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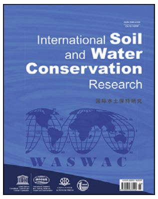

Original Research Article

Crop productivity, soil health, and energy dynamics of Indian Himalayan intensified organic maize-based systems

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ABSTRACT

The sustainability of prevailing maize-fallow system in rainfed ecosystems of the Eastern Himalayan region (EHR) of India is often questioned due to poor economic return and negative impact on soil health. Hence, the six cropping systems, maize-fallow (M-F), maize + cowpea-rapeseed (M + C-Rs), maize + cowpea-buckwheat (M + C-Bw), maize + cowpea-barley (M + C–B), maize + cowpea-garden pea (M + C-GP) and maize + cowpea–rajmash (M + C-R) in the main plot and three soil moisture conservation measures, no-mulch (NM), maize stover mulch (MSM) and maize stover + weed biomass mulch (MSM + WBM) in sub-plot were evaluated for four consecutive years (2014-18) at a Research Farm in fixed plot fashion. Results indicated that cowpea co-culture with maize and inclusion of winter crop increased maize yield by 6.2–23.5% over M-F. Among the systems, the M + C-GP recorded the highest crop productivity. The residual effect of MSM + WBM increased maize grain yield by 19.1% over NM. Cultivation of maize + cowpea-winter crops significantly improved the available N (3.2–12.9%), P (3.6–12.7%), K (1.9–26.3%), organic carbon (9.2–16.8%), microbial biomass carbon-MBC (15.2–43.9%) and dehydrogenases-DHA (17.2–42.3%) in soil at 0–15 cm depth as compared to M-F. The M + C-GP also recorded maximum net return (US $2460 ha^{-1}), benefit:cost (B: C) ratio (2.86) and energy use efficiency (7.9%). The MSM + WBM recorded higher net return (US $1680 ha^{-1}) and B:C ratio (2.46) over NM. Hence, cowpea + maize-garden pea (M + C-GP) along with the application of MSM + WBM is a sustainable production practice to intensify the organically managed maize-fallow system in rainfed regions of the EHR of India and other similar ecosystems.

1. Introduction

The sustainability of conventional agricultural production systems in the rainfed ecosystems of the Himalayan region is threatened by triple challenges of declining farm productivity and profitability, shrinking natural resources, and energy crises (Babu, Mohapatra, et al., 2020; Das et al., 2017; Yadav et al., 2018). The major concern of the researchers and policymakers is that agriculture has to meet the twin challenges of feeding a burgeoning population with rising food demand, and simultaneously minimizing its negative global environmental impact (Babu, Singh, et al., 2020; Tal, 2018). Therefore, conventional production systems need to shift towards eco-friendly agriculture systems that combine low ecological footprint to produce more crops/commodities to ensure food, nutritional, soil, and environmental security. Organic farming in such production system that has less negative impact on the environment, soil health, and energy consumption (Ponisio et al., 2015; Reganold & Wachter, 2016; Seufert et al., 2012). Furthermore, globally demand for organic food has increased many folds over inorganic products (Andreotti et al., 2018; Chen et al., 2020; Nicolopoulou et al., 2016; Willer & Lernoud, 2019). Organic farming has the potential to provide quality and safe food with premium price of produce as compared

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to conventional farming (Giles, 2004; Gopinath et al., 2008). Albeit, some researchers have reported that the productivity of crops under organic agriculture is lower than the conventional agriculture (Badgley et al., 2007; De Ponti et al., 2012; Kirchmann et al., 2008), but magnitudes of yield reduction depends on types and numbers of crops grown, management practices and climatic conditions (Avasthe et al., 2020; Ponisio et al., 2015; Seufert et al., 2012). At the same time, organic production systems have the potential to contribute to a sustainable ecosystem through better soil microbial diversity (Mäder et al., 2002; Tsiafouli et al., 2014) and build-up of soil organic matter (SOM) (Das et al., 2017).

Cropping system intensification allows growing more crops on a given piece of land over a definite period. Intensification of cereal-based systems with legumes enhances the system productivity, farmers' income besides considerable improvement in soil health in diverse climatic conditions in various regions of the world under chemical-based conventional production system (Franzluebbers et al., 2000; Gaba et al., 2015; Stetson et al., 2012; Tong et al., 2017; Zuber et al., 2015). Diversification and intensification of cereal-based production system with the inclusion of short duration crops along with conservation effective soil and crop management practices also increased the land, water, and nutrient productivity in Indo Gangetic plains (Hazra et al., 2018; Jat et al., 2019; Parihar et al., 2016) and coastal region of India (Manjunath et al., 2017) under conventional management system with assured irrigation facilities. However, such kind of information is lacking in the domain of organically managed rainfed ecosystems of Eastern Himalayas. Although, the maize-French bean system was reported as an energy-efficient and environmentally safe cropping system to intensify the maize-fallow land under the inorganically managed condition of the hilly region of Eastern India (Babu, Mohapatra, et al., 2020). Thus, there is an urgent need for redesigning the cropping systems to match their water requirements including both legumes and manures as a realistic approach to organic farming systems.

Eastern Himalayan Region (EHR) of India spread over 26.2 M ha supports 49 million population. Predominantly agriculture in the EHR of India is traditional (low use of fertilizers), subsistence (monocropping) and rainfed (Avasthe et al., 2020; Das, Ghosh, Lal, Saha, & Ngachan, 2017; Yadav et al., 2018). The EHR receives very scanty rainfall during the winter season from November to February which compels the farmers to keep the land fallow. Escalating production costs, poor crop productivity, and soil degradation questioned the sustainability of conventional monocropped production systems (Avasthe et al., 2020; Sokolowski et al., 2020). Traditional agriculture in the EHR is not a remunerative affair hence, the livelihood security of hill farmers is under threat (Babu, Singh, et al., 2020; Singh et al., 2016). Considering the ecological condition, diversity, and cropping nature of the EHR, the Government of India is promoting the EHR as an organic hub. Thus, there is dire need to intensify the existing maize-fallow system with cost-effective moisture conservation and fertility restorative practices for enhancing farm productivity and profitability besides maintaining soil health. Maize has wide adaptability under the rainfed condition and maybe a potential crop under the organic production system. Owing to vigorous growth pattern and wider intra rows there lies an opportunity for inclusion of a leguminous crop as an intercrop with maize (Saha et al., 2012). Despite that most of the intensification strategies mainly focused on the induction of winter crops in the maize-fallow system (Babu, Mohapatra, et al., 2020). Hence, we have tested the innovative idea of induction of legume crop with maize followed by winter season crops along with *in-situ* moisture conservation measures which was not tested earlier in the EHR. Association of cereal and legume crops in system approach has the potential to enhance the system productivity and improve the soil fertility (Betencourt et al., 2012; Latati et al., 2014; Nascente & Stone, 2018). But such information is not available for the rainfed ecosystem under organic management in the EHR of India. Thus, systematic research is required on the inclusion of cowpea as an intercrop under the maize-based system in rainfed acid soils for sustainable organic farming systems.

