of nutrients from deeper soil layers, providing N through biological fixation and addition of organic matter after chemical desiccation to soil (19). Legumes have the ability to mitigate soil nitrogen (N) deficiency through symbiotic biological N_2 fixation and phosphorus (P) deficiency by changing the soil pH of the root zone (20,21). Association of cereal and legume crops has potential to enhance yields in cropping systems under organic crop production (22, 21, 23, 24). Cropping systems has the ability to change the SOC levels through addition of crop residues and soil aggregation (25, 26). Cowpea intercropped with maize is reported to considerably increase rhizospheric P availability (20) which is a limiting factor in acid soils. Thus, a systematic research on inclusion on cowpea as intercrop under maize-based cropping in acid soils for organic farming is warranted.

Diversification of mono-cropped maize system with the inclusion of leguminous crops is of paramount importance for enhancing productivity, sustainability and farmers' income. Substantial increase in SOC is often reported from intensive multiple cropping systems (27, 28, 29). Hence, the identification of efficient cropping systems is the main source for the efficient organic production systems. Cultivation of winter crop after maize is hardly possible in hills due to non-availability of soil moisture and adequate nutrition under organic agriculture. Therefore, the proper organic nutrition to meet the nutrient demand for rainy and winter season crop in system is a major challenge. Further, weed menace also affects the growth and development at initial growth stages of maize under organic condition resulting in low productivity during rainy season. Growing winter (*Rabi*) season crops on sloping and upland hilly region (70% of the region) without suitable soil moisture conservation measure is almost terrible (30). Abundant amount of organic manure availability (46 million mega gram (Mg)) and relatively high SOC (15.0-35.0 g kg^{-1}) provides opportunity to use as mulch for sustaining the organic farming (31,32). Bio-mulching is one of the options to utilize the residual soil moisture for growing second crop during winter season after harvest of rainy maize. Bio-mulching provides buffering effect to reduce the negative environmental influence of soil (33), improves physical and chemical properties of soil, checks soil erosion by reducing runoff and increasing infiltration by providing more opportune time (34), helps in regulating soil temperature, minimizes evaporation loss to air and checks weed growth (35,36). The maize stalks after harvesting of cobs/grains along with locally available weed biomass as mulch may enhance physical and chemical conditions (37). In addition, the use of crop and weed biomass as mulch in agriculture provides many benefits to the soil by increasing nutrient cycling, promoting soil enzyme activity and enhancing soil aggregate stability. Furthermore, the use of crop and weed biomass as mulch not only conserves the soil moisture but its slow decomposition initiates the formation of SOM and micro aggregates and subsequently, to that of macro aggregates through binding of SOC to diverse clay and silt fraction by following hierarchy theory of aggregation. The formation of stable soil aggregates and improvement in soil structure are attributed to addition of plant biomass and subsequent increase the micro porosity in soil which helps in storing more water for a longer period. However, the performance of these agronomic measures alone and in combination has not been tested under organic farming systems. In view of these facts and considering cost effectiveness and wider adoption among the farming community, maize stover and locally available weed biomass were evaluated for the *in situ* SMC. Maize stalks are not frequently been used as fodder mainly due to availability of green fodder during rainy season and also due to its quality deterioration after harvest owing to high humid condition in rainy season. Thus, maize stalks are either removed from fields or burned. Hence, the present investigation was undertaken to test the hypothesis whether intercropping of cowpea in maize and subsequent cultivation of winter (second) crop on residual moisture with surface application crop/weed biomass enhances crop, water, energy productivity and soil health in comparison to business as usual (maize-fallow system) under organic management. The specific objectives of study were: 1) evaluate the effect of cowpea co-culture with maize in maize-based system on productivity enhancement over prevailing maize fallow system, and 2) study the feasibility of inclusion of short duration winter crop after maize on residual soil moisture with appropriate residue management practice for enhancement of productivity and soil health.

2. Materials and Methods

A four year (2014-15 to 2017-18) field experiment was conducted to study the feasibility of inclusion of winter season crops after rainy season maize co-culture with cowpea under organic rainfed condition.

2.1. Experimental site

The experimental site is located in the leap of North East Himalayas, India. The Research Farm of ICAR-National Organic Farming Research Institute, Gangtok, Sikkim, India (Formerly ICAR Research Complex for North Eastern Himalaya, Sikkim Centre) is located at 27^{o}32’ N latitude, 88^{o}60’ E longitude with an altitude of 1350 meter above mean sea level. The field was under organic management practices since, 2005 and maize crop was sown before study to confound the effect of previous treatments. Soil samples were collected prior to initiation of the treatment imposition randomly from the experimental plots at a depth of 0 to 30 cm and analyzed as per the standard procedures. Soil of the experimental site was sandy loam in texture, deep and free from hard pan and gravels (Haplumbrepts). The SOC content (12.1 g kg^{-1}) of the soil was determined by TOC analyzer (ElementerVario Select, Germany) following dry combustion method (38). The available soil N. P and K determined following procedures as suggested by Prasad et al. (39) were 322.7 kg ha^{-1}, 16.1 kg ha^{-1}, and 338.9 kg ha^{-1}, respectively. The pH of the soil was 5.7 (1:2.5 soil and water ratio) and bulk density (ρb) was 1.35 Mg m^{-3} (core sampler method).

2.2. *Weather*

The metrological data was obtained from meteorological observatory (IMD) at ICAR-National Organic Farming Research Institute, Gangtok, Sikkim. Long period average (30 years) total rainfall of the region is 3057.3 mm. The experimental site received cumulative mean total rainfall of 2946.3 mm during 2014-18. Almost >80% of the total rainfall was received during mid of March to end of September. Variation in temperature was observed across the years during experimentation, maximum temperature (mean value of four years) was recorded in May (28.3˚C) while minimum temperature was recorded in January (7.3˚C) during the crop growing season. The mean temperature, relative humidity, rainfall and sunshine hours at the experimental site from 2014-18 are depicted in Fig. 1, 2.

2.3. Experimental design and treatment details

The experiments was laid out in a split plot design with six treatment combinations of cropping sequences *viz*., maize–fallow (MF), maize + cowpea–rapeseed (MCRs), maize + cowpea–buckwheat (MCBw), maize + cowpea–barley (MCB), maize + cowpea–vegetable pea (MCV) and maize + cowpea–rajmash (MCR) in main plots, along with three mulching as *in-situ* organic soil moisture conservation (SMC) practices *viz*., no-mulch (NM), maize stover mulch (MSM) and maize stover + weed biomass mulch (MSM+WBM) in sub-plots. The 30% of the total harvested maize stover was used as maize stover mulch (MSM) and applied to the winter season crops at 10 days after sowing. While mixed weed biomass was collected from adjoining areas of cultivated field and applied @ 5.0 Mg/ha fresh weight basis along with MSM at 10 days after sowing of winter season crops. The maize crop was sown in the month of March every year. While the winter season crops were sown in the last fortnight of September every year.

