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RESEARCH ARTICLES

Impact of farm yard manure on cropping cycle in a rainfed agroecosystem of Central Himalaya

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Abstract

Crops, livestock and forests are interlinked components of Central Himalayan agro-ecosystems. Traditionally, farm yard manure is produced from forest leaf litter and excreta of livestock obtaining > 50% feed from forests. Chemical fertilizers are not used in rainfed farms on slopes. Experiments were conducted to test whether increase in FYM input rates results improvement in economic and environmental functions of agro-ecosystems. Increase in FYM input rate from 30 t/ha/crop-season currently practiced by farmers to 60 t/ha/crop-season showed substantial increase in crop yield and soil quality. Rice and wheat were more responsive to FYM input than the legume black gram. Harvest index is maximum for 60 t/ha/crop-season FYM treatment for rice and wheat. In blackgram maximum harvest index was obtained when no FYM was provided. During the 3 years of study, soil pH decreased (becoming more acidic) as compared to that recorded at the start of the study. Soil organic carbon generally declined upto second kharif season and then improved during second rabi (fallow) under no input treatment, and 16t/ha/crop-season FYM treatment and levels of N, P and Mg too showed patterns similar to soil organic carbon, but the trends varied for Ca, Na and K. Soils of fields put to 0 and 16 t/ha/crop-season FYM treatments showed a net decrease in concentration of these elements and those put to 30 and 60 t/ha/crop-season FYM treatments showed increase in their level.

Keywords Rainfed · FYM · Crop-season · Harvest index · Biomass · Yield

Introduction

Environmental, biological, socio-cultural and economic variation existing in the Central Himalaya have led to the evolution of diverse and unique traditional agro-ecosystems (Lal 2004; Chandra et al. 2010a, b, 2011a; b; Mahanta et al. 2013; Dinakaran et al. 2018). In settled agro-ecosystems on terraced slopes, soil fertility is traditionally maintained by incorporation of farm yard manure (FYM) generated from leaf litter collected from the forest floor and excreta of livestock drawing > 50% of their feed from forests. Traditional practices are fast degenerating and transforming under the influence of multiple factors including lack of analysis of their potential in scientific terms. While inaccessibility and rainfed conditions on terraced slopes have delimited use of chemical fertilizers, increasing labor scarcity arising from diversion of labor to non-farm economic activities and restrictions on utilization of forest resources from diversion of forest land to production of industrial raw material and conservation of biodiversity reduced quality and quantity of farm yard manure. Traditional knowledge is deficient in optimal dozes of farm yard manure, while conventional agricultural scientists have not included exclusive farm yard manure treatment in long term soil fertility experiments (Saxena and Rao 2016). Experiments do show that crop yields are more stable in FYM with chemical fertilizer treatments than exclusive fertilizer treatments (Nambiar 1994; Yadav et al. 1998; Bhandari et al. 2002; Ladha et al. 2003; Kundu et al.

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2007a; Chandra et al. 2011a, b; Bhadauria et al. 2014; Singh et al. 2017; Datta et al. 2018). Farmers often do not pay attention to farm yard manure input because of a conception that nutrient stress (Bhandari et al. 2002; Singh et al. 2004; Kundu et al. 2007b) is not as crucial as wildlife intrusions and climate change in lowering crop yields. Cultivation of crops performing in low soil fertility, fallowing and leasing land are the common ways of coping with the situation (Chandra et al. 2010a, b, 2011a, b, c, 2013; Maikhuri et al. 2015; Rao et al. 2016). The loss of agro-biodiversity and its multiple functions has emerged as major concern at local, regional and national scales in recent period (Negi et al. 2009; Chandra et al., 2011a, b). Increase in farm yard input is likely to increase crop yields by maintaining soil quality (Nayak et al. 2007; Liu et al. 2013; Mahanta et al. 2013; Blanchet et al. 2016; Dinakaran et al. 2019) and also promote forest conservation and restoration for availability of high quality leaf litter and forage. High farm yard manure input based farming in the Himalayan scenario thus reinforces sustainable forest management and carbon sequestration within croplands (Rao et al. 2016).

The present study is an attempt to find out optimal dozes for farm yard manure in rainfed settled agro-ecosystems in Central Himalayan Region of India.

Methods

General description of experimental site

A farmer's field plot experiment with the traditional cropping cycle was conducted during April 2003 to May 2006 on rainfed terraced farms in the Langasu–Uttaron village of Chamoli district in the Garhwal Himalaya (30° 17.368′ N latitude and 77° 16.868′ E longitude). Rainfed cultivated land is mainly on sloping land where irrigation facilities are not available and thus crop cultivation is done using moisture input from rain. Village agricultural land is divide two almost equal halves, "Mulla Sar" below and "Malla Sar" above clustered dwellings. Traditionally, one of these halves is put to fallow in one winter season over two years. Typical cropping sequence in a Sar is: kharif crop (first crop season)—rabi crop (second crop season)—kharif crop (third crop season)—fallow. Thus, second rabi season (fourth crop season) is put to fallow (Chandra 2007; Chandra et al. 2010a, b, 2011a; b).

The parent soil material is represented by feldspathic quartz schist, quartz muscovite schist and chlorite schist and can be classified as Dystric cambisol according to FAO soil classification system (Semwal and Maikhuri 1996). Farmers generally apply FYM @ 30–35 t/ha during first kharif for growing rice, 12–16 t/ha during first rabi for growing wheat and no FYM for growing pulses during second kharif (Chandra et al. 2011a, b; Dinakaran et al. 2019). Daily rainfall (mm), relative humidity (%), minimum and maximum atmospheric temperature and soil temperature during study period were recorded with help of rain gauge, humidity meter and thermometers. Barring April, November and December, the study area did not suffer from moisture stress as it received sufficient rains in all other months (Figs. 1, 2).

Experimental design

The cropping sequence commenced in the month of April, 2003 on Mullasar with rice followed by wheat (October 2003–May 2004), black gram (June–September 2004), fallow (October 2004–April 2005), rice (April–September 2005) and wheat (October 2005–May 2006) (Fig. 3).