Cultivation of winter crop after maize harvest is difficult due to inadequate soil moisture and satisfactory nutrition under organic agriculture in EHR. Hence, it was assumed that suitable soil moisture conservation measures can facilitate the cultivation of winter season crops on sloping lands which may boost land productivity and also extend the cropping duration. Extended cropping duration can also help in reducing the loss of soil and nutrients. Hence, biomulching of maize stalk and farm litter may be one of the better options to utilize the residual soil moisture for growing second crop during the winter season after harvest of rainy maize. Furthermore, the use of crop residue and weed biomass as mulch not only to conserves the soil moisture but also improves soil health. Because of these facts and considering the cost-effectiveness, maize stover and locally available weed biomass were evaluated for *in situ* SMC under maize-based intensified systems. The present investigation was undertaken to test the hypothesis that intercropping maize with cowpea and subsequent cultivation of winter (second) crop on residual soil moisture with surface retention of maize stover/weed biomass enhances crop, water, energy productivity, economic returns, and soil health in comparison to business as usual (maize-fallow system) under organic management. The specific objectives of the study were: 1) to evaluate the effect of cowpea co-culture with maize and induction of winter crop in the maize-based system on productivity enhancement, economic returns, energy dynamics over the prevailing maize-fallow system, and 2) test the effect of various intensified systems and soil moisture conservation practices on soil health.

2. Materials and methods

2.1. Description of experimental site

The experimental site, Research Farm of ICAR-National Organic Farming Research Institute, Gangtok, Sikkim, India is located at 27°32′ N latitude, 88°60′ E longitude at an altitude of 1350 m above mean sea level. The experimental site received cumulative mean annual precipitation of 2946.3 mm during 2014-18. Temperature variation was observed across the years during experimentation; maximum temperature (mean value of four years) was recorded in May (28.3 °C) while the average minimum temperature was recorded in January (7.3 °C) during the crop growing season (Suppl. Fig. 1&2).

The experimental field was under organic management since 2003 and maize crop was sown before the study to confound the effect of previous treatments. To assess the basal soil fertility status of the experimental field, soil samples were randomly collected from the experimental plots at 0–15 cm and 15–30 cm depths before the commencement of the experiment and analyzed as per the standard procedures. The soil of the experimental site was sandy loam in texture, moderately deep (>50 cm depth) (Haplumbrepts). The surface soil (0–15 cm depth) had more SOC, available N, P and K, and lower bulk density (ρb) than subsurface soil (15–30 cm depth) (Table 3).

2.2. Experimental design and treatment details

A four year (2014-18) fixed plot field experiment was conducted to evaluate the feasibility of growing winter season crops after rainy

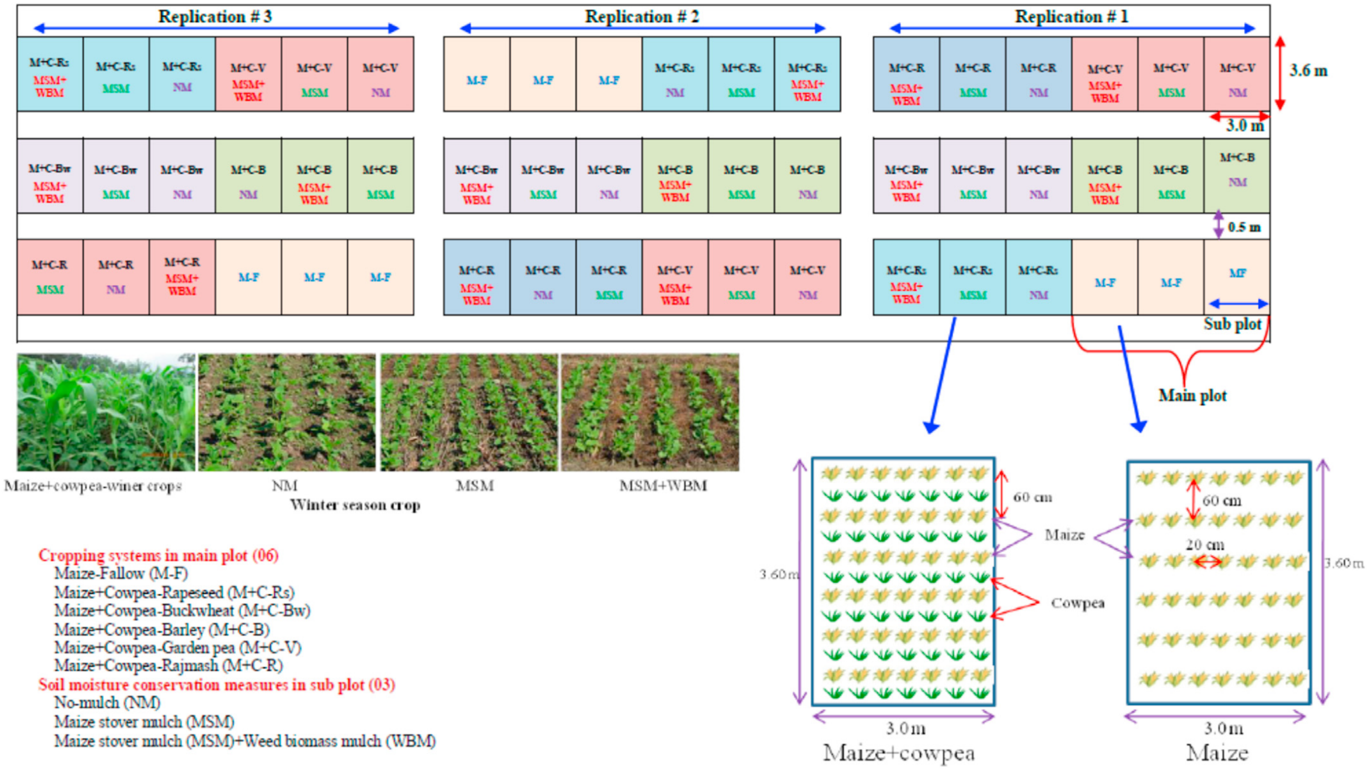

Fig. 1. Experimental layout and field photographs.