Maize crop was sown at a spacing of 60 cm × 20 cm. Cowpea was grown as an intercrop (2+1) in between rows of maize at 20 cm plant spacing. Recommended doses of N to each crops were applied through mixed compost (MC), vermicompost (VC) and neem cake (Table 1). The treatment combinations were replicated three times and same plots were maintained for respective treatments during the four years of experimentation. The gross plot size was 3.5 m × 3 m. The details of cultivars used, their duration, spacing, time of sowing and recommended doses are presented in Table 1.

2.4. *Crop management*

Individual plots were thoroughly prepared by manually operated power tiller with a view to avoid the mixing of the soil in different plots with different nutrient treatments. Organic nutrients were applied as per the recommended dose of N to the individual crop (Table 2). The detailed nutrient composition of different mulching materials and organic inputs is given in Table 2. Neem cake and mixed weed biomass had N contents of 31.8 g/kg and 25.8 g/kg, respectively. Other nutrient elements that were analyzed are P, K and C. Neem cake (NC) had the highest P content (9.7 g/kg) followed by mixed weed biomass (7.2 g/kg) and the lowest P content was in vermicompost (VC) (5.9 g/kg). Mixed weed biomass (448.5 g/kg) and VC (312.7 g/kg) had the highest and the lowest C content, respectively. The combination of mixed compost (prepared from farmyard manure and locally available biomass), VC and NC were used for organic nutrition. The full amount of well decomposed mixed compost (MC) was applied prior to sowing in all the crops. While VC and NC were applied in furrows opened for sowing of the crops. Weeds were managed by manual hand weeding twice at 20 and 40 days after sowing (DAS) followed by earthing up in maize while two manual weeding was done at 20 and 40 DAS in all the winter season crops. As preventive measure of insects' pest and diseases, seeds were treated with *Trichoderma* sp. @ 4 g/kg for each crop prior to sowing. Neem oil (1500 ppm) @ 5 ml/l of water was applied for management of aphids, white fly *etc.* at 10 days interval for 2-3 times during winter season crops.

2.5. Harvesting and economic yield

Maize crop was harvested at maturity stage during the first fortnight of August in all the years. While the cowpea green pods were harvested during second fortnight of May to first fortnight of June during all the years. Fresh yield of cowpea was recorded immediately after harvest. Maize cob was removed manually by using a sickle and the stover harvested immediately after removal of cobs. The net plot area of 3.0 × 2.5 m^2 was considered for measurements of maize grain yield. The harvested biomass and cob was kept at threshing floor for 5-6 days for sun drying. The maize grains from cob were removed by manual maize sheller. Grain yield of maize was recorded at 14% moisture content for all the years and converted into Mg/ha. Similarly, winter season crops were also harvested at their physiological maturity by sickle. Cowpea and vegetable pea pod were picked at 60-65 days after sowing in each year. Except cowpea and vegetable pea other crops were harvested manually at their physiological maturity and observations on yields of respective crops were recorded. After threshing and cleaning yield were recorded at 14% moisture level and reported into Mg/ha.

2.6. Economics

The variable and fixed costs were used for obtaining of cost of cultivation which was based on the prevailing market price of organic inputs (2017-18). The gross returns, net returns and benefit cost (B:C) ratio of different cropping systems and SMC measures were computed from the cost incurred for different organic inputs and the sale price of the produce/output. The net return was calculated by deducting cost of cultivation from gross return. While the B:C ratio was obtained by dividing gross return with the cost of cultivation. The sale prices of various outputs were: maize grain INR 15000/Mg, cowpea pod INR 24000/Mg, rapeseed seed INR 40000/Mg, buckwheat seed INR 20000/Mg, barley seed INR 15000/Mg, vegetable pod INR 50000/Mg and rajmash INR 70000/Mg. Since prices of different outputs are based on the prevailing market prices the economics presented may change as per the market situation and demand. All economic parameters were calculated by using the formulae given by Babu *et al.* (40).

Maize equivalent yield (MEY)

$$\mathrm{MEY} = \mathrm{Ya}\,(\mathrm{Pa})/\mathrm{Pm}$$

Where, Ya is the yield of crop a (t/ha of economic harvest), Pa is the price of crop a, and Pb is the price of maize

2.7. Energetics

The energy input is dependent on direct and indirect renewable and non-renewable energy which consists of diesel, human power and electricity, while the indirect energy contains seed, farmyard manure (FYM), pesticides and machinery. The input energy and its conversion to energy equivalents was done by multiplying their per unit energy equivalents (41). The farm produce (seed and straw yield) was also converted into energy in terms of energy output (MJ) using crop yields multiplied by their energy equivalents per unit. Based on the energy equivalents of the inputs and output, energy use efficiency (EUE), energy productivity (EP), energy intensity in physical terms and energy intensity in economic terms were calculated (39).

2.8. Soil sampling and analysis

The soil samples were collected after completion of four cropping cycles from 0-30 cm depth from each plot for analysis of physico-chemical properties. The soil was analyzed for ρb, pH, SOC, available N, P and K, soil microbial biomass carbon (SMBC), dehydrogenase activities (DHA) and acid phosphatase activities. Dry combustion method (38) was used for determination of total soil C using TOC analyzer (ElementarVario Select, Germany). It was assumed that SOC value is equal to total soil C with negligible inorganic C concentration as the pH of the soil < 7.0 (42). The alkaline permanganate method (43) was used for analysis of available N in soil; available P was estimated by $NaHCO_3$ (44) spectro-photometrically (880 nm); and available K was determined by neutral normal NH_4OAc extraction using flame photometer (45). The soil fumigation technique (46) was used for determining the SMBC. The DHA of soil was analyzed by the procedure suggested by Tabatabai (47) by reducing 2,3,5-triphenyl tetrazolium chloride (48). The ρb was estimated by using a core method of 5.6 cm and 5.1 cm diameter at 0-15 cm and 15-30 cm depth and oven dried at 105 $^{\circ}$C from each plot (49).

2.9. Water productivity

Water productivity was calculated by dividing grain yield obtained from different winter season crops (kg/ha m^{-3}) with crop water requirement (ETc). The crop water requirement value (ETc) was estimated by multiplying reference evapotranspiration (ETo) (16). The reference evapotranspiration (ETo) value was obtained from pan evaporation data recorded at IMD station. The crop coefficient (Kc) value was obtained by devising growth stages into four equal stages and the respective Kc value was taken from FAO-56 (50). The summed value of all the four stages revealed the total water requirement (ETc) of respective crops grown during winter season.

2.10. *Statistical analysis*

The experimental data were subjected to analysis of variance (ANOVA) and significance was estimated by test of significance (51). The overall statistical differences among the treatments was tested with appropriate least significant difference (LSD) value at 5% probability (*p*=0.05)

3. Results and Discussion

3.1. *Nutrient content of different inputs*

Nutrient content of different plant biomass and organic manures applied in this experiment is presented in Table 2. NC had the highest content of N (31.8±3.1 g/kg) and K (12.6±1.2 g/kg) followed by mixed weed biomass (N 25.8±4.6 g/kg and K 11.1±1.2 g/kg) while maize stover had the lowest content of all the nutrients (Table 2). Mixed weed biomass was rich in P (7.2±1.5 g/kg) and C (448.5±54.3 g/kg) whiles the lowest in VC (P 5.9±0.8 g/kg and C 312.7±56.4 g/kg). The higher content of N and K in NC attributed to the concentration of nutrient in cake after oil extraction. However, more nutrient content in mixed weed biomass might be because of its being an admixture of various nutrient rich plants. Weed plants are generally rich nutrient than their crop counterpart (52). Thus, use of weed biomass provides an opportunity for nutrient recycling and soil moisture conservation provides and helps in productvity enhancement and mangement of noxious weeds.