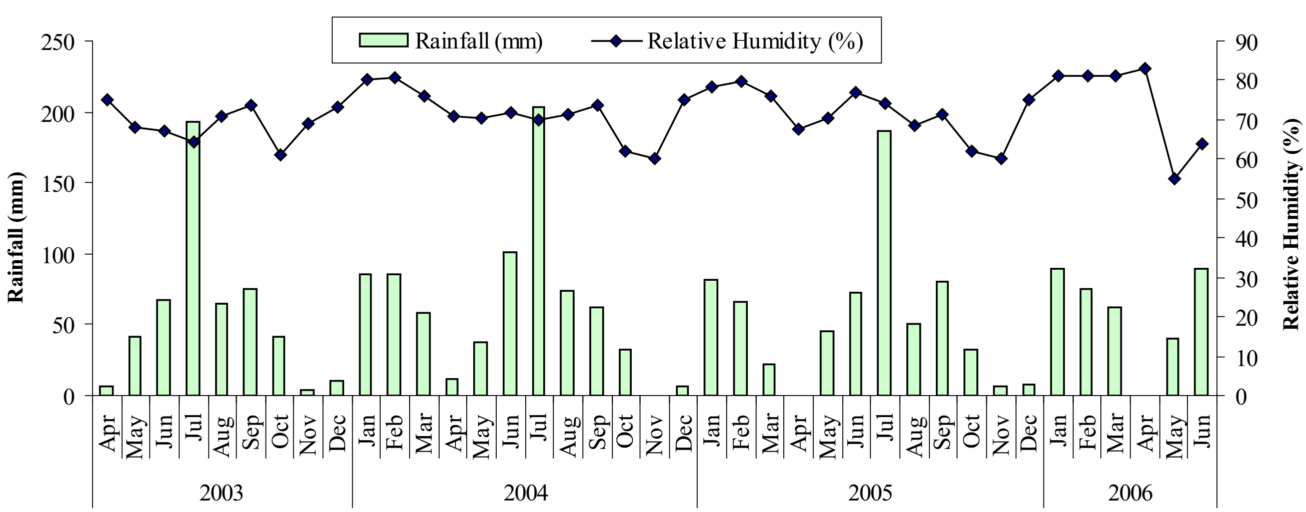

Fig. 1 Monthly rainfall (mm) and relative humidity (%) at village Langasu-Uttaron, Chamoli district, Garhwal Himalaya, India

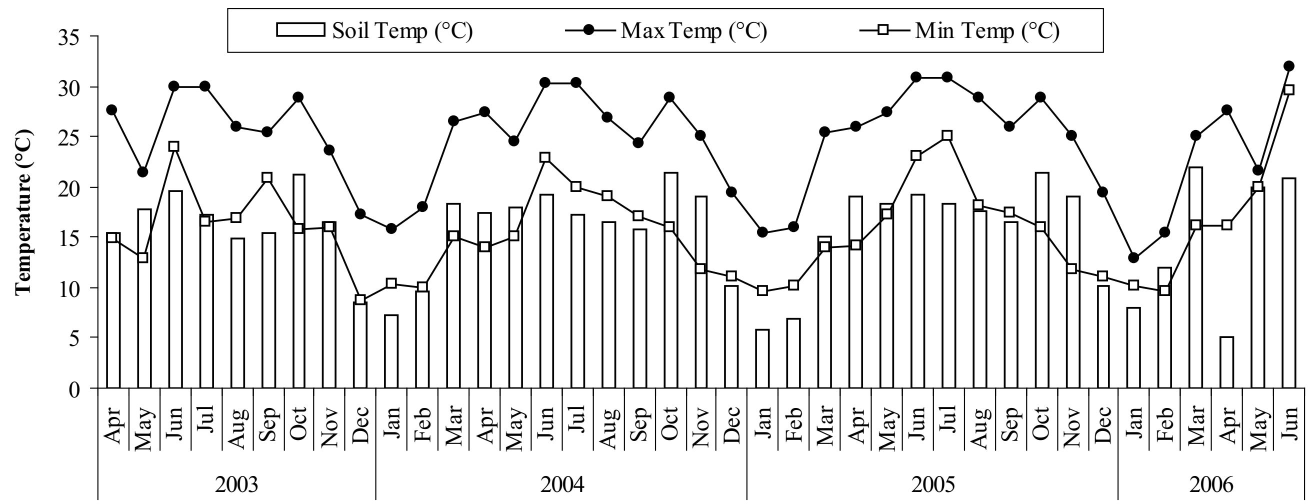

Fig. 2 Minimum and maximum atmospheric temperature and soil temperature (°C) during study period at village Langasu-Uttaron, Chamoli district, Garhwal Himalaya, India

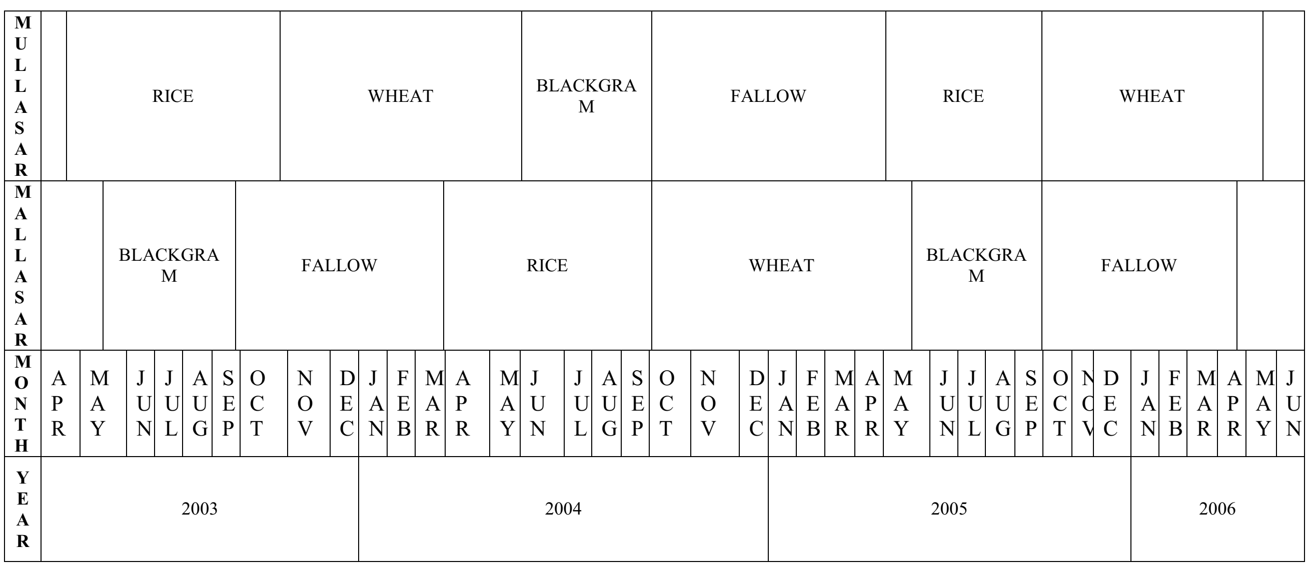

Fig. 3 Crop calendar of experiment under various treatment of FYM

Similarly, on Mallasar the cropping sequence commenced with black gram (May–September 2003) followed by the fallow period (October 2003–April 2004), rice (April–September 2004), wheat (October–May 2004), black gram (May 2005–September 2005) and fallow period (October 2005–April 2006) (Fig. 3).

For assessing the effect of FYM a simple experiment was performed in farmer's field in 3×3-m plots. A total 12 plots (three replicates per treatment) were established. These plots were separated from each other by one-meter distance. Care was taken to ensure similar topographic conditions to minimize the errors in analysis. FYM was applied @ 0, 16, 30, 60 t/ha (fresh weight) at the time of ploughing in each crop season.

Crop management

Seed sowing

Rice, wheat and black gram were sown in April (first kharif), October (first rabi) and June (second kharif), respectively. Sowing was done after ploughing and land preparation activities. Seed input @ 30 kg/ha was decided on the basis of prior discussions with farmers practicing traditional cropping for decades. Density of plants was maintained by thinning the plants from the crowded places after 15 days of seed germination. Care was taken to uproot thin and weak plants during the thinning operation.