season maize co-cultured with cowpea under organic rainfed condition. The experiment was undertaken in a split-plot design with six treatment combinations of cropping system *viz*., maize (*Zea mays*)-fallow (M-F), maize + cowpea (*Vigna unguiculata*)-rapeseed (toria) (*Brassica campestris* var. toria) (M + C-Rs), maize + cowpea-buckwheat (*Fagopyrum esculentum*) (M + C-Bw), maize + cowpea-barley (*Hordeum vulgare*) (M + C–B), maize + cowpea-garden pea (*Pisum sativum* var. Hortense) (M + C-GP) and maize + cowpea-rajmash (*Phaseolus vulgaris*) (M + C-R) 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 treatment combinations {cropping systems = 6 (assigned in main plots) and *in-situ* moisture conservation measures = 3 (assigned in subplots) with three replications}, hence, the total number of plots was 54. The net plot size was 3.6 m × 3 m. Bunds were made between the main plots and sub-plots. Each subplot was separated with 0.4 m bund, while each main plot was kept at 0.5 m distance from each other. Details of the layout plan of the experiment are shown in Fig. 1. Thirty percent of the total maize stover harvested was used as maize stover mulch (MSM) and applied to the winter season crops 10 days after sowing. While fresh mixed weed biomass at the early vegetative stage was collected from adjoining fields and applied @ 5.0 t ha^{-1} after 10 days of sowing winter season crops as per the treatments. The maize crop was sown in March every year. While, the winter season crops *viz*., rapeseed (toria), buckwheat, barley, garden pea, and rajmash were sown during the fourth week of September after harvesting maize and cowpea every year. Maize crop was sown at a spacing of 60 cm × 20 cm. Cowpea was intercropped with maize in a 1:1 ratio (one row of cowpea planted in between two rows of maize as an additive series). Recommended doses of N were applied to each crop through mixed compost (MC), [MC was a mixture of cow dung, *Artemisia vulgaris*, *Eupatorium odoratum*, and leaves of *Alnus nepalensis* tree in equal proportion and allowed to decompose in the pit for > 3 months], vermicompost (VC) and neem cake. Recommended inputs for the growing of all the crops were used during the entire study period (Suppl. Table 1).

2.3. Crop management

Individual plots were thoroughly tilled by a power tiller (Honda Power Tiller FJ 500). During the entire period of experimentation bunds between the plots were not dismantled to avoid the mixing of the soil in different plots. Organic nutrients were applied as per the recommended dose of N to the individual crop (Suppl. Table 1). The nutrient composition varied among the different mulching materials and organic inputs (Suppl. Table 2). The combination of mixed compost (a well-decomposed mixture of dung, *Artemisia vulgaris*, *Eupatorium odoratum*, and *Alnus nepalensis* leaves), VC, and NC were used for organic nutrition. The full amount of mixed compost (MC) was applied to flatbeds before sowing in all the crops. VC and NC were applied in furrows opened for the sowing of the crops. To reduce the weed problem in maize two hand weeding at 20 and 40 days after sowing (DAS) followed by earthing up was done. Two manual weedings were done at 20 and 40 DAS in all the winter season crops. As a preventive measure of insect-pests and diseases, seeds were treated before sowing with *Trichoderma viride* for each crop @ 4 g kg^{-1}. Neem oil (1500 ppm) @ 5 ml l^{-1} of water was applied for management of aphids, whitefly *etc.* at 10 days interval 2–3 times in the winter season crops.

2.4. Harvesting and yield measurement

Maize crop was harvested at physiological maturity during the second week of August in all the years. The cowpea green pods

Table 1
Yield of maize and intercrop (cowpea) as influenced by *in-situ* moisture conservation measures and cropping systems.

	Maize yield (t ha^{-1})					Intercrop (cowpea) yield (t ha^{-1})				
Cropping system	Y1	Y2	Y3	Y4	Mean	Y1	Y2	Y3	Y4	Mean
Maize-fallow	3.51^{a}	3.02^{def}	3.05^{e}	3.20^{f}	3.19^{f}	–	–	–	–	–
Maize + cowpea-rapeseed	3.65^{a}	3.28^{cd}	3.30^{d}	3.43^{cde}	3.41^{d}	1.56^{a}	1.49^{c}	1.39^{c}	1.46^{c}	1.47^{c}
Maize + cowpea-buckwheat	3.63^{a}	3.47^{bc}	3.58^{c}	3.62^{c}	3.57^{c}	1.64^{a}	1.43^{cd}	1.36^{cd}	1.42^{cd}	1.46^{cd}
Maize + cowpea-barley	3.55^{a}	3.25^{cde}	3.30^{d}	3.47^{cd}	3.39^{de}	1.62^{a}	1.42^{cde}	1.35^{cde}	1.41^{cde}	1.45^{cde}
Maize + cowpea- garden pea	3.67^{a}	3.95^{a}	4.03^{a}	4.12^{a}	3.94^{a}	1.57^{a}	1.70^{a}	1.51^{a}	1.63^{a}	1.60^{a}
Maize + cowpea-Rajmash	3.80^{a}	3.71^{ab}	3.88^{ab}	3.97^{ab}	3.84^{ab}	1.67^{a}	1.60^{ab}	1.49^{ab}	1.61^{ab}	1.59^{ab}
Moisture conservation measures										
NM	3.61^{a}	2.99^{c}	3.22^{c}	3.29^{c}	3.28^{c}	1.31^{a}	1.22^{bc}	1.14^{bc}	1.19^{c}	1.22^{c}
MSM	3.61^{a}	3.53^{b}	3.55^{b}	3.68^{b}	3.59^{b}	1.38^{a}	1.25^{b}	1.18^{ab}	1.27^{b}	1.27^{b}
MSM + WBM	3.68^{a}	3.81^{a}	3.79^{a}	3.92^{a}	3.80^{a}	1.34^{a}	1.34^{a}	1.23^{a}	1.31^{a}	1.31^{a}

NM= No-mulch (Control), MSM = maize stover mulch (30%), WBM = weed biomass mulch (5.0 t ha^{-1} fresh wt. basis) Y1 = 2014-15, Y2 = 2015-16, Y3 = 2016-17, Y4 = 2017-18, Values followed by different letters are significantly different at $p < 0.05$. Total plots # 54 {6(cropping sequence) × 3 (mulching) × 3 (replication)}.

Table 2
Productivity and water use efficiency of second crop as influenced by *in-situ* moisture conservation measures.

In- situ moisture conservation measures	Rapeseed		Buckwheat		Barley		Garden pea		Rajmash	
	Seed yield (t ha^{-1})	WP (kg m^{-3})	Seed yield (t ha^{-1})	WP (kg m^{-3})	Seed yield (t ha^{-1})	WP (kg m^{-3})	Pod yield (t ha^{-1})	WP (kg m^{-3})	Grain yield (t ha^{-1})	WP (kg m^{-3})
NM	0.63^{c}	0.79^{c}	0.75^{c}	1.23^{c}	1.74^{c}	1.33^{c}	2.96^{c}	3.86^{c}	0.91^{c}	1.36^{c}
MSM	0.73^{b}	0.94^{b}	1.00^{b}	1.59^{b}	2.67^{b}	2.04^{b}	4.06^{b}	4.67^{b}	1.15^{b}	1.64^{b}
MSM + WBM	0.86^{a}	1.08^{a}	1.11^{a}	1.71^{a}	3.01^{a}	2.29^{a}	4.53^{a}	4.95^{a}	1.32^{a}	1.81^{a}

NM= No-mulch (Control), MSM = maize stover mulch (30%), WBM = weed biomass mulch (5.0 t ha^{-1} fresh wt. basis), WP = water productivity, Values followed by different letters are significantly different at $p < 0.05$.