3.2. Operation-wise energy utilization pattern

Total energy inputs ranged from 1343 to 11045 MJ/ha under different maize-based cropping sequences (Table 3). Cultivation of rajmash (11045 MJ/ha) followed by maize (10273 MJ/ha) required maximum energy inputs. The highest use of energy in rajmash and maize cultivation is attributed to the high requirement of nutrients of these crops and subsequently laid high use of organic manure. It is evident that among all the management practices/operations with regard to individual crop organic nutrient management has the highest share of input energy followed by farm machineries and labour. The total energy input was lowest with intercropping of cowpea (1343 MJ/ha) with maize followed by rapeseed (6717 MJ/ha). The lowest energy was consumed in land preparation operation (31 MJ/ha) while the maximum energy was consumed for organic fertilization to each crop in maize-based cropping sequence.

3.3. Maize and cowpea yield

The maize grain yield varied significantly among the different cropping sequences across the years except the year of establishment. The inclusion of second crop in place of fallow and cowpea intercropping increased average maize grain yield by 6.2 to 23.5% as compared to that of MF. Intercropping cereals with legumes have the potentially to enhance productivity and soil fertility (53, 54). This might have attributed to the higher yield of maize grain under other cropping sequences than those produced by MF. Inclusion of second crop in place of fallow might have attributed to higher growth and development of maize-led higher grain yield because the addition of 2nd crop may supply the additional organic matter to soil which helps in building of plant available essential nutrient. The dynamics of nutrients in organic manures is different from inorganic fertilizer in soil. The organic manures releases nutrient slowly in the soil, approximately 30-40% of nutrient present in organic manure may be available to 1st crop (55) and rest of it is utilized by subsequent crops. That might be the mechanism which is responsible for higher yield of maize after inclusion of second crop than that of MF. Cropping sequences, MCV produced significantly higher maize grain yield than the other cropping sequences but remained at par with MCR after second year onwards. Maize grain yield reflected a variable trend in diverse cropping sequences over the years. Maize grain yield decreased over the years under sequences of MF, MCRs, MCBw, MCB (Fig 3). At the end of fourth year, the mean maize grain yields of previous three year were 2.02 to 11.97% lower than those over 1st year yield (3.5 to 3.7 Mg/ha) under MF, MCRs, MCBw and MCB cropping sequences. However, the magnitude of yield decline was highest in MF (11.97%) and lowest in MCBw (2.02). Whereas, on one hand the three year mean yield of maize grain under MCV and MCR were 9.9% and 1.4% higher over their respective first year yields (Fig 3). Under an organic production system, there are two main ways to supply the crop N requirements: introducing or reinforcing legumes in crop rotations and/or using organic amendments allowed for organic farming. Legumes must be able to fulfill their own N needs, by fixing atmospheric N_2, and must supply enough N for the succeeding crops (56). Increase in crop yield through intensification involving legumes is reported by many researchers (57, 58). While comparing the mean yield of four years, significantly higher maize grain yield was recorded in MCV cropping sequence (3.94 t/ha) followed by MCR (3.84 t/ha) than those under other cropping sequences (Table 4). MCV cropping sequence produced 23.5, 15.5, 10.4 and 2.6% higher maize grain yield than the MF, MCRs, MCBw, MCB, and MCR sequences, respectively. The yield enhancement in MCV system may be due to better physiological and biological growth rate of maize. Inclusion of vegetable pea had several positive effects on soil like fixes atmospheric N, improves soil aggregation and helps in building soil fertility and subsequently leads to higher productivity of succeeding crop (59, 60). The intercropping of cowpea with maize not only increased the maize grain yield but it also provided an additional pod yield (1.45 to 1.60 Mg/ha) for vegetable purpose. However, the pod yield of intercropped cowpea was marginally greater under MCV (1.60 Mg/ha) followed by MCR (1.59 Mg/ha) than those under other cropping sequences (Table 4). The inclusion of cowpea as intercrop in maize has a myriad of benefits *e.g.*, suppression of weeds, protection of soil carbon and nutrient loss due to high and intense rainfall in hilly region, fixation of atmospheric N, improvement in soil health and many more (18), all these factors might have contributed to higher yield of maize. The entire biomass of cowpea was left on soil surface as *in-situ* mulch which on decomposition might have improved the overall soil health resulting in further yield improvements when compared to sole maize. There are many reports that inclusion of legumes in cereal-based cropping sequences enhanced the availability of N through the symbiotic biological N fixation and increasing the availability of P by changing the soil pH in the rhizosphere (20, 61, 21, 23). The acid soils have high P fixation capacity in the form of Fe and Al phosphate. The inclusion of pulses in cropping systems can moderate the soil pH and increases the P availability leading to higher system productivity (62).

Use of mulches during winter season to conserve the soil moisture not only increases the productivity of winter crop but it also has significant effect on productivity of succeeding crops. In our study MSM alone and MSM+WBM applied during winter produced higher maize grain yield than that with NM from second year onwards. During the first year, the effects were not significant because mulch was not applied to the crop prior to maize. Maize grown on residual effect of MSM+WBM produced higher grain yield over those under MSM and NM. Similarly, maize grain yield under MSM was significantly higher than that of NM. Use of MSM+WBM increased maize grain yield by 19.1 and 6.5% over MSM and NM, respectively. Cowpea as intercrop under maize yielded higher pod yield under MSM+WBM (1.31 t/ha) compared to that under MSM (1.27 t/ha) and NM (1.22 t/ha). Improvement in soil health and plant available nutrient due to application of diverse mulches might have attributed to higher maize grain and cowpea pod yields than NM. Mulching play a vital role by improving soil physical properties leading to increase in aggregation, infiltration and reduction in erosion loss (63,36,64,18) all of these might `at have attributed to higher plant growth and yield of crops. Furthermore, use of MSM+WBM might have reduced the weed infestation covering the soil surface, hence most of the broad leaves weed did not emerge from surface due to physical impedance (65,66) and provided a competition free environment for growth and development of crops, leading to higher maize and cowpea yields.

3.4. System productivity

Among the cropping sequences, MCV registered significantly higher system productivity (12.11 t/ha) compared to all other systems tested. Increase in crop yield through intensification is reported from many regions of the world (57,58). Intensification of MF cropping system with intercropping of cowpea and through inclusion of second crop on residual soil moisture increased system productivity (67,68).

Among all the mulches, crops grown with MSM+WBM produced highest yield (8.73 t/ha) while the lowest was registered under NM (7.06 t/ha). Average yield over four years was more with MSM alone and MSM+WBM by 7.5 and 23.7 per cent respectively over NM. Increase in system productivity with double mulching comprising retention of previous crop residues along with external application of weed biomass has been previously reported Das et al. (37).