Weeding

Weeds were removed by hand thrice, twice and once in rice, wheat and black gram plots, respectively.

Harvesting

Rice was harvested in September, wheat in April and black-gram in October. The harvest was done manually using a sickle. The plants were cut just a little above the ground level and heaped in the field for drying. The harvested produce of each plot was collected separately, tied into bundles and labelled. The produce of each plot was weighed by a spring balance. After harvesting each plot was hoed to pull out the roots. These roots were pooled and weighed in field.

Threshing and winnowing

The sun dried produce of each plot was threshed manually by rubbing ears with feet for rice and beating with help of wooden stick over a hard surface for wheat and black gram. Seeds were separated from chaff and cleaned by hand fan (Soopa). Finally, the clean seeds obtained from each plot were weighed on a spring balance.

Dry matter

100 gm of shoot, root and grain from each plot were sun dried, packed and labelled. These packets were carried to the laboratory and kept in an oven at 60 ± 2 °C for 72 h or until they attained constant weight. The oven dry weights of different components of crop were recorded on an electronic balance.

Soil sampling and analysis

Soil sampling was carried out at depth of 0–30 cm prior to the initiation of the experiment in both the “Sars” and after harvesting of each crop in both kharif and rabi seasons. i.e., in the months of April/May and October/November, respectively. Soil was sampled from five random locations in each of the three replicate plots. Samples from each plot were mixed thoroughly to obtain one composite sample per plot. Soil pH was measured following Jackson (2005). Soil organic carbon content was determined by the method of Walkley and Black (1934). Organic carbon free soil samples were used to determine total N, K, Ca, Mg, Na and available P. The digestions were carried out using Kjeldhal apparatus (Anderson and Ingram 1989). Total N was estimated by micro- Kjeldhal method (Allen 1974). Available phosphorous was measured at 880 nm wavelength using ammonium molybdate blue menthod (Systronics 160). Total calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K) were estimated using the same filtrate by atomic absorption spectrophotometry (AA 6300 Shimadzu, Japan).

Harvest index, equivalent rice yield and protein

Harvest Index (HI) was computed following Mandal et al. (2009), equivalent rice yield Rautaray et al. (2003) and Protein content following Singh et al. (2002) and Gopalan et al. (2004).

Statistical analysis

Analysis of variance across years (Gomez and Gomez 1984) was performed to determine the effects of treatment, year, and their interactions on productivity and simple student t test—paired two samples for mean ($P < 0.05$) were used to compare different soil and plant parameters between different seasons and treatment using Microsoft Excel.

Results

Production of roots, shoots and grains in rice, wheat and black gram increased with increase in the FYM input in both the “Sars”. Overall, yields were highest in 60 t/ha/crop-season FYM treatment and lowest in control (no FYM application). Highest harvest index was recorded in 60 t/ha/crop-season FYM treatment in rice and wheat but in control (no FYM input), in black (Tables 1, 2).

In general, there was no significant variation in the yield across years and FYM input rates. While the harvest index was quite stable in rice, it varied substantially in wheat indicating that this crop was quite sensitive to FYM input rates and year-to-year variations in climatic conditions determining soil moisture in rainfed conditions. Blackgram, like rice, also did not show any significant variation in harvest index with variation in FYM rates or year-to-year variation in climatic conditions (Fig. 4).

Grain yield of rice, wheat, blackgram or total yield of cropping sequence did not show any significant ($P > 0.05$) variation between Mullasar and Mallasar. Rice biomass under FYM treatment of 16 t/ha/crop-season varied significantly ($P < 0.05$) between the two Sars. In all other cases, no significant variation in total biomass production was recorded between the two Sars. Significant difference ($P < 0.05$) was observed in the total biomass production over a cropping sequence between the two Sars in both 16 and 60 t/ha/crop-season FYM treatments. However, the harvest

Table 1 Biomass (kg/ha; mean ± standard deviation) and harvest index of crops during the six growing seasons under varied FYM input in Mullasar

	FYM treatments (t/ha/crop-season)	April–October 2003 rice	October 2003–May 2004 wheat	June–October 2004 black-gram	October 2004–April 2005 fallow	April–October 2005 rice	October 2005–May 2006 wheat
Root	0	1776 ± 269	1481 ± 160	94 ± 5	–	1768 ± 58	1525 ± 267
	16	1838 ± 125	1944 ± 278	114 ± 2	–	1821 ± 151	1946 ± 161
	30	2021 ± 569	1981 ± 224	123 ± 6	–	1950 ± 113	1872 ± 22
	60	1820 ± 115	2128 ± 165	143 ± 14	–	2066 ± 111	2155 ± 258
Shoot	0	2319 ± 96	2241 ± 195	434 ± 7	–	2376 ± 140	1930 ± 158
	16	2318 ± 208	1907 ± 128	419 ± 21	–	2402 ± 111	2427 ± 234
	30	2705 ± 224	2410 ± 175	482 ± 5	–	2704 ± 77	2592 ± 288
	60	2803 ± 230	2740 ± 140	518 ± 17	–	3491 ± 117	2806 ± 215
Grain	0	2065 ± 389	1018 ± 160	1808 ± 52	–	2151 ± 45	865 ± 122
	16	2352 ± 153	1182 ± 225	1840 ± 29	–	2432 ± 65	932 ± 77
	30	2602 ± 252	1481 ± 160	1894 ± 59	–	2547 ± 344	1636 ± 144
	60	3361 ± 237	1759 ± 424	2094 ± 49	–	3079 ± 116	2555 ± 198
Total Biomass	0	6160 ± 444	4740 ± 195	2335 ± 54	–	6295 ± 187	4321 ± 309
	16	6508 ± 287	5033 ± 440	2373 ± 13	–	6655 ± 86	5304 ± 298
	30	7328 ± 479	5873 ± 362	2500 ± 57	–	7201 ± 412	6099 ± 446
	60	7984 ± 51	6626 ± 665	2755 ± 73	–	8636 ± 110	7516 ± 559
HI	0	33.43 ± 4.95	21.59 ± 4.13	77.39 ± 0.45	–	34.19 ± 1.08	20.21 ± 4.22
	16	36.19 ± 2.89	23.41 ± 3.12	77.55 ± 0.91	–	36.55 ± 0.98	17.65 ± 2.38
	30	35.71 ± 5.30	25.28 ± 2.96	75.76 ± 0.66	–	35.27 ± 2.82	26.81 ± 0.59
	60	42.10 ± 3.13	26.31 ± 3.75	76.01 ± 0.62	–	35.67 ± 1.64	34.04 ± 2.38

Table 2 Biomass (kg/ha; mean ± standard deviation) and harvest index of crops during the six growing seasons under varied FYM input in Mallasar