Table 3
Nutrient status as influenced by cropping system and mulching (after four cropping cycle).

Treatment	BD (Mg cm^{-3})		SOC (g kg^{-1})		Available N (kg ha^{-1})		Available P (kg ha^{-1})		Available K (kg ha^{-1})		Microbial biomass carbon (μg MBC g^{-1} soil)	Dehydrogenase activity (μg TPF g^{-1} soil h^{-1})
	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	1.34^{a}	1.37^{a}	11.9^{e}	11.7^{e}	330.3^{f}	323.2^{f}	16.5^{e}	16.1^{cd}	345.9^{de}	338.6^{bc}	247.4^{f}	11.55^{f}
Maize + cowpea - rapeseed	1.32^{b}	1.35^{b}	13.1^{c}	12.9^{c}	344.8^{d}	335.9^{de}	17.7^{bc}	17.1^{ab}	352.5^{d}	329.1^{cdef}	286.0^{cd}	13.71^{d}
Maize + cowpea-buckwheat	1.32^{b}	1.34^{c}	13.0^{d}	12.8^{d}	354.8^{c}	349.8^{c}	18.6^{a}	17.7^{a}	391.7^{b}	359.1^{b}	285.0^{cde}	13.54^{de}
Maize + cowpea - barley	1.32^{b}	1.34^{c}	13.2^{b}	13.0^{b}	341.0^{de}	336.9^{d}	17.1^{bcd}	16.2^{c}	334.2^{ef}	332.4^{cde}	295.7^{c}	15.05^{c}
Maize + cowpea-garden pea	1.29^{d}	1.31^{e}	13.9^{a}	13.6^{a}	373.1^{a}	366.0^{a}	18.1^{ab}	17.1^{ab}	436.9^{a}	434.7^{a}	355.9^{a}	16.43^{a}
Maize + cowpea-rajmash	1.30^{c}	1.32^{d}	13.2^{b}	12.9^{c}	362.4^{b}	357.3^{b}	17.8^{abc}	17.1^{ab}	361.6^{c}	334.8^{bcd}	339.8^{ab}	15.83^{ab}
Moisture conservation measures												
NM	1.34^{a}	1.36^{a}	12.7^{c}	12.5^{c}	343.2^{c}	337.7^{c}	17.1^{c}	16.4^{c}	366.8^{c}	349.7^{a}	288.3^{c}	13.63^{bc}
MSM	1.31^{b}	1.33^{b}	13.1^{b}	12.9^{b}	352.1^{b}	344.8^{b}	17.8^{ab}	17.1^{ab}	372.2^{ab}	357.9^{a}	304.7^{ab}	14.45^{b}
MSM + WBM	1.30^{c}	1.32^{c}	13.4^{a}	13.1^{a}	357.9^{a}	352.1^{a}	18.1^{a}	17.3^{a}	372.4^{a}	356.7^{a}	311.8^{a}	14.99^{a}
Initial soil value	1.35	1.38	12.1	11.6	322.7	311.4	16.1	15.8	338.9	327.2	196.3	9.5

NM= No-mulch (Control), MSM = maize stover mulch (30%), WBM = weed biomass mulch (5.0 t ha^{-1} fresh wt. basis), Values followed by different letters are significantly different at $p < 0.05$. Total plots # 54 {6(cropping sequence) × 3 (mulching) × 3 (replication)}.

were harvested manually during the fourth week of May to the first week of June. The fresh yield of green cowpea pods was recorded immediately after harvest and expressed in t ha^{-1} (tonnes hectare^{-1}). Maize cob was removed manually and the stover was immediately harvested after removal of the cobs. The harvested cobs were kept on the threshing floor for 5–6 days for sun drying. The maize grains from cobs were removed by manual maize sheller. Grain yield of maize was recorded at 14% moisture content in all the years and converted into t ha^{-1}. Similarly, all winter season crops were also harvested with iron sickle at their physiological maturity leaving 4–5 cm stubble in the field except garden pea. Each year green pods of garden pea were picked at 60–65 days after sowing. At harvest the entire biomass of winter season crops was removed from the field. After threshing and cleaning of all the winter crops, the yield was recorded at 12% moisture level except rapeseed and converted to t ha^{-1}. The yield of rapeseed was reported at 8% moisture level.

2.5. *Water productivity*

Water productivity was calculated by dividing grain yield (economic productivity) obtained from different winter season crops (kg ha^{-1} m^{-3}) with their crop water requirement (ETc). The crop water requirement value (ETc) was estimated by multiplying reference evapotranspiration (ETo) with crop coefficient (Kc) of individual crop (Das et al., 2017). The reference evapotranspiration (ETo) value was obtained from pan evaporation data recorded at IMD station situated within the Research Farm. The crop coefficient (Kc) value was obtained by dividing growth into four equal stages and the respective Kc value was taken from FAO-56 (Allen et al., 2011). The summed up value of all the four stages revealed the total water requirement (ETc) of respective crops grown during the winter season.

2.6. Soil sampling and analysis

The soil samples were collected after completion of four cropping cycles up to 0–30 cm depth (0–15 cm and 15–30 cm depth) from each plot for analysis of physico-chemical properties. Sampling was done randomly at three points from each plot and mixed to make the composite soil sample from each depth. After processing soil samples were stored in airtight plastic bags for analysis of various soil chemical properties. One part from each composite fresh soil samples from each plot was stored at freezing temperature for analyzing SMBC and dehydrogenase activity. The soil organic carbon (SOC) of the samples was analyzed by the wet oxidation method (Walkley & Black, 1934). The available N, P, and K were determined as per the procedure outlined by Prasad et al. (2006). The soil microbial biomass carbon (SMBC) was determined by the soil fumigation technique (Anderson et al., 1993). The dehydrogenase activity (DHA) was analyzed by the procedure of reducing 2, 3, 5-triphenyl tetrazolium chloride (Tabatabai, 1982). For estimation of ρb core of known volume (5.6 cm length and 5.1 cm diameter) was used to draw the soil samples at 0–15 cm and 15–30 cm depth from each plot. After sampling, the soil was brought to laboratory and oven-dried at 105 °C to get the constant soil weight and ρb was calculated as per the protocol suggested by Blake and Hartge (1986).

2.7. Energy calculations

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, mixed compost (MC), pesticides, and machinery (Suppl. Table 3). The input energy was calculated by multiplying the inputs applied and operations performed with their established energy equivalents (Babu et al., 2016; Singh et al., 2016). 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 input and output, energy use efficiency (EUE) and energy productivity (EP) were calculated as per the equations outlined by Babu et al. (2016).