3.5. Yield of winter season crops

The yields of all the winter crops were significantly higher under MSM+WBM as compared to those under MSM and NM (Table. 6). Average yield of rapeseed was by 37.2 and 17.1% higher under MSM+WBM than those under NM and MSM, respectively.

Similarly, buckwheat yield was 46.8 and 10.8% higher under MSM+WBM compared to NM and MSM, respectively. However, the increment in terms of yield increase was the highest in case of barley (73.1 and 12.8%) and rajmash (45.5 and 15.3%) under MSM+WBM over NM and MSM, respectively. Mulching increases in soil moisture content and plant available water, moderate soil temperature, promotes soil aggregation and builds SOM (69,70) which might have contributed to higher yield of winter crops.

3.6. Water productivity

Water productivity (WP) of rapeseed, buckwheat, barley, vegetable pea and rajmash was significantly (p=0.05) influenced by different SMC measures (Table 6,7,8). Among the winter season crops, rapeseed had minimum WP (0.79 to 1.07 kg/m) while maximum was in vegetable pea (3.86 to 4.95 kg/m). Use of MSM+WBM in winter crops enhanced WP than the use of MSM and NM. The highest WP of vegetable pea was due to cumulative effect of higher yield corresponds to short duration. In-field residue retention or straw mulching is an effective practice which promotes water conservation by reducing soil water evaporation during the summer fallow period (71), which can increase WP by 25 to 46% (63,72,73). In the dry season, when compared with NM, the mulch treatments increased WP significantly which was attributed to the increase in available soil moisture. This indicated that crop residue retention is more beneficial when soil moisture and precipitation is limiting. As other studies have shown the application of mulch or retention of plant residue on the soil surface improves soil hydrothermal properties and thus, decreases evaporation and increases WUE (74). Mulch treatments improved the yield of winter crops thereby increasing WP.

3.7. Soil health

Soil health is an interactive function of physical, chemical and biological properties (75,76). Changes in any of these properties affect the soil functioning and productivity (77,78). Soil properties like, ρb, SOC (SOC), available N, P, K and MBC, DHA were significantly affected by the different cropping sequences and mulches (Table 8). Available N in top 0-15 cm (373.1 kg/ha) and 15-30 cm (366.0 kg/ha) under MCV cropping systems was significantly greater than those under soils of other cropping sequences (330.3 to 362.4 kg/ha in 0-15 cm and 323.2 to 357.3 kg/ha in 15-30 cm). Generally, available N. P and K were higher in top 0-15 cm than that of 15-30 cm soil depth. Soils under maize-winter crop systems had significantly higher amount of available NPK at both the depths under study (0-15 cm and at 15-30 cm) over MF. Available P was significantly higher in 0-15 cm (18.6 kg/ha) under MCBw over the soils under MF and MCB but remained at par with rest of the treatments. Similarly, in 15-30 cm, MCBw cropping system had higher available P than the soils under other cropping sequences. Cropping sequence MCBw had 12.7 and 9.9% higher available P than that under MF at 0-15 and 15-30 cm, respectively. Herein, inclusion of legumes did not significantly effect changes in available P as compared to other crops in the system. Soils under cropping system MCV had significantly higher available K (436.9 and 437.7 kg ha^{-1} at 0-15 cm and 15-30 cm, respectively) over soils of rest of the systems under study. The lowest amount of K was reported under MCB at 0-15 cm (334.2 kg/ha) while MF at 15-30 cm (329.1 kg/ha).

The plant available nutrients (N, P and K) were significantly influenced by different SMC measures used in this study. MSM+WBM had significantly higher available N in both the soil layers of 0-15 cm (357.9 kg/ha) and 15-30 cm (352.1 kg/ha) than the soils under MSM and NM. Plant available P and K had shown a trend similar to that of available N at 0-15 cm and 15-30 cm depths. Plant available P was 5.8 and 5.5% higher in soils under MSM+WBM and available K was 1.5 and 2.0% higher than the soil under NM at 0-15 cm and 15-30 cm depth, respectively. The plant available N, P and K concentration under MSM+WBM and MSM might have been higher mainly due to more favourable and congenial conditions for mineralization of added biomass than NM. Generally, organic mulches viz., maize stover and weed biomass used under study was rich in P and K, that might have attributed to higher available P and K than NM.

The SOC concentration was relatively higher in upper layer of soil (0-15cm) as compared to deeper layer (15-30 cm). Intensified cropping sequence (maize+cowpea-winter crops) had significantly higher SOC concentration at both the depths (0-15 cm and 15-30 cm) than the plots under MF. Cropping sequence MCV had significantly higher SOC (13.9 g kg^{-1} and 13.6 g kg^{-1}) at 0-15 cm and 15-30 cm depths than under rest of the sequences. The higher SOC concentration under different intensified cropping sequences might be due to the addition of more root biomass in four cropping cycles as compared to MF. Generation of more biomass of MCP might have attributed to higher SOC concentration under MCV than the soils under other cropping sequences and MF at both the soil depths. Studies suggested that relatively higher SOC is indicator of positive soil productivity (29). Hence, inclusion of legumes in maize-based mono-cropping system under organic farming may have the ability to enhance the SOC value (79,80).

Mulching increased the SOC concentration because of decomposition and release of C in soil. MSM+WBM had 5.5 and 4.8% higher SOC at 0-15 cm and 15-30 cm depths than those under

NM, respectively. Similarly, MSM also had 3.14 and 3.2% higher SOC than NM at 0-15 and 15-30 cm depths, respectively. The higher SOC concentration under different SMC measures were mainly attributed to long term application of crop residue as organic inputs having higher OC (37).

The ρb after completion of four cropping cycles was significantly affected by different cropping sequences. Intensified cropping sequences had relatively lower ρb compared to that under MF. Relatively lower ρb was observed at surface (0-15 cm) as compared to the deeper layer (15-30 cm). The results are in contrasts to the findings of others where cropping sequences have failed to show any significant effect on ρb (81). In our study the higher ρb value may be due to compaction under MF. Addition of relatively more root biomass and incorporation more organic inputs under intensified cropping sequences than MF might have reduced ρb under the present study.

Application of different SMC measures reduced the ρb than that under NM. Soils under MSM and MSM+WBM had 2.24 and 2.99% lower ρb at 0-15 cm and 2.21 and 2.94% lower ρb at 0-15 cm depth than that of NM. The application of SMC measures improved the physical soil properties thereby enhanced the total soil porosity (82) and subsequently reduced the soil ρb.

Both MBC and DHA were significantly higher in soils under intensified cropping sequences as compared to those under MF. Cropping sequence MCV had significantly higher MBC (355.9 μg g^{-1} soil) and DHA (16.43 μg/g soil) when compared with all other cropping sequences and MF. The lowest MBC (247.4 μg/g soil) and DHA (11.55 μg/g soil) was registered in soils under MF. Addition of more organic matter through root biomass for different diversified cropping systems having leguminous crops increased the microbial activity which promotes micro-aggregates to form macro-aggregates which are particularly held by fungal hyphae, polysaccharides and fibrous roots (37).