	FYM treatments (t/ha/crop-season)	June-October 2003 black-gram	October 2003–April 2004 fallow	April–October 2004 rice	October 2004–May 2005 wheat	Jnue-October 2005 black-gram	October 2005–April 2006 fallow
Root	0	98 ± 4	–	1735 ± 83	1659 ± 202	96 ± 5	–
	16	138 ± 43	–	1848 ± 257	1882 ± 172	117 ± 14	–
	30	116 ± 6	–	1919 ± 142	1952 ± 84	114 ± 13	–
	60	134 ± 0.2	–	1961 ± 149	2056 ± 195	159 ± 5	–
Shoot	0	404 ± 15	–	2325 ± 87	2055 ± 266	435 ± 7	–
	16	421 ± 5	–	2538 ± 145	2331 ± 213	440 ± 21	–
	30	479 ± 10	–	2597 ± 114	2359 ± 171	481 ± 10	–
	60	526 ± 17	–	3574 ± 473	2856 ± 282	513 ± 37	–
Grain	0	1789 ± 58	–	2175 ± 223	1078 ± 151	1776 ± 55	–
	16	1822 ± 29	–	2333 ± 15	1169 ± 103	1822 ± 71	–
	30	1940 ± 21	–	2475 ± 288	1693 ± 212	1941 ± 27	–
	60	2091 ± 62	–	3100 ± 164	2425 ± 52	2084 ± 76	–
Total Biomass	0	2291 ± 72	–	6235 ± 360	4792 ± 216	2307 ± 54	–
	16	2381 ± 27	–	6720 ± 334	5382 ± 486	2379 ± 78	–
	30	2535 ± 32	–	6990 ± 366	6003 ± 20	2536 ± 24	–
	60	2751 ± 76	–	8635 ± 561	7337 ± 91	2756 ± 59	–
HI	0	78.09 ± 0.11	–	34.83 ± 1.73	22.62 ± 4.21	76.98 ± 0.67	–
	16	76.54 ± 1.62	–	34.78 ± 1.71	21.72 ± 0.28	76.58 ± 0.51	–
	30	76.53 ± 0.31	–	35.34 ± 2.70	28.20 ± 3.54	76.53 ± 0.34	–
	60	76.01 ± 0.33	–	35.95 ± 1.75	33.05 ± 0.68	75.59 ± 1.41	–

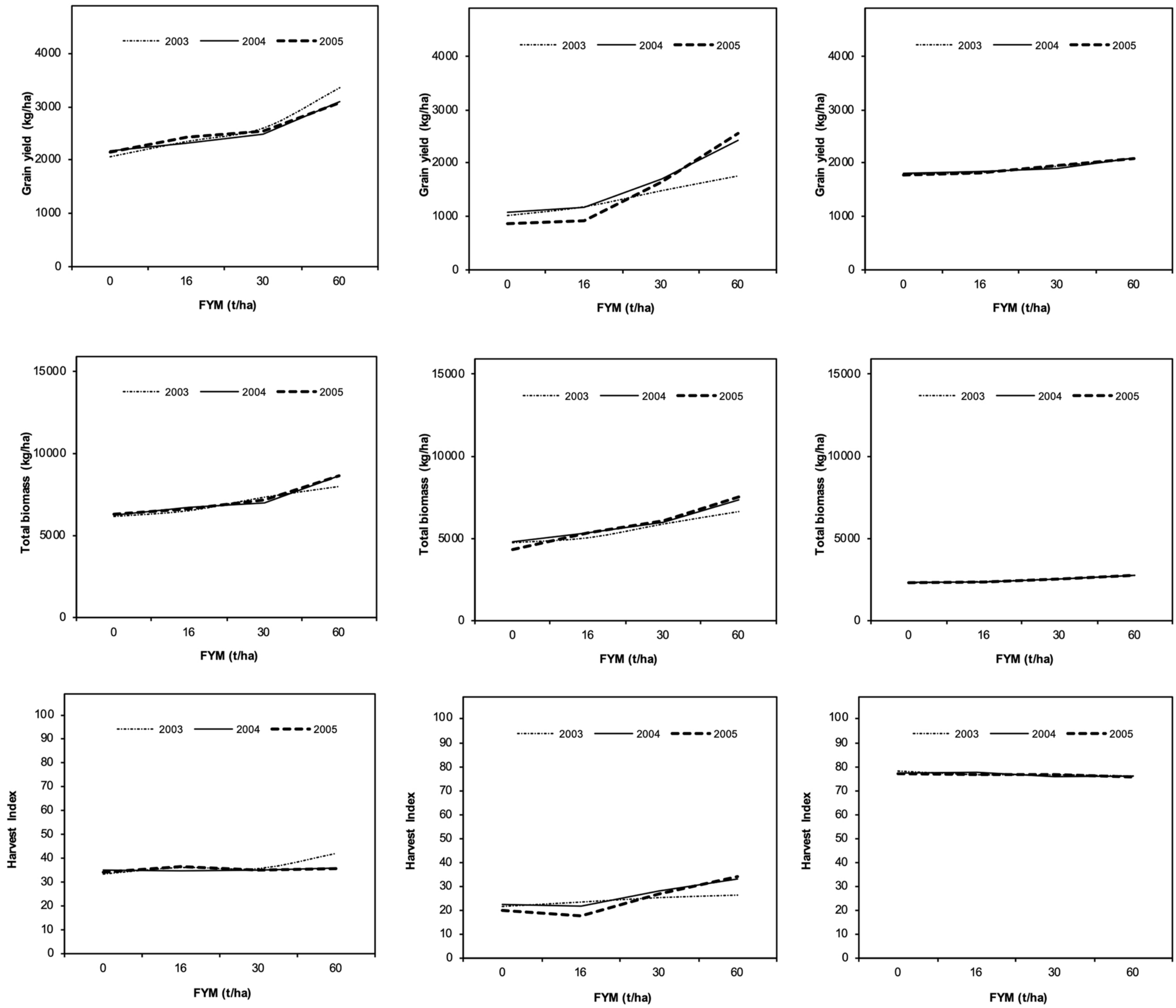

Fig. 4 Grain yield, total biomass and harvest index under various treatments of FYM

indices were not significantly (P > 0.05) different for crop sequences under 16 t/ha/crop-season FYM treatment.

Variation in economic yields of component crops and economic rice equivalent yield of crop sequences during years is shown in Table 3. The coefficient of variation of economic yield in different years was greater for wheat as compared to rice and black gram. The percentage increase in mean economic yield for varied doses of FYM over no input treatment showed that wheat had positive effect of FYM; yields in the 16t/ha FYM treatment were 17%, 30 t/ha FYM 72% and 140% in 60 t/ha FYM treatment higher than the control (no FYM input). Results for rice, wheat and blackgram for economic rice equivalent yield (Table 4) indicate that while yields were significantly different (P < 0.05) in different FYM treatments but not in different years. On the other hand, the economic rice equivalent yield of cropping sequence showed significant differences (P < 0.05) between FYM treatments as well as years. Protein level increased in all crops with increase in FYM input rate (Table 5). This trend was most conspicuous in wheat followed by rice and blackgram.

Soil organic carbon, total nitrogen, sodium, calcium, magnesium and available phosphorus levels in the soil generally showed direct positive relationship with the FYM input rates (Tables 6, 7). Thus, the highest levels of these elements were recorded in 60 t/ha/crop-season FYM treatment and lowest in control (no FYM input).