2.8. Financial analysis

The variable and fixed (depreciation cost of machinery used and land revenue) costs were used to calculate the cost of cultivation which was based on the prevailing market price of organic inputs in the locality. The gross return, the net return, and 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 the cost of cultivation from the gross return. The B:C ratio was obtained by dividing gross return with the cost of cultivation. All economic parameters were calculated using the formulae of Babu et al. (2016). The sale price of various outputs was: maize grain US $ 230 t^{-1}, cowpea pods $ 368 t^{-1}, rapeseed seed/toria $ 614 t^{-1}, buckwheat seed $ 307 t^{-1}, barley seed $ 230 t^{-1}, garden pea pod $ 768 t^{-1} and rajmash $ 1075 t^{-1}.

2.9. Statistical analysis

The multiple comparisons of different cropping systems and *in-situ* moisture conservation measures were performed as per the procedure of the split-plot design. The experimental data were subjected to analysis of variance (ANOVA) and significance was estimated by the test of significance (Gomez & Gomez, 1984). The overall statistical differences among the treatments were tested with the least significant difference (LSD) value at 5% probability ($p = 0.05$).

3. Results

3.1. Maize and cowpea productivity

The productivity (economic yield) of maize varied significantly among the different cropping systems across the years except for the year of establishment (2014). The inclusion of second crop in place of fallow and cowpea intercrop increased average maize grain yield by 6.2 and 23.5% under M + C–B and M + C-GP as compared to M-F (Table 1). M + C-GP produced significantly higher maize grain yield than other cropping systems in the first year but from the second year onwards it remained at par with M + C-R. Maize grain yield reflected a variable trend in diverse cropping systems over the years. Maize grain yield decreased over the years under M-F, M + C-Rs, M + C-Bw, M + C–B cropping sequences (Fig. 2). At the end of the fourth year, the mean maize productivity of the previous three years was 2.02–11.97% lower than over the first year yield (3.5–3.7 t ha^{-1}) under M-F, M + C-Rs, M + C-Bw, and M + C–B cropping systems. However, the magnitude of yield decline was the highest in M-F (11.97%) and the lowest in M + C-Bw (2.02%). Contrarily, the three-year maize productivity under M + C-GP and M + C-R was 9.9% and 1.4% higher over their respective first-year productivity (Fig. 2). While comparing the mean yield of four years, significantly higher maize grain yield was recorded in the M + C-GP cropping system (3.94 t ha^{-1}) followed by M + C-R (3.84 t ha^{-1}) than those obtained under other cropping systems (Table 1). M + C-GP cropping system produced 23.5, 15.5, 10.4, and 2.6% higher maize grain yield than the M-F, M + C-Rs, M + C-Bw, M + C–B, and M + C-R systems, respectively. The intercropping of cowpea with maize not only increased the maize grain yield but also provided additional pod yield (1.45–1.60 t ha^{-1}). The pod yield of intercropped cowpea was marginally greater under M + C-GP (1.60 t ha^{-1}) followed by M + C-R (1.59 t ha^{-1}) than other cropping

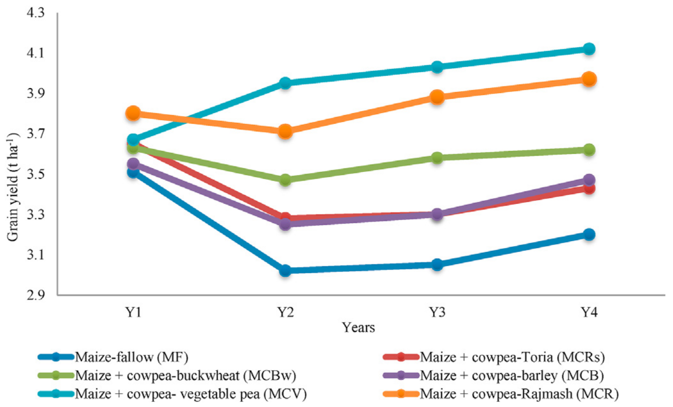

Fig. 2. Grain yield of maize (t ha^{-1}) in different cropping systems (CS).

systems (Table 1).

In the present study, maize stover mulch (MSM) alone and MSM + WBM applied during winter season had a pronounced effect on succeeding maize crop in the next season (Table 1). Of the various mulching treatments, maize grown on residual MSM + WBM had 19.1% and 6.5% higher grain yield over those under MSM and NM, respectively. Cowpea as an intercrop under maize yielded higher under MSM + WBM (1.31 t ha^{-1}) when compared to MSM (1.27 t ha^{-1}) and NM (1.22 t ha^{-1}).

3.2. *Yield of winter season crops and water productivity*

The four-year mean yield of all the winter season crops was significantly higher under maize stover mulch + weed biomass mulch (MSM + WBM) as compared to maize stover mulch (MSM) and no mulch (NM) (Table 2). The average yield of rapeseed was 36.5 and 17.8% higher under MSM + WBM than NM and MSM, respectively. Similarly, buckwheat yield was 48.0 and 11.0% higher under MSM + WBM as compared to NM and MSM, respectively. However, yield increment was the highest in the case of barley (73.0 and 12.7%) and rajmash (45.1 and 14.8%) under MSM + WBM over NM and MSM, respectively.

The water productivity (WP) of rapeseed, buckwheat, barley, garden pea, and rajmash was significantly ($p < 0.05$) influenced by different SMC measures (Table 2). Among the winter season crops, rapeseed had minimum WP (0.79–1.08 kg m^{-1}) while the maximum WP was in garden pea (3.86–4.95 kg m^{-1}).

3.3. *Soil health measurement*

All the soil physical (ρb), chemical (SOC, available N, P, and K) and biological properties (MBC and DHA) had relatively higher values after four cropping cycles when compared with the initial soil values (Table 3). Soil properties like ρb, SOC, available N, P, K, and MBC, DHA were significantly ($p < 0.05$) affected by the different cropping systems and moisture conservation measures (mulches) (Table 3). Available N in top 0–15 cm (373.1 kg ha^{-1}) and 15–30 cm (366.0 kg ha^{-1}) under M + C-GP was significantly greater than other cropping systems (330.3–362.4 kg ha^{-1} in 0–15 cm and 323.2–357.3 kg ha^{-1} in 15–30 cm). Soils under maize-winter crop systems had significantly higher amount of available N, P, K in both the depths under study (0–15 cm and at 15–30 cm) over M-F. Available P (18.6 kg ha^{-1}) was significantly higher in surface (0–15 cm) under M + C-Bw than the M-F and M + C–B but remained at par with the rest of the cropping systems. Similarly, at 15–30 cm soil depth, M + C-Bw had higher available P as compared with other cropping systems. M + C-Bw had 12.7 and 9.9% higher available P than the M-F at 0–15 and 15–30 cm soil depth, respectively. The inclusion of legumes did not significantly influence changes in available P as compared to other crops in the system. Soils under M + C-GP had significantly higher available K in both the soil depths (436.9 and 434.7 kg ha^{-1} at 0–15 cm and 15–30 cm, respectively) than the rest of the systems. The lowest amount of K was reported under M + C–B at 0–15 cm (334.2 kg ha^{-1}) and M-F at 15–30 cm (329.1 kg ha^{-1}).