Different SMC measures had shown significant effect on MBC and DHA after four cropping cycles. The MBC and DHA were significantly higher under MSM and MSM+WBM than those under NM. The soils under MSM+WBM and MSM recorded 8.1 and 5.7% higher MBC than NM. Similarly, DHA value was 10.0 and 6.0% higher under MSM+WBM and MSM than NM, respectively. Plant and weed biomass mulching improved the physical condition of soil that might have enhanced the MBC and DHA activities in soils.

3.8. Energy analysis in cropping system

Energy consumption in agriculture sector mainly involves machines, labour, input used and diesel. Under organic production systems it is necessary to reduce the energy consumption and to enhance the energy productivity to overcome the worldwide growing energy demands in agriculture sector. In the present study, cropping sequence MF had required lowest energy input (10610 MJ/ha) while MCR had maximum energy input (23066 MJ/ha). The gross energy output was significantly influenced by diversified cropping sequences. Among the sequences, MCV recorded significantly higher gross energy output (155962 MJ/ha) over rest of the treatments. All the cropping sequences had significantly higher gross energy output over MF. Similar trends were also found in net energy output. EUE was significantly higher under MCV (7.90%) over rest of the cropping sequences. Energy productivity was higher with MCV but varied response was observed for other cropping sequences. Among the diversified cropping sequences, MCR had significantly higher energy productivity in physical terms (1.37 MJ/kg) over all other sequences. MCB had significantly higher energy productivity in economic terms (1.98 MJ/ha) over the rest of the cropping sequences. Substantially higher energy input under MCR was mainly due to higher N used for production and also other inputs having higher initial energy value. The lowest energy productivity under MF (0.95 kg/MJ) was due to mono-cropping of maize. Relatively higher energy output was recorded under diversified cropping sequences compared to sole maize. Higher grain and biomass yields with corresponding energy value were reflected in MCV over other cropping sequences. Similarly, higher EUE and EP were also reflected under MCV cropping sequence over others. The lower energy productivity in physical terms was recorded under MCV cropping sequence. However, lower economic productivity was observed under MCR cropping sequence followed by MF.

The MSM+WBM produced significantly higher gross energy output (130226 MJ/ha) over MSM and NM. Similar trends were followed for net energy output. MSM+WBM and MSM had 25.1 and 16.6% higher net energy over NM, respectively. The EUE was also significantly higher under MSM+WBM (1.09%) followed by MSM (1.04%). Energy productivity in economic terms was 12.8 and 8.3% lower under MSM+WBM and MSM than that of NM.

3.9. Economics

Economic analysis (Table 10) indicated that the highest cost was incurred in MCV cropping system [INR85,587/ha (INR is Indian Rupees and 1 US $65.13 INR in April 2018)] followed by MCR (INR 78,347 /ha). The lowest cost was incurred in MF system (INR 37,940/ha). This was because the highly intensified system involved more input, labour and other cost for managing the crop throughout the year. However, the net return (INR 159.99 $\times 10^3$/ha) and B:C ratio (2.86) was significantly higher with MCV system followed by MCR cropping system. This was due to higher system productivity of crops by growing three crops in a year. On the other hand, the lowest return and B:C ratio (1.76) was recorded in MF cropping system. This can be attributed to variation in yield, cost of cultivation and prices of economic produce of component crops of cropping systems. Increase in net returns and benefit cost ratio with inclusion of high value crops in cropping systems have also been reported by several workers (83,84)

The highest cost was incurred for MSM+WBM (INR 71,355/h) followed by MSM (INR 70,522/h). The higher cost in MSM+WBM and MSM compared to NM was due to the labour cost and cost of organic mulches. Gross returns was significantly higher under MSM+WBM (INR 180.8$\times 10^3$/h) followed by MSM (INR 168.19$\times 10^3$/h) and lowest with NM (146.22$\times 10^3$/h). Similarly, significantly higher net returns were observed under MSM+WBM (INR 109.44$\times 10^3$/h) under MSM (INR 97.6$\times 10^3$/h) and NM (INR 78.61$\times 10^3$/h). Benefit to cost ratio (B:C ratio) was also significantly higher under MSM+WBM (2.46) than that of MSM (2.31) and NM (2.11). Higher yields under MSM+WBM was reflected in net returns and B:C ratio over MSM and NM. The higher net returns and B:C ratio in maize-toria cropping systems with double mulching was also reported by Das et al. (37).

4. Conclusions

The results presented in the study proved the hypothesis that inclusion of legumes as an intercrop in maize-based cropping system and short cycle winter crops after maize enhances the crop, water, energy productivity and soil health as compared to maize-fallow under organic production systems. The inclusion of second crop (winter season crop after maize) and co-culture of cowpea enhanced the maize grain yield by 6.2-23.5% when compared with maize-fallow (MF) system. Among the cropping sequences, MCV had higher system productivity, lower ρb, higher SOC, MBC and DHA, N and K compared to all other sequences. Similarly, the residual effect of MSM+WBM had positive effect leading to enhanced maize yield by 19.1 and 6.5%

over MSM and NM, respectively. Moreover, application of MSM+WBM enhanced the yield of all the winter season crops compared to NM. The MSM+WBM as SMC measures had 23.7% higher SP than those under NM. Among the OSMC, maximum water productivity, higher SOC, MBC, DHA, available N and P and lower ρb was under MSM+WBM. Therefore, the present study provides the information to stakeholders and the policy-makers for sustainable organic production, the technology of co-culture of cowpea with maize in rainy season and inclusion of short duration winter vegetable pea along with organic soil moisture conservation measures (MSM+WBM) after harvest of rainy maize in maize-based cropping sequence is favourable for higher productivity of crop, water, energy and soil health.

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Table 1. Details of crop cultivars and agronomic practices adopted in the experiment

Crop	Cultivar	Duration (in days)	Spacing (cm)	Time of sowing	Recommended N (kg/ ha)
Maize	DA 61 A	125	60 × 20	Second fortnight of March	60
Cowpea	KashiKanchan	90	60 × 20	Second fortnight of March	20
Rapeseed	TS - 36	115	30 × 10	Second fortnight of September	50
Barley	VL Jau 116	145	22.5 × solid sowing	Second fortnight of September	50
Vegetable Pea	VRP 6	92	30 × 15	Second fortnight of September	30
Rajmash	SKR 57 A	120	30 × 15	Second fortnight of September	60

Table 2. Nutrient content of different inputs used as a nutrition and organic mulches in experiment (*N*=12)

Organic input	**N (g/kg)**	**P (g/ka)**	**K (g/kg)**	**C (g/kg)**
Maize stover	6.3 ± 0.9	3.2 ± 0.6	9.8 ± 1.2	398.8 ± 25.2
Mixed weed biomass	25.8 ± 4.6	7.2 ± 1.5	11.1 ± 1.2	448.5 ± 54.3
Mixed compost	12.1 ± 1.9	6.9 ± 1.2	9.3 ± 1.5	372.4 ± 39.2
Vermicompost	17.3 ± 3.3	5.9 ± 0.8	10.3 ± 1.3	312.7 ± 56.4
Neem cake	31.8 ± 3.1	9.7 ± 0.9	12.6 ± 1.2	342.9 ± 18.7