During the three year study the amount of total nitrogen in the soil pool decreased after first kharif (rice) and rabi (wheat) cropping but increased after second kharif (black gram) and second rabi (fallow) in control (no FYM input), did not show any major changes in 16 and 30 t/ha/

Table 3 Economic yield (t/ha) of crop and rice equivalent yield (t/ha) of different crop sequences under varied FYM treatments

FYM treatments (t/ha/crop season)	Rice					Wheat					Blackgram					Economic rice equivalent yield				
	2003	2004	2005	Mean	% increase over 0 (t/ha)	2003	2004	2005	Mean	% increase over 0 (t/ha)	2003	2004	2005	Mean	% increase over 0 (t/ha)	2003–2004	2004–2005	2005–2006	Mean	% increase over 0 (t/ha)
0	2.06	2.18	2.15	2.13	0	1.02	1.08	0.87	0.99	0	1.79	1.81	1.78	1.79	0	12.96	13.25	12.78	13.00	0
16	2.35	2.33	2.43	2.37	12.32	1.18	1.17	0.93	1.09	16.83	1.82	1.84	1.82	1.83	2.24	13.65	13.71	13.39	13.58	4.46
30	2.6	2.47	2.55	2.54	20.38	1.48	1.69	1.64	1.60	71.49	1.94	1.89	1.94	1.92	7.26	14.92	14.83	15.08	14.94	14.92
60	3.36	3.1	3.08	3.18	47.39	1.76	2.42	2.55	2.24	140.09	2.09	2.09	2.08	2.09	16.76	16.86	17.5	17.6	17.32	33.23

crop-season FYM treatment and increased continuously under 60 t/ha/crop-season FYM treatment in both Mullasar and Malasar (Tables 6, 7). Soil pH decreased with cropping length and increased during legume cropping and fallow phases (Tables 6, 7). The changes in soil pH were more pronounced in control (no FYM input) and 16 t/ha/crop-season FYM treatments as compared to 30 and 60 t/ha/crop-season FYM treatments. As a general trend during the three years of study, soil pH decreased (becoming more acidic) as with passage of time. Soil organic carbon generally declined up to second kharif season and then showed improvement during second rabi (fallow) under no input FYM treatment and 16 t/ha/crop-season FYM treatment. However, plots receiving FYM 30 and 60 t/ha/crop-season generally showed a gradual buildup of soil organic carbon, though there was a transient depletion phase during rice crop phase (Tables 6, 7). Total N, Mg and available P showed temporal patterns similar to soil organic carbon. Total Ca, Na and K showed quite different patterns (Tables 6, 7).

Net changes C, total N, K and available P are given in Table 8. While the soils of fields exposed to 0 and 16 t/ha/crop-season FYM treatments showed a net decrease, those exposed to 30 and 60 t/ha/crop-season FYM treatments showed a net increase in the levels of these elements.

Discussion

Agriculture productivity depends on various inputs and environmental conditions, specifically soil type, rainfall and temperature. To achieve the goal of higher agricultural production, optimal dozes and combinations of inputs are necessary. Inputs can be (1) conventional such as land, labour, capital and irrigation; (2) biophysical/chemical such as FYM, fertilizers and pesticides; (3) biological such as seeds and other genetic resources; and (4) environmental such as soil, rainfall and temperature. Several workers have concluded organic and inorganic fertilizers and crop varieties as the most crucial inputs determining crop yields across varied soil types and climate regimes (Gupta et al. 2003; Meertens et al. 2003; Kiani et al. 2005; Shah and Ahmad 2006; Shrestha et al. 2006; Mushtaqe et al. 2007; Singh et al. 2007; Zingore et al. 2007; Han et al. 2016; Dinakaran et al. 2019).

FYM input rates in traditional farming enormously vary (Table 9). This variation may be related to quality of FYM, type of cropping systems and soil conditions. The farmers in the study area generally applied about 30–35 t FYM/ha during kharif rice cropping, 16–25 t FYM/ha during rabi wheat cropping and 8–12 t FYM/ha during kharif millet cropping. FYM is not applied for growing legumes, while millets mixed with legumes generally received lower dozes (~6–8 t FYM/ha). Participation in designing, implementing

Table 4 ANOVA results for rice, wheat, blackgram and rice equivalent yields

	Years	FYM treatments	Year vs. FYM treatments
Rice	NS (F = 0.336; *P* = 0.718)	S (F = 36.734; *P* = 0.000004)	NS (F = 0.595; *P* = 0.732)
Wheat	NS (F = 4.384; *P* = 0.024)	S (F = 80.645; *P* = 0.000001)	S (F = 4.658; *P* = 0.003)
Blackgram	NS (F = 0.025; *P* = 0.975)	S (F = 59.148; *P* = 0.000003)	NS (F = 0.403; *P* = 0.870)
Rice equivalent yields	NS (F = 0.857; *P* = 0.437)	S (F = 186.258; *P* = 0.0000001)	NS (F = 1.185; *P* = 0.347)

NS not significant, *S* significant

Table 5 Protein production (kg/ha) under various FYM treatments

FYM treatments (t/ha/crop season)	Rice				Wheat				Blackgram			
	2003	2004	2005	Mean	2003	2004	2005	Mean	2003	2004	2005	Mean
0	125.37	132.08	130.63	129.36	110.56	117.06	93.95	107.19	429.30	433.81	426.32	429.81
16	142.80	141.66	147.69	144.05	128.27	126.86	101.15	118.76	437.33	441.68	437.36	438.79
30	157.98	150.27	154.66	154.30	160.82	183.76	177.62	174.07	465.60	454.52	465.89	462.00
60	204.08	188.22	186.97	193.09	190.92	263.25	277.36	243.84	501.90	502.62	500.12	501.55

and monitoring led local farmers to realize scope of raising crop yields as well as soil quality by increasing FYM input. The present study shows that if the farmers can maintain application of 30 t/ha of FYM during rice and wheat phase of cropping, rise in yields as well as soil organic carbon pools could be maintained in a healthy status and the use of long fallow helps them in achieving the yield stability. Shrestha et al. (2006) reported that rice–wheat system receiving about 10t FYM/ha/year and 157 kg inorganic fertilizer/ha/year in warm temperate conditions accumulated higher soil C as compared to subtropical rice–wheat system receiving only 5 t FYM/ha/year and comparable inorganic fertilizer input in Nepal. Similar trends are reflected from many other studies (Kaini et al. 2005; Kundu et al. 2007a, b; Hartmann et al. 2015; Abe et al. 2016; Luo et al. 2016; Dinakaran et al. 2019).

Many researchers have attributed scarcity to sub-optimal dozes of FYM (Yadav et al. 1998; Ladha et al. 2003; Singh et al. 2004; Kundu et al. 2007a). Such reductions in FYM applications could lead to reduction in economic as well as biological yields. The results of the present study confirm the pattern observed by Shah and Ahmad (2006) in Azad Kashmir, Gupta et al. (2003) in Indo–Gangetic Plains and Shrestha et al. (2006) in Nepal. Production efficiency of cropping systems differing in crop sequences can be compared in terms of economic yield equivalents of major crops. The present study showed that the winter season crop (wheat) was most responsive to FYM input in all years. Similar trends were also reported by Shah and Ahmad (2006). Another indicator could be protein production from the cropping systems. Grain protein levels increased significantly with increase in rate of FYM for all crops. However, the quantity of grain protein varied between the years. Such variations were also reported by Singh et al. (2002).