The plant-available nutrients (N, P, and K) were significantly ($p < 0.05$) influenced by different SMC measures used in this study. MSM + WBM had significantly higher available N in both the soil depths of 0–15 cm (357.9 kg ha^{-1}) and 15–30 cm (352.1 kg ha^{-1}) than the soils under MSM and NM (Table 3). Plant available P and K exhibited 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 SOC concentration was relatively higher in surface soil (0–15 cm) as compared to the sub-surface (15–30 cm). Intensified cropping systems (maize + cowpea-winter crops) had significantly higher SOC concentration at both the soil depths (0–15 cm and 15–30 cm) as compared to MF. M + C-GP had significantly higher SOC (13.9 g kg^{-1} and 13.6 g kg^{-1}) at 0–15 cm and 15–30 cm soil depths than other cropping systems (Table 3).

Mulching increased the SOC concentration because of the decomposition and release of C in the soil. MSM + WBM had 5.5 and 4.8% higher SOC at 0–15 cm and 15–30 cm soil depths than the NM, respectively (Table 3). Similarly, MSM had 3.14 and 3.2% higher SOC than NM at 0–15 and 15–30 cm soil depths, respectively. The ρb after completion of four cropping cycles was significantly ($p < 0.05$) affected by the different cropping systems. Intensified cropping systems had relatively lower ρb as compared to M-F. Relatively lower ρb was observed at the surface (0–15 cm) than the deeper layer (15–30 cm). The application of different SMC measures resulted in lower ρb than NM. Soils of 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 15–30 cm depth than NM (Table 3). Both MBC and DHA were significantly higher in soils under intensified cropping systems as compared to M-F. The M + C-GP had significantly higher MBC (355.9 μg g^{-1}soil) and DHA (16.43 μg g^{-1}soil) when compared with all other cropping systems and M-F. The lowest MBC (247.4 μgg^{-1}soil) and DHA (11.55 μgg^{-1}soil) was registered in soils under M-F. Different SMC measures had a significant ($p < 0.05$) effect on MBC and DHA after four cropping cycles. The MBC and DHA were significantly higher in MSM and MSM + WBM than NM. The soils of MSM + WBM and MSM recorded 8.1 and 5.7% higher MBC than NM, respectively. Similarly, the DHA value was 10.0 and 6.0% higher under MSM + WBM and MSM than NM, respectively.

3.4. *Energy dynamics*

In the present study, the M-F cropping system required the lowest energy input (10,610 MJ ha^{-1}) while M + C-R had the maximum (23,066 MJ ha^{-1}). The gross energy output was significantly ($p < 0.05$) influenced by the diversification of cropping systems (Table 4). Among the systems, M + C-GP recorded significantly ($p < 0.05$) higher gross energy output (155,962 MJha^{-1}) over the rest of the systems. All the intensified cropping systems had significantly ($p < 0.05$) higher gross energy output than M-F. Similar trends were also noticed in net energy output. EUE was significantly higher in M + C-GP (7.90%) than all other cropping systems. Energy productivity was greater with M + C-GP but a varied response was observed for other cropping systems. The lowest energy productivity was under M + C-R (0.73 kg MJ^{-1}) followed by M + C-Rs.

The MSM + WBM produced significantly higher gross energy output (130,226 MJ ha^{-1}) over MSM and NM (Table 4). 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 also was significantly higher under MSM + WBM (1.09%) followed by MSM (1.04%). Energy productivity was 14.7 and 9.5% higher in MSM + WBM and MSM than NM, respectively.

3.5. *Financial analysis*

Financial analysis after four-year study (Table 5) indicated that the highest cost was incurred in the M + C-GP cropping system (US $1310 ha^{-1}) followed by M + C-R (US $1200 ha^{-1}). The lowest cost was incurred in the M-F system (US $580 ha^{-1}). However, the net return (US $2460 ha^{-1}) and B: C ratio (2.86) was significantly higher with M + C-GP followed by the M + C-R cropping system. On the other hand, the lowest net return (US $ 440 ha $^{-1}$) and B:C ratio (1.76) was recorded in the M-F cropping system.

Table 4

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

Treatment	Energy input used (MJ ha^{-1})	Gross energy out put (MJ ha^{-1})	Net energy output (MJ ha^{-1})	Energy use efficiency (%)	Energy Productivity (kg MJ^{-1})
Cropping system					
Maize-fallow	10,610	60211^{f}	49601^{f}	5.67^{e}	1.20^{b}
Maize + cowpea - rapeseed	18,997	111670^{e}	92673^{e}	5.88^{d}	0.90^{e}
Maize + cowpea-buckwheat	19,099	144407^{b}	125308^{b}	7.56^{b}	0.95^{d}
Maize + cowpea - barley	19,766	130731^{c}	110965^{c}	6.61^{c}	1.12^{c}
Maize + cowpea- garden pea	19,748	155962^{a}	136214^{a}	7.90^{a}	1.27^{a}
Maize + cowpea-rajmash	23,066	118000^{d}	94934^{d}	5.12^{f}	0.73
Moisture conservation measures					
NM	18,491	107716^{c}	89225^{c}	5.83^{c}	0.95^{c}
MSM	18,556	122548^{b}	103992^{b}	6.57^{b}	1.04^{b}
MSM + WBM	18,596	130226^{a}	111630^{a}	6.97^{a}	1.09^{a}

NM= No-mulch (Control), MSM = maize stover mulch (30%), WBM = weed biomass mulch (5.0 t ha^{-1} fresh wt. basis), Values followed by different letters are significantly different at $p < 0.05$. Total plots # 54 {6(cropping sequence) × 3 (mulching) × 3 (replication)}.

Table 5

Economics of the system (pooled over four years).

Treatment	Cost of cultivation (US $ ha^{-1})	Gross returns (US $ ha^{-1})	Net returns (US $ ha^{-1})	B:C ratio
Cropping system				
Maize-fallow	580	1030^{f}	440^{f}	1.76^{f}
Maize + cowpea - rapeseed	1070	2290^{de}	1230^{e}	2.15^{d}
Maize + cowpea-buckwheat	1120	2360^{d}	1240^{d}	2.10^{de}
Maize + cowpea - barley	1150	2590^{c}	1450^{c}	2.25^{c}
Maize + cowpea- garden pea	1310	3770^{a}	2460^{a}	2.86^{a}
Maize + cowpea-rajmash	1200	3170^{b}	1970^{b}	2.63^{b}
Moisture conservation measures				
NM	1040	2250^{c}	1210^{c}	2.11^{c}
MSM	1080	2580^{b}	1500^{b}	2.31^{b}
MSM + WBM	1100	2780^{a}	1680^{a}	2.46^{a}

NM= No-mulch (Control), MSM = maize stover mulch (30%), WBM = weed biomass mulch (5.0 t ha^{-1} fresh wt. basis), $: US Dollar. Values followed by different letters are significantly different at $p < 0.05$. Total plots # 54 {6(cropping sequence) × 3 (mulching) × 3 (replication)}.