Note ± SD

Table 3. Energy inputs of different crops

	Energy value for different crops (MJ/ha)						
Particulars	Maize	Cowpea	Toria	Buckwheat	Barley	Garden pea	Rajmash
Land preparation	31		31	31	31	31	31
Seed	304	351	114	503	1040	975	1052
Organic fertilizers	6516		3276	3276	3276	3276	6516
Bi-pesticides	600	600	600	360	600	600	600
Farm machineries	1505		1505	1505	1505	1505	1505
Labour	1317	392	1192	1403	1293	1340	1340
Total	10273	1343	6717	7078	7745	7727	11045

Table 4. Yield of maize and inter-crop (cowpea) as influenced by *in-situ* moisture conservation measures and cropping systems

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	Maize yield (t/ha)					Intercrop (cowpea) yield (t/ha)				
Cropping system	Y1	Y2	Y3	Y4	**Mean**	Y1	Y2	Y3	Y4	**Mean**
Maize-fallow	3.51	3.02	3.05	3.20	3.19	--	--	--	--	--
Maize + cowpea-Toria	3.65	3.28	3.30	3.43	3.41	1.56	1.49	1.39	1.46	1.47
Maize + cowpea-buckwheat	3.63	3.47	3.58	3.62	3.57	1.64	1.43	1.36	1.42	1.46
Maize + cowpea-barley	3.55	3.25	3.30	3.47	3.39	1.62	1.42	1.35	1.41	1.45
Maize + cowpea-vegetable pea	3.67	3.95	4.03	4.12	3.94	1.57	1.70	1.51	1.63	1.60
Maize + cowpea-Rajmash	3.80	3.71	3.88	3.97	3.84	1.67	1.60	1.49	1.61	1.59
SEm ±	0.06	0.12	0.06	0.05	0.03	0.04	0.04	0.02	0.02	0.02
LSD(P=0.05)	NS	0.37	0.19	0.18	0.10	NS	0.13	0.06	0.06	0.06
Moisture conservation measures										
NM	3.61	2.99	3.22	3.29	3.28	1.31	1.22	1.14	1.19	1.22
MSM	3.61	3.53	3.55	3.68	3.59	1.38	1.25	1.18	1.27	1.27
MSM+WBM	3.68	3.81	3.79	3.92	3.80	1.34	1.34	1.23	1.31	1.31

SEm ±	0.05	0.06	0.06	0.04	0.03	0.05	0.03	0.02	0.01	0.02
LSD(P=0.05)	NS	0.17	0.16	0.11	0.10	NS	0.09	0.05	0.03	0.05

NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis) Y1= 2014-15, Y2= 2015-16, Y3=2016-17, Y4=2017-18

Table 5. Maize equivalent yields as influenced by cropping system and soil moisture conservation measures

	MEY (t/ha)				
Cropping system	**Y1**	**Y2**	**Y3**	**Y4**	**Mean**
Maize-fallow	3.51	3.02	3.05	3.19	3.19
Maize + cowpea-toria	7.30	7.13	6.73	7.23	7.10
Maize + cowpea-buckwheat	7.57	6.98	6.96	7.28	7.20
Maize + cowpea-barley	8.17	8.06	7.57	8.37	8.04
Maize + cowpea- garden pea	11.19	12.58	12.25	12.42	12.11
Maize + cowpea-rajmash	9.47	10.48	10.40	10.27	10.16
SEm ±	0.10	0.20	0.08	0.09	0.11
LSD(*P*=0.05)	0.30	0.63	0.24	0.27	0.36
Organic moisture conservation measures					
NM	7.39	6.80	6.75	7.28	7.06
MSM	7.92	8.26	7.95	8.34	8.12

MSM+WBM	8.30	9.06	8.79	8.76	8.73
SEm ±	0.07	0.07	0.08	0.06	0.07
LSD(P=0.05)	0.21	0.21	0.22	0.16	0.20

NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis) Y1= 2014-15, Y2= 2015-16, Y3=2016-17, Y4=2017-18

Table 6. Yield and water use efficiency of second crop as influenced by *in-situ* moisture conservation measures

In- situ moisture conservation measures	**Rapeseed yield (t/ha)**				**Water productivity (kg/m^3)**				**Buckwheat yield (t/ha)**				**Water productivity (kg/m^3)**			
	Y1	**Y2**	**Y3**	**Y4**	**Y1**	**Y2**	**Y3**	**Y4**	**Y1**	**Y2**	**Y3**	**Y4**	**Y1**	**Y2**	**Y3**	**Y4**
NM	0.53	0.72	0.56	0.69	0.76	0.91	0.75	0.75	0.84	0.65	0.73	0.79	1.50	1.21	1.15	1.07
MSM	0.63	0.82	0.65	0.83	0.91	1.04	0.90	0.90	0.95	0.99	0.93	1.12	1.69	1.57	1.57	1.52
MSM+WBM	0.81	0.90	0.82	0.90	1.16	1.15	1.01	0.98	1.16	1.10	1.02	1.14	2.06	1.69	1.55	1.54
SEm ±	0.01	0.009	0.01	0.009	0.007	0.004	0.001	0.004	0.01	0.01	0.009	0.01	0.009	0.016	0.010	0.010
LSD(P=0.05)	0.01	0.01	0.02	0.01	0.021	0.010	0.004	0.013	0.02	0.03	0.01	0.02	0.027	0.045	0.028	0.029

NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis), Y1= 2014-15, Y2= 2015-16, Y3=2016-17, Y4=2017-18

Table 7. Yield and water use efficiency of second crop as influenced by *in-situ* moisture conservation measures

In- situ moisture conservation measures	**Barley yield (t/ha)**				**Water productivity (kg/m^3)**				**Garden pea yield (t/ha)**				**Water productivity (kg/m^3)**			
	Y1	**Y2**	**Y3**	**Y4**	**Y1**	**Y2**	**Y3**	**Y4**	**Y1**	**Y2**	**Y3**	**Y4**	**Y1**	**Y2**	**Y3**	**Y4**
NM	1.47	1.65	1.37	2.47	1.27	1.17	0.98	1.89	2.98	2.82	2.65	3.38	4.22	4.10	3.41	3.71
MSM	2.48	2.97	2.34	2.89	2.15	2.12	1.66	2.21	3.5	4.33	4.29	4.13	4.96	5.08	4.12	4.53
MSM+WBM	2.61	3.4	3.03	3.01	2.26	2.42	2.16	2.30	3.85	5.03	5.02	4.2	5.46	5.33	4.41	4.60
SEm ±	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.015	0.03	0.025	0.021
LSD(P=0.05)	0.06	0.06	0.03	0.06	0.05	0.04	0.02	0.02	0.03	0.03	0.04	0.06	0.044	0.087	0.072	0.062

NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis), Y1= 2014-15, Y2= 2015-16, Y3= 2016-17, Y4=2017-18