Huge amounts of nutrients are mined from soil in the form of food and feed products taken out of crop fields. Application of FYM and leaving the field as fallow are two major strategies used by the farmers to improve soil nutrient status in almost all systems of organic agriculture, with FYM input rates varying depending on socio-ecological conditions (Table 9). The soil nutrient status (i.e. elemental concentrations) reduced significantly during the three year study period when the soils received FYM @16 t/ha/crop-season and increased in treatments receiving FYM @ 30 or 60 t/ha/crop-season. This study thus indicates that the farmers realize a need of increasing FYM input in cereals but are unable to satisfy this need because of scarcity of labor rather than of biomass needed to produce FYM application during blackgram cropping did not provide any significant additional economic or biological yield benefits. Farmer's practices of growing legumes on residual soil fertility and of millet-legume mixed crops with quite low FYM inputs are thus scientifically sound. Apart from incorporation of FYM, inclusion of legumes, which fix nitrogen and whose shoots do not have any direct economic uses and hence left out in the field in the crop sequences is one major strategy adapted by farmers to maintain soil fertility and achieve land and labor productivity in rainfed slopes at par with wet rice monoculture in valley lands (Chandra 2007). The benefits of legumes in rotation are not solely due to biological fixation of nitrogen but also due to improved soil structure, reduced disease incidence and increased mycorrhizal colonization (Wani et al. 1995; Singh et al. 2002, 2007; Zingore et al. 2007).

Table 6 Changes in concentration (mg/100 g) of elements in soil during 3 years cropping in Mullasar

	FYM treatments (t/ha/crop-season)	October 2002–April 2003 fallow	April–October 2003 rice	October 2003–May 2004 wheat	June–October 2004 blackgram	October 2004–April 2005 fallow	April–October 2005 rice	October 2005–May 2006 wheat
C	0	1.585 ± 0.021^{a}	1.441 ± 0.0416^{c}	1.357 ± 0.036^{a}	1.297 ± 0.042^{cb}	1.439 ± 0.055^{d}	1.345 ± 0.021^{d}	1.295 ± 0.021^{c}
	16	1.585 ± 0.021^{a}	1.513 ± 0.0208^{bc}	1.597 ± 0.021^{c}	1.549 ± 0.042^{b}	1.583 ± 0.042^{c}	1.477 ± 0.042^{cd}	1.499 ± 0.042^{b}
	30	1.585 ± 0.021^{a}	1.585 ± 0.0208^{ab}	1.837 ± 0.055^{b}	2.053 ± 0.021^{a}	2.087 ± 0.021^{b}	1.849 ± 0.021^{b}	1.883 ± 0.036^{b}
	60	1.585 ± 0.021^{a}	1.681 ± 0.0360^{a}	1.993 ± 0.083^{a}	2.161 ± 0.021^{a}	2.183 ± 0.055^{a}	1.981 ± 0.042^{ac}	2.111 ± 0.042^{c}
N	0	0.123 ± 0.006^{a}	0.105 ± 0.006^{b}	0.097 ± 0.009^{c}	0.115 ± 0.003^{b}	0.111 ± 0.009^{b}	0.107 ± 0.009^{c}	0.103 ± 0.007^{b}
	16	0.123 ± 0.006^{a}	0.121 ± 0.009^{b}	0.123 ± 0.006^{b}	0.123 ± 0.007^{b}	0.119 ± 0.012^{ab}	0.117 ± 0.009^{bc}	0.115 ± 0.003^{b}
	30	0.123 ± 0.006^{a}	0.123 ± 0.006^{b}	0.125 ± 0.009^{bc}	0.129 ± 0.009^{b}	0.121 ± 0.015^{ab}	0.125 ± 0.012^{b}	0.123 ± 0.009^{b}
	60	0.123 ± 0.006^{a}	0.147 ± 0.00^{a}	0.167 ± 0.003^{a}	0.170 ± 0.007^{a}	0.147 ± 0.009^{a}	0.162 ± 0.006^{a}	0.164 ± 0.007^{a}
P	0	0.043 ± 0.002^{a}	0.040 ± 0.001^{b}	0.039 ± 0.002^{b}	0.040 ± 0.002^{b}	0.037 ± 0.001^{b}	0.040 ± 0.003^{a}	0.036 ± 0.002^{b}
	16	0.043 ± 0.002^{a}	0.046 ± 0.001^{a}	0.041 ± 0.0002^{b}	0.042 ± 0.002^{ab}	0.045 ± 0.006^{b}	0.041 ± 0.006^{a}	0.043 ± 0.003^{ab}
	30	0.043 ± 0.002^{a}	0.051 ± 0.001^{a}	0.044 ± 0.004^{ab}	0.047 ± 0.003^{ab}	0.050 ± 0.002^{ab}	0.043 ± 0.001^{a}	0.048 ± 0.001^{a}
	60	0.043 ± 0.002^{a}	0.051 ± 0.003^{ab}	0.049 ± 0.002^{a}	0.045 ± 0.006^{a}	0.049 ± 0.001^{a}	0.046 ± 0.005^{a}	0.050 ± 0.002^{a}
K	0	0.104 ± 0.002^{a}	0.098 ± 0.003^{b}	0.089 ± 0.009^{c}	0.078 ± 0.001^{b}	0.071 ± 0.002^{b}	0.071 ± 0.002^{b}	0.077 ± 0.004^{b}
	16	0.104 ± 0.002^{a}	0.104 ± 0.004^{b}	0.092 ± 0.005^{bc}	0.080 ± 0.004^{ab}	0.073 ± 0.004^{ab}	0.106 ± 0.005^{a}	0.080 ± 0.002^{b}
	30	0.104 ± 0.002^{a}	0.114 ± 0.003^{a}	0.114 ± 0.003^{a}	0.082 ± 0.002^{ab}	0.086 ± 0.003^{a}	0.111 ± 0.001^{a}	0.111 ± 0.002^{a}
	60	0.104 ± 0.002^{a}	0.126 ± 0.004^{a}	0.114 ± 0.003^{ab}	0.089 ± 0.004^{a}	0.081 ± 0.010^{ab}	0.114 ± 0.004^{a}	0.110 ± 0.001^{a}
Na	0	0.074 ± 0.009^{a}	0.061 ± 0.003^{a}	0.060 ± 0.005^{b}	0.064 ± 0.005^{a}	0.064 ± 0.001^{b}	0.056 ± 0.004^{ab}	0.058 ± 0.006^{ab}
	16	0.074 ± 0.009^{a}	0.068 ± 0.004^{a}	0.064 ± 0.004^{a}	0.065 ± 0.004^{a}	0.065 ± 0.002^{ab}	0.055 ± 0.001^{b}	0.058 ± 0.004^{b}
	30	0.074 ± 0.009^{a}	0.070 ± 0.007^{a}	0.064 ± 0.001^{ab}	0.064 ± 0.001^{a}	0.068 ± 0.004^{ab}	0.066 ± 0.002^{a}	0.062 ± 0.004^{a}
	60	0.074 ± 0.009^{a}	0.065 ± 0.003^{a}	0.065 ± 0.001^{ab}	0.068 ± 0.003^{a}	0.069 ± 0.002^{a}	0.066 ± 0.002^{a}	0.063 ± 0.002^{ab}
Ca	0	0.090 ± 0.001^{a}	0.075 ± 0.001^{c}	0.072 ± 0.002^{c}	0.071 ± 0.001^{c}	0.070 ± 0.003^{b}	0.074 ± 0.001^{b}	0.074 ± 0.002^{c}
	16	0.090 ± 0.001^{a}	0.086 ± 0.001^{b}	0.084 ± 0.001^{b}	0.076 ± 0.002^{b}	0.072 ± 0.002^{b}	0.085 ± 0.004^{b}	0.085 ± 0.001^{b}
	30	0.090 ± 0.001^{a}	0.089 ± 0.001^{a}	0.085 ± 0.003^{ab}	0.096 ± 0.004^{a}	0.084 ± 0.001^{a}	0.097 ± 0.012^{ab}	0.085 ± 0.003^{b}
	60	0.090 ± 0.001^{a}	0.092 ± 0.002^{a}	0.096 ± 0.002^{a}	0.113 ± 0.012^{a}	0.088 ± 0.003^{a}	0.117 ± 0.006^{a}	0.104 ± 0.005^{a}
Mg	0	0.093 ± 0.003^{a}	0.085 ± 0.005^{b}	0.076 ± 0.003^{c}	0.083 ± 0.002^{c}	0.081 ± 0.007^{d}	0.085 ± 0.001^{c}	0.086 ± 0.002^{c}
	16	0.093 ± 0.003^{a}	0.086 ± 0.007^{ab}	0.081 ± 0.003^{bc}	0.096 ± 0.006^{bc}	0.121 ± 0.004^{c}	0.133 ± 0.010^{b}	0.130 ± 0.002^{b}
	30	0.093 ± 0.003^{a}	0.093 ± 0.004^{ab}	0.086 ± 0.006^{b}	0.114 ± 0.005^{ab}	0.119 ± 0.006^{bc}	0.136 ± 0.006^{b}	0.129 ± 0.004^{b}
	60	0.093 ± 0.003^{a}	0.109 ± 0.005^{a}	0.104 ± 0.001^{a}	0.123 ± 0.002^{a}	0.180 ± 0.005^{a}	0.158 ± 0.003^{a}	0.163 ± 0.006^{a}