The highest cost was incurred in MSM + WBM (US $1100ha^{-1}) followed by MSM (US $1080 ha^{-1}). Gross return was significantly higher in MSM + WBM (US $ 2780 ha^{-1}) followed by MSM (US $ 2580 ha^{-1}) and the lowest with NM (US $ 2250 ha^{-1}). Similarly, significantly higher net return was observed in MSM + WBM (US $ 1680ha^{-1}) than MSM (US $ 1500 ha^{-1}) and NM (US $1210 ha^{-1}). Benefit to cost ratio (B:C ratio) was also significantly higher in MSM + WBM (2.46) than MSM (2.31) and NM (2.11).

4. Discussion

4.1. Crop and water productivity

Inclusion of cowpea (legume) as intercrop and short duration winter crops along with *in-situ* moisture conservation measures significantly improved the maize productivity over the maize-fallow system under organic management. Sustainable intensification of the cereal-based system along with site-specific soil and crop management practices enhances land, crop, and water productivity under diverse agroecosystems was also reported by Parihar et al. (2016) and Jat et al. (2019). The inclusion of cowpea as an intercrop in maize apart from the additional economic gain has myriad benefits such as suppression of weeds, protection of nutrient loss due to high and intense rainfall in the hilly region, fixing atmospheric N, and an overall improvement in soil health (Kermah et al., 2017; Masvaya et al., 2017; Yadav et al., 2019). Complementary resource use effect in time and space further witnessed improvement in maize productivity with cowpea intercropping (Fischer et al., 2020). In the present study, the entire biomass of cowpea was retained on the soil surface as *in-situ* mulch which on decomposition improved the overall soil health (Table 3) resulting in further yield improvement as compared to M-F. The inclusion of legumes in cereal-based cropping systems enhances the productivity by improving the soil N availability through the biological N fixation and by increasing the availability of P through changing the soil pH in the rhizosphere (Betencourt et al., 2012; Latati et al., 2014). Thereby, the inclusion of cowpea enhanced the maize productivity under the intensified rainfed organic production system.

The inclusion of legumes (cowpea, garden pea) in our study perhaps reinforced the soil nutrients' status and subsequently leads to higher productivity of the succeeding crops. Under the organic production system, there are two main ways to supply the crop N requirements: introducing legumes in crop rotations and/or using organic amendments (Das et al., 2017; Singh et al., 2016; Avasthe et al., 2020). An increase in crop yield by integrating legumes in intensified systems has been reported in many studies (Gan et al., 2015; Gurr et al., 2016; Ghosh et al., 2020; Liu et al., 2020). Inclusion of the second crop in maize monoculture resulted in higher grain yield of preceding crops may be due to the addition of more organic matter to the soil which possibly helped in providing additional essential plant nutrients. Nutrients' release pattern in organic manures is very dynamic and slow (approximately 25–30% of nutrient be available to the first crop) and the accumulated nutrients are utilized by the subsequent crops (Das et al., 2017). That mechanism might be responsible for the higher yield of maize following the inclusion of the second crop as compared to M-F. Furthermore, a progressive yield decline trend in maize was noticed in the present study, and maximum yield reduction in the maize-fallow system over maize legume integration was recorded in the four years of experimentation (Fig. 2). Non-addition of the residue having poor nutrient recycling ability and exposure of crop to intense rainfall during grand growth stage resulted in yield penalty under the M-F system. Being nutrient exhaustive crop, continuous cultivation of maize depleted the soil fertility from the same soil layers year after year causing soil fertility fatigue which perhaps caused progressive decline in maize productivity (Ghosh et al., 2020).

Use of bio-mulches during winter season conserves soil moisture and increases the productivity of winter and succeeding crops. Application of diverse mulches provides cover to the soil surface which regulated the soil temperature, suppressed weed growth and conserved soil moisture for a longer period, and promoted soil aggregation and built SOM (Yang et al., 2018; Zhou et al., 2019) leading to higher yields.

Water productivity is the measure of performance expressed as ratio between crop yield and the crop water requirement. The higher water productivity under rainfed condition is the crop performance (yield) indicator against drought (Das et al., 2017; Huang et al., 2005). Bio-mulching improved the yield of winter crops thereby increasing WP. SMC measures enhanced the WP of all the winter season crops. In-field residue retention is an effective practice that promotes water conservation by reducing soil water evaporation during the summer fallow period (Wanga et al., 2018) which can increase WP (Huang et al., 2005; Lu et al., 2015; Su et al., 2007). In the present study 28.2–39.0% higher water productivity was noticed in different crops over NM. This indicated that crop residue retention is more beneficial when soil moisture and precipitation are limiting during the winter season. Hence, our study inferred that site-specific bio-mulching is a pre-requisite for double cropping in maize-fallow land under the rainfed ecosystems in the EHR of India.

4.2. Soil health

Inclusion of legumes (cowpea) as intercrop in intensified maize-based cropping systems and use of bio-mulches as SMC measure improved the soil physico-chemical and biological properties after four years of experimentation. Intensified cropping systems (maize + cowpea-winter crops) had relatively lower ρb over the M-F. Three crops in intensified cropping systems had generated more root biomass and also the incorporation of additional organic inputs compared to M-F might have resulted in reduced ρb in the present study. Inclusion of legumes and other crops in monocropping systems drastically reduces the soil ρb both under organic and inorganic management practices (Grant & Lafond, 1993; Babu, Singh, et al., 2020). Similarly, the use of bio-mulches as SMC measure reduced the soil ρb as compared to NM. The application of SMC measures improved the soil physical properties which thereby enhanced the total soil porosity and subsequently reduced the soil ρb (Mulumba & Lal, 2008). The cultivation of M + C-GP and M + C-R cropping systems resulted in higher SOC at both the surface (0–15 cm) and sub-surface (15–30 cm) soil layers over the M-F system. Intensified systems produced more root biomass at both surface and sub-surface soil resulted in higher SOC over less intensified systems (Borase et al., 2020; Tong et al., 2017). The low C/N ratio and higher lignopolyphenol complex of the legumes may have resulted in rapid mineralization and the binding ability to the soil clay complex might be the possible reason for higher SOC in pulse-based cropping systems (Ashworth et al., 2020). Bio-mulching possibly increased the SOC concentration by releasing C in the soil after decomposition. The higher SOC concentration under different SMC measures can be attributed to the long term application of crop residues as organic inputs containing higher OC. The inclusion of legumes in maize-based mono-cropping systems under organic farming enhanced the SOC (Das et al., 2017; Marka & Garye, 2003). The inclusion of cowpea as intercrop, garden pea, and rajmash as winter legumes had a positive effect on available N in the surface (0–15 cm) and sub-surface (15–30 cm) soil as compared to M-F and other winter season crops. M + C-GP ascribed higher available N (12.9%) and available K (26.3%) in the surface soil than MF after four cropping cycles. The legumes depleted less N from soils when compared with cereals under continuous cropping systems as a result of biological N fixation, and the ability to mineralize higher N content contributed to increased soil available N (Hossain et al., 2016; Liu et al., 2020). This relates to higher soil available N in the legumes' embedded cropping systems relative to maize fallow systems. M + C-Bw had 12.7% higher residual available P in the surface soil than M-F after four cropping cycles. The higher soil available P under M + C-Bw might be due to the higher solubilization potential of weakly labile P pool by buckwheat crop under the maize-based system (Teboh & Franzen, 2011). The inclusion of legumes did not show significant effect on the changes in available P as compared to other crops in the system. The plant-available nutrients (N, P, and K) were significantly higher ($p < 0.05$) under SMC measures at both depths of soil. The plant-available N, P, and K concentration under MSM + WBM might have been higher mainly due to the more favorable and congenial conditions for mineralization of added biomass than NM. Generally, organic mulches *viz*., maize stover and weed biomass used in the study are rich in P and K (Suppl. Table 2) which might have led to higher available P and K than NM.