Table 8. Yield and water use efficiency of second crop as influenced by *in-situ* moisture conservation measures

In- situ moisture conservation measures	**Rajmash (t/ha)**				**Water productivity (kg/m^3)**			
	Y1	**Y2**	**Y3**	**Y4**	**Y1**	**Y2**	**Y3**	**Y4**
NM	0.75	1.02	0.96	0.9	1.31	1.67	1.26	1.20
MSM	0.86	1.3	1.24	1.18	1.50	1.92	1.55	1.57
MSM+WBM	1.11	1.44	1.48	1.25	1.94	2.00	1.64	1.67
SEm ±	0	0.01	0.01	0	0.003	0.013	0.009	0.005
LSD(P=0.05)	0.01	0.02	0.02	0.01	0.01	0.036	0.027	0.015

NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis), Y1= 2014-15, Y2= 2015-16, Y3=2016-17, Y4=2017-18

Table 9. Available nutrient status as influenced by cropping system and mulching (after four cropping cycle)

Treatment	**Nitrogen (kg/ha)**		**P (kg/ha)**		**K (kg/ha)**		**SOC (g/kg)**		**BD (Mg/cm^3)**		**Microbial biomass carbon (μg MBC/ g soil)**	**Dehydrogenase activity (μg TPF/g soilh^{-1})**	**Biomass yield (t/ha)**
	0-15 cm	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**	**0-15 cm**	**15-30 cm**			
Cropping system													
Maize-fallow	330.3	323.2	16.5	16.1	345.9	338.6	11.9	11.7	1.34	1.37	247.4	11.55	5.90
Maize + cowpea - toria	344.8	335.9	17.7	17.1	352.5	329.1	13.1	12.9	1.32	1.35	286.0	13.71	11.56
Maize + cowpea-buckwheat	354.8	349.8	18.6	17.7	391.7	359.1	13.0	12.8	1.32	1.34	285.0	13.54	12.22
Maize + cowpea - barley	341.0	336.9	17.1	16.2	334.2	332.4	13.2	13.0	1.32	1.34	295.7	15.05	14.38
Maize + cowpea-pea	373.1	366.0	18.1	17.1	436.9	434.7	13.9	13.6	1.29	1.31	355.9	16.43	15.83
Maize + cowpea-rajmash	362.4	357.3	17.8	17.1	361.6	334.8	13.2	12.9	1.30	1.32	339.8	15.83	14.18
SEm ±	1.9	1.8	0.4	0.2	3.0	7.9	0.002	0.002	0.005	0.005	6.6	0.20	0.08
LSD(*P*=0.05)	5.9	5.7	1.2	0.8	9.4	24.8	0.006	0.005	0.016	0.016	20.7	0.62	0.25
Moisture conservation measures													
NM	343.2	337.7	17.1	16.4	366.8	349.7	12.7	12.5	1.34	1.36	288.3	13.63	11.50
MSM	352.1	344.8	17.8	17.1	372.2	357.9	13.1	12.9	1.31	1.33	304.7	14.45	12.49
MSM+WBM	357.9	352.1	18.1	17.3	372.4	356.7	13.4	13.1	1.30	1.32	311.8	14.99	13.04
SEm ±	1.0	1.1	0.2	0.2	1.6	3.7	0.001	0.001	0.002	0.004	3.3	0.13	0.06
LSD(P=0.05)	2.9	3.3	0.6	0.5	4.7	10.8	0.002	0.02	0.007	0.012	9.5	0.37	0.16

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NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis)

Table 10. Effect of cropping system and soil moisture conservation measures on energetics

Treatment	Energy input used (MJ/ha)	Gross energy out put (MJ/ha)	Net energy output (MJ/ha)	EUE (%)	Energy Productivity (kg/MJ)	Energy productivity in physical term (MJ/kg)	Energy productivity in economic term (MJ/ha)
Cropping system							
Maize-fallow	10610	60211	49601	5.67	1.20	0.83	1.59
Maize + cowpea - toria	18997	111670	92673	5.88	0.90	1.11	1.61
Maize + cowpea-buckwheat	19099	144407	125308	7.56	0.95	1.05	1.98
Maize + cowpea - barley	19766	130731	110965	6.61	1.12	0.90	1.74
Maize + cowpea- pea	19748	155962	136214	7.90	1.27	0.79	1.82
Maize + cowpea-rajmash	23066	118000	94934	5.12	0.73	1.37	1.50
SEm ±	--	970	970	0.05	0.01	0.01	0.01
LSD(*P*=0.05)	--	3057	3057	0.16	0.02	0.02	0.04
Moisture conservation measures							
NM	18491	107716	89225	5.83	0.95	1.09	1.59
MSM	18556	122548	103992	6.57	1.04	1.00	1.72
MSM+WBM	18596	130226	111630	6.97	1.09	0.95	1.81
SEm ±	--	575	575	0.03	0.004	0.004	0.01
LSD(*P*=0.05)	--	1663	1663	0.09	0.012	0.012	0.02

NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis)

Table 11. Economics of the system (pooled over four years)

Treatment	Cost of cultivation (INR/ha)	Gross returns (INR/ha)	Net returns (INR./ha)	B:C ratio
Cropping system				
Maize-fallow	37940	66.82	28.88	1.76
Maize + cowpea - toria	69397	149.20	79.80	2.15
Maize + cowpea-buckwheat	72847	153.40	80.56	2.10
Maize + cowpea - barley	74847	168.98	94.13	2.25
Maize + cowpea- pea	85587	245.58	159.99	2.86
Maize + cowpea-rajmash	78347	206.44	128.09	2.63
SEm ±	--	1.38	1.38	0.02
LSD(*P*=0.05)	--	4.35	4.35	0.06
Moisture conservation measure				
NM	67605	146.22	78.61	2.11
MSM	70522	168.19	97.67	2.31
MSM+WBM	71355	180.80	109.44	2.46
SEm ±	--	0.74	0.74	0.01
LSD(P=0.05)	-	2.14	2.14	0.03

NM= No-mulch (Control), MSM= maize stover mulch (30%), WBM= weed biomass mulch (5.0 t/ha fresh wt basis)