Concentrations of an element in different FYM treatments are significantly different ($P < 0.05$) at a given sampling time if they are followed by different alphabet

With prohibition on expansion of agricultural land use with enforcement of Forest Conservation Act 1980 and increasing population within Himalaya as well as Indo–Gangetic plains dependent on ecosystem services flowing from it, sustainable agricultural land use intensification assumes importance for local food, nutritional and income security (Laishram et al. 2009, 2020). This study shows that increase in FYM input accompanies not only increase in productivity and profitability but substantial increase in carbon stocks serving the global community in terms of climate change mitigation. With availability of > 5 ha of forest land per ha of agricultural land and prohibition on logging since 1970s, leaf litter removal, pruning of fodder trees and harvesting of grasses for hay from forests to generate FYM needed for incorporation @ 60 t/ha/crop-season or so is likely to improve forest health by reducing dominance/favoring diversity together with improving agricultural productivity and climate change mitigation potential of agricultural land. There is a need of rewarding contribution of organic farms to carbon sequestration which is at present confined to forests. In situations where high quality forest leaf litter is not available, incentives for use of vermin-compost in place of traditional farm yard manure would be a feasible option (Rao et al. 2016; Saxena and Rao 2016). The present experiment was carried out in poor quality agricultural land and hence optimal dozes of farm yard manure is likely to be far below the highest input treatment of 60 t of FYM input/ha after a decade or so based which needs to evaluated through long-term trials and mathematical models.

Table 7 Changes in concentration (mg/100 g) of elements in soil during 3 years of cropping in Mallasar