Soil biological health is an important tool for soil microbial enzymatic function as MBC and DHA (Borase et al., 2020). In the present study, an increase in soil MBC activity in intensified cropping sequences over M-F signified that the intercropping of legumes and intensification could improve soil health. Higher DHA activities are the indicators of a good mineralization process which facilitates nutrients' availability to crops (Borase et al., 2020; Monti et al., 2019). Inclusion of pulse and winter season crop biomass may enhance the SOC and SMBC which serves as a substrate for microbial proliferation and enhances the soil enzymatic activities. The addition of more organic matter through root biomass by different diversified cropping systems presumably increased microbial activity which in turn promoted micro-aggregates to form macro-aggregates that are particularly held by fungal hyphae, polysaccharides, and fibrous roots (Babu, Singh, et al., 2020; Das et al., 2017). In the present study, SMC measures significantly increased the MBC and DHA after four cropping cycles. Plant and weed biomass mulching (a mixture of differently decomposable materials) improved the soil physical condition to support greater microbial biomass and faunal community structure of soil that might have enhanced the MBC and DHA activities in soils.

4.3. Energy and financial calculations

Analysis of energy efficiency in cropping systems is an important mechanism for achieving a green economy (Babu, Mohapatra, et al., 2020; Yadav et al., 2018). The energy efficient system must produce more economic output per unit energy consumed. The M + C-Rs had higher energy input over other systems. The highest energy consumption in M + C-R was due to the higher use of organic manures, seed, machinery, and labor. MF consumed the lowest energy since farm operations were limited to one season. The energy consumption positively correlated with the inputs and their corresponding energy value under the organic production system (Babu et al., 2016). With regards to energy output, M + C-GP recorded 159% and 175% higher gross and net energy over M-F.

Variations recorded in various cropping systems were mainly due to differences in productivity of various crops under study. M + C-R had 5.8% higher energy productivity over the mono-cropping of maize. Higher grain and biomass yields with corresponding EUE and EP were reflected in M + C-GP over other cropping systems. Among the SMC measures, application of MSM + WBM recorded higher gross and net energy over NM. Furthermore, the combined use of MSM and WBM resulted in 19.6% and 14.7% higher EUE and EP over NM, respectively. The results indicated that the inclusion of cowpea as an intercrop and the short duration winter crops with MSM + WBM as SMC measure was the energy-saving and environment-friendly production system to intensify the M-F under rainfed organic management in the EHR of India.

Economic analysis indicated that the cost of cultivation (COC) was in the range of US $ 580 to 1310 ha^{-1} (Table 5). All the intensified systems had a higher COC over the M-F system. The highest COC was noticed with the M + C-GP system. This was mainly because the intensified system involved more input, labor, and other costs for managing the crops throughout the year (Babu, Mohapatra, et al., 2020; Yadav et al., 2013). Intensified systems recorded two-three fold higher gross and net return over M-F. Similarly, cropping system intensification resulted in a 62.5% higher B: C ratio over the M-F system. In the present study, the induction of the second crop in place of fallow in the M-F system increased crop productivity with corresponding increase in the economic return. Cultivation of more crops on the same piece of land in a definite timeframe resulted in higher system productivity and profitability of mono-cropping (Babu et al., 2016; Yadav et al., 2013). The application of mulching increases the COC over NM. But the escalated COC due to mulching was compensated by higher economic output over the MF system. Application of MSM + WBM recorded 16.6% higher B: C ratio over NM. Mulching improves the soil physico-chemical and biological properties and conserves the soil moisture which provides congenial environment for crop growth and yield (Yadav et al., 2018) which ultimately turned into high economic return.

5. Conclusions

The study proved the hypothesis that the inclusion of legumes as an intercrop in maize-based cropping system and short cycle winter crops enhances the crop, water, energy productivity, profitability, and soil health as compared to maize-fallow under organic production systems in EHR of India.

5.1. The study supports the following conclusions

1. The inclusion of the second crop (winter season crop after maize) and co-culture of cowpea as intercrop enhanced the maize grain yield by 6.2–23.5% when compared with maize-monoculture (M-F).
2. All the intensified cropping systems significantly increase the energy return, use efficiency and productivity over the M-F system. The system resulted in the highest energy use efficiency (7.90%) and energy productivity (1.27 kg MJ^{-1}). Application of MSM and WBM significantly increased the energy use efficiency over NM.
3. The intensified system significantly improved the SOC, MBC, and DHA, available N and K over the M-F system besides reducing the soil ρb (4.37%). The maize + cowpea-garden pea (M + C-GP) recorded three-fold higher productivity and profitability over the M-F system.
4. Application of MSM + WBM enhanced the productivity and profitability of winter crops by two to three times and doubled the water productivity besides improving soil health as compared to NM. The residual effect of maize stover mulch and weed biomass mulch (MSM + WBM) enhanced maize productivity by 19.1% over NM.

Co-culture of cowpea (inter-cropping) with maize in the rainy season and the inclusion of short duration winter garden pea along with organic soil moisture conservation measures (MSM + WBM) in maize-based cropping system is the energy-efficient, economically viable and sustainable system to intensify the maize-fallow system under organic rainfed condition. Therefore, the study suggested this production system should be the focal recommendation while designing the sustainable development policy for organic farming under rainfed condition of the EHR of India and other similar eco-regions.

Declaration of competing interest

The authors declare no potential conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.iswcr.2020.11.003.

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