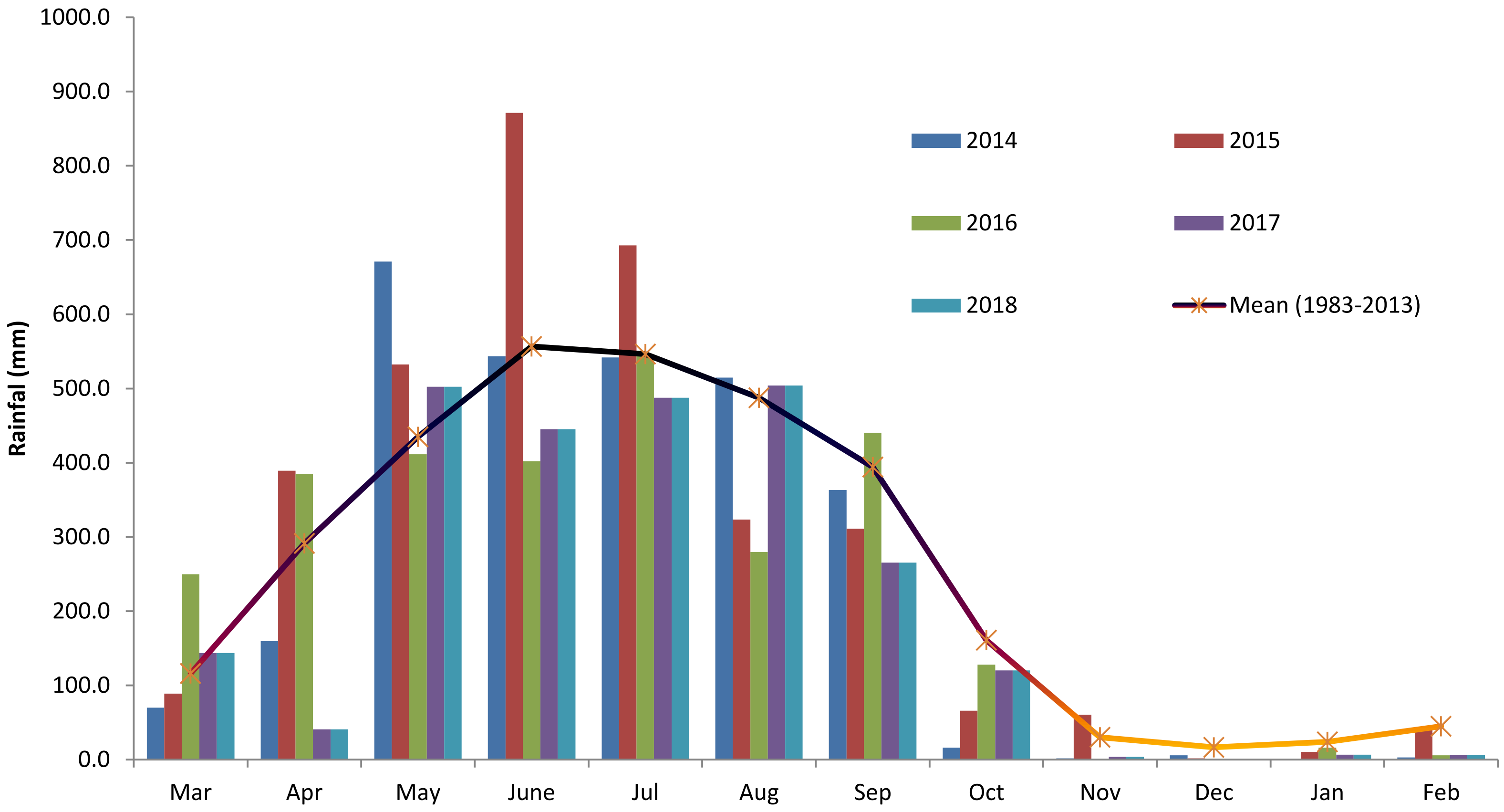

Fig. 1. Rainfall data during experimentation (2014-2018) and mean data over 31 years (1983-2013) recorded at ICAR Research Farm

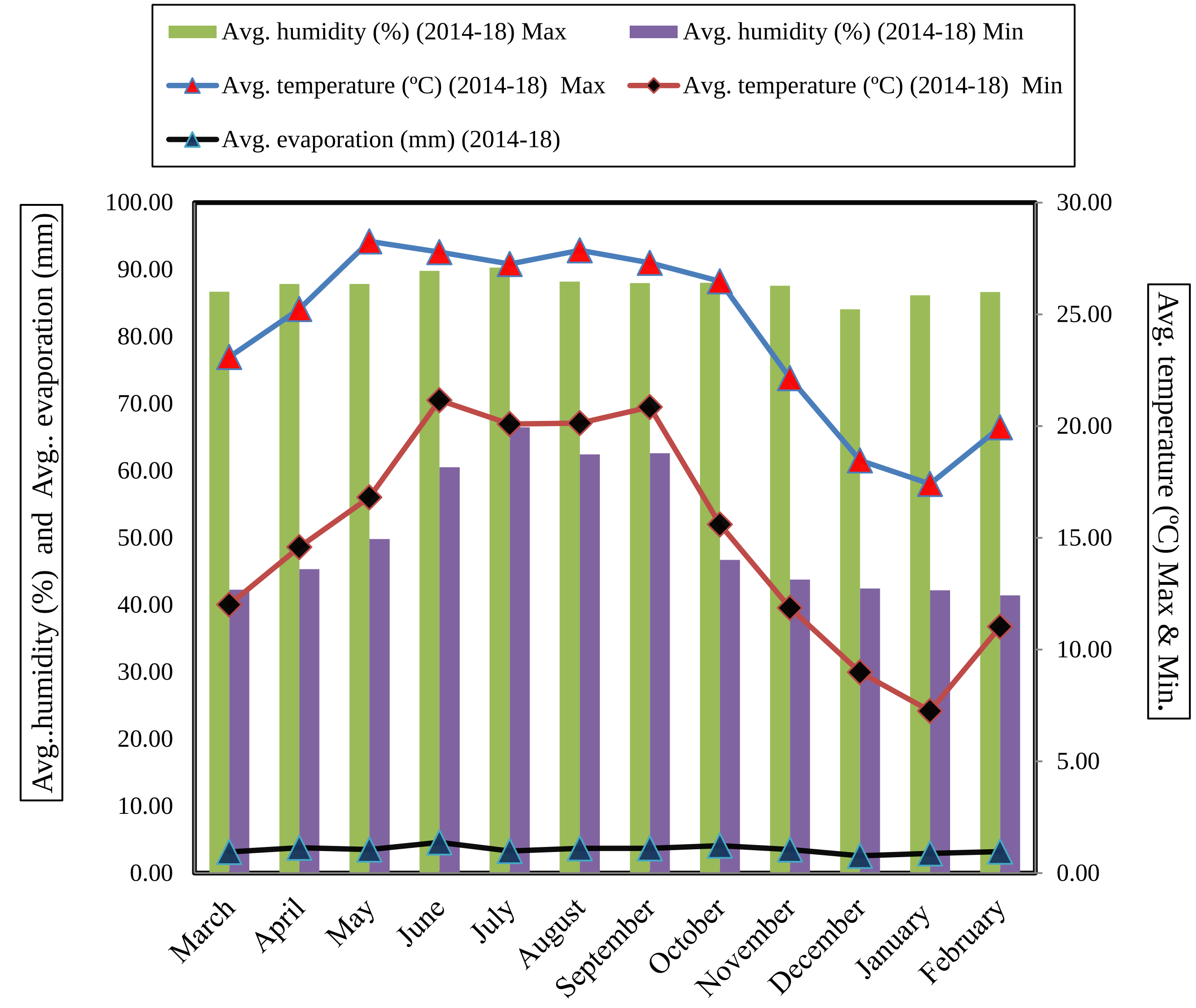

Fig. 2. Monthly weather data during 2014-18

Fig. 3. Grain yield (Mg/ha) of maize in different CS (Pooled over four years)