	FYM treatments (t/ha/crop-season)	October 2002–May 2003 wheat	Jnue–October 2003 blackgram	October 2003–April 2004 fallow	April–October 2004 rice	October 2004–May 2005 wheat	June–October 2005 blackgram	October 2005–April 2006 fallow
C	0	1.859 ± 0.042[a]	1.523 ± 0.036[b]	1.585 ± 0.055[ab]	1.355 ± 0.042[c]	1.307 ± 0.157[c]	1.296 ± 0.062[c]	1.356 ± 0.021[c]
	16	1.859 ± 0.042[a]	1.607 ± 0.021[ab]	1.897 ± 0.036[b]	1.583 ± 0.021[bd]	1.595 ± 0.036[bc]	1.620 ± 0.036[b]	1.680 ± 0.075[c]
	30	1.859 ± 0.042[a]	1.703 ± 0.036[ab]	1.993 ± 0.075[ab]	1.679 ± 0.042[a]	1.679 ± 0.042[b]	1.692 ± 0.062[b]	2.076 ± 0.055[b]
	60	1.859 ± 0.042[a]	1.787 ± 0.021[a]	2.041 ± 0.072[a]	1.715 ± 0.042[ad]	1.811 ± 0.095[a]	2.040 ± 0.091[a]	2.052 ± 0.036[a]
N	0	0.131 ± 0.007[a]	0.143 ± 0.003[d]	0.129 ± 0.006[b]	0.101 ± 0.006[a]	0.089 ± 0.012[c]	0.117 ± 0.009[c]	0.117 ± 0.003[c]
	16	0.131 ± 0.007[a]	0.149 ± 0.003[c]	0.131 ± 0.003[c]	0.123 ± 0.009[b]	0.123 ± 0.007[b]	0.131 ± 0.007[b]	0.127 ± 0.009[b]
	30	0.131 ± 0.007[a]	0.155 ± 0.004[bd]	0.143 ± 0.009[ac]	0.137 ± 0.006[a]	0.143 ± 0.006[a]	0.152 ± 0.003[b]	0.147 ± 0.009[a]
	60	0.131 ± 0.007[a]	0.167 ± 0.003[ac]	0.165 ± 0.010[a]	0.162 ± 0.012[a]	0.168 ± 0.007[ac]	0.192 ± 0.006[a]	0.166 ± 0.006[a]
P	0	0.041 ± 0.006[a]	0.040 ± 0.002[a]	0.038 ± 0.003[b]	0.042 ± 0.008[a]	0.039 ± 0.004[a]	0.039 ± 0.004[a]	0.040 ± 0.002[b]
	16	0.041 ± 0.006[a]	0.041 ± 0.002[a]	0.037 ± 0.0004[b]	0.044 ± 0.006[a]	0.044 ± 0.002[a]	0.039 ± 0.006[a]	0.045 ± 0.002[ab]
	30	0.041 ± 0.006[a]	0.044 ± 0.002[a]	0.045 ± 0.001[a]	0.046 ± 0.002[a]	0.044 ± 0.002[a]	0.045 ± 0.002[a]	0.049 ± 0.001[a]
	60	0.041 ± 0.006[a]	0.043 ± 0.003[a]	0.043 ± 0.009[ab]	0.050 ± 0.006[a]	0.044 ± 0.002[a]	0.048 ± 0.004[a]	0.052 ± 0.001[a]
K	0	0.115 ± 0.003[a]	0.109 ± 0.002[b]	0.101 ± 0.003[b]	0.093 ± 0.003[c]	0.093 ± 0.001[b]	0.086 ± 0.007[a]	0.110 ± 0.004[a]
	16	0.115 ± 0.003[a]	0.112 ± 0.002[a]	0.113 ± 0.003[a]	0.107 ± 0.004[b]	0.106 ± 0.003[c]	0.113 ± 0.004[a]	0.104 ± 0.009[a]
	30	0.115 ± 0.003[a]	0.111 ± 0.002[ab]	0.110 ± 0.002[a]	0.107 ± 0.007[abc]	0.107 ± 0.003[ac]	0.108 ± 0.010[a]	0.115 ± 0.003[a]
	60	0.115 ± 0.003[a]	0.113 ± 0.002[a]	0.111 ± 0.001[a]	0.112 ± 0.004[a]	0.112 ± 0.002[a]	0.111 ± 0.006[a]	0.118 ± 0.600[a]
Na	0	0.063 ± 0.004[a]	0.064 ± 0.004[a]	0.063 ± 0.005[bc]	0.066 ± 0.003[a]	0.066 ± 0.008[bc]	0.064 ± 0.004[a]	0.065 ± 0.016[acd]
	16	0.063 ± 0.004[a]	0.062 ± 0.005[a]	0.074 ± 0.003[bd]	0.073 ± 0.004[a]	0.074 ± 0.001[b]	0.076 ± 0.004[a]	0.067 ± 0.005[bc]
	30	0.063 ± 0.004[a]	0.066 ± 0.002[a]	0.071 ± 0.004[b]	0.072 ± 0.003[a]	0.077 ± 0.003[b]	0.077 ± 0.003[a]	0.080 ± 0.007[a]
	60	0.063 ± 0.004[a]	0.064 ± 0.002[a]	0.066 ± 0.003[ac]	0.082 ± 0.008[a]	0.082 ± 0.002[ac]	0.076 ± 0.004[a]	0.082 ± 0.005[ad]
Ca	0	0.095 ± 0.003[a]	0.096 ± 0.002[c]	0.077 ± 0.002[c]	0.084 ± 0.002[b]	0.081 ± 0.002[b]	0.080 ± 0.004[b]	0.083 ± 0.003[b]
	16	0.095 ± 0.003[a]	0.100 ± 0.003[b]	0.084 ± 0.005[bc]	0.098 ± 0.006[ab]	0.095 ± 0.004[ab]	0.095 ± 0.001[ab]	0.094 ± 0.001[a]
	30	0.095 ± 0.003[a]	0.104 ± 0.005[abc]	0.093 ± 0.003[b]	0.103 ± 0.004[a]	0.096 ± 0.002[a]	0.097 ± 0.003[ab]	0.098 ± 0.004[a]
	60	0.095 ± 0.003[a]	0.111 ± 0.005[a]	0.100 ± 0.005[a]	0.098 ± 0.001[a]	0.106 ± 0.007[a]	0.104 ± 0.010[a]	0.096 ± 0.003[a]
Mg	0	0.096 ± 0.001[a]	0.096 ± 0.001[b]	0.093 ± 0.003[c]	0.091 ± 0.002[b]	0.087 ± 0.001[c]	0.090 ± 0.002[b]	0.093 ± 0.002[d]
	16	0.096 ± 0.001[a]	0.101 ± 0.003[b]	0.106 ± 0.003[b]	0.114 ± 0.012[ab]	0.100 ± 0.002[b]	0.104 ± 0.005[a]	0.103 ± 0.003[c]
	30	0.096 ± 0.001[a]	0.125 ± 0.001[a]	0.132 ± 0.010[ab]	0.123 ± 0.004[a]	0.113 ± 0.007[b]	0.109 ± 0.003[a]	0.116 ± 0.003[b]
	60	0.096 ± 0.001[a]	0.136 ± 0.003[a]	0.138 ± 0.003[a]	0.133 ± 0.003[a]	0.123 ± 0.005[a]	0.114 ± 0.006[a]	0.125 ± 0.001[a]

Concentrations of an element in different FYM treatments are significantly different ($P < 0.05$) at a given sampling time if they are followed by different alphabet

Table 8 Net changes in the concentration of soil organic C, total N, P, K (mg/100 g) under different FYM treatments after 3 years of cropping

FYM treatment (t/ha/crop-season)	Organic C		Total N		Total P		Total K	
	Mullasar	Mallasar	Mullasar	Mallasar	Mullasar	Mallasar	Mullasar	Mallasar
0	−0.29040	−0.50280	−0.01998	−0.01404	−0.00678	−0.00037	−0.02651	−0.00422
16	−0.08640	−0.17880	−0.00810	−0.00414	−0.00029	0.00458	−0.02390	−0.01024
30	0.29760	0.21720	−0.00018	0.01566	0.00486	0.00816	0.00683	0.00040
60	0.52560	0.19320	0.04134	0.03546	0.00751	0.01164	0.00643	0.00329

Table 9 FYM inputs and yields reported in other studies and the present present

S. no	Quantity of FYM (t/ha)	Crop	Location	Yield (kg/ha)	References
1	15	Rice	Nepal hills	1500–2200	Sherchand et al. (1999)
	15	Wheat	Nepal hills	3000–4500	
2	2	Wheat	Garhwal Himalaya, India	398	Tripathi and Sah (2001)
	2.1	Finger millet		755	
	2.4	Barnyard millet		607	
	0.4	Soybean		531	
	2.7	Potato		1047	
	1.7–5.8	Pea		356–742	
	2	French bean		798	
3	0	Sorghum	Africa	3500	Alemu and Bayu (2005)
	5	Sorghum		3900	
	10	Sorghum		4400	
	15	Sorghum		4400	
4	0	Sorghum	West Africa	408–1160	Ouédraogo et al. (2001)
	5	Sorghum		1689	
	10	Sorghum		1380	
5	10		Rainfed agroecosystem in Central Himalaya	–	Maikhuri et al. (2001)
	15–35				
6	5		North Nigeria, Africa	–	Agbenin and Goladi (1997)
7	20	Tomato	Himachal Pradesh	–	Sharma and Sharma (2004)
	0	Carrot	Himachal Pradesh	–	Sharma et al. (2003)
	10	Carrot		–	
	12	Carrot		–	
8	10 (oak)	Wheat	central Himalaya	582	Rao et al. (2005); Saxena et al. (2005)
	10 (Pine)	Wheat		467	
9	15–16.5	–	Himalaya 1100–1850 msl	–	Sen et al. (1997); Saxena et al. (2005)
	18.3–27.4	–	Himalaya 1850–2400 msl	–	
	16.8–32.4	–	Himalaya 2400–2600 msl	–	
10	30.7	Paddy	Langasu-Uttaron village of Chamoli district, Garhwal Himalaya	2620	Chandra et al. (2011a)
	30.0	Paddy + others		3248	
	27.7	Barnyard millet		1524	
	12.3	Foxtail millet		623	
	9.1	Wheat + mustard		1306	
	4.4	Barley		1036	
	14.4	Finger millet		2344	
	12.4	Finger millet + Blackgram (mixed)		2482	
	12.5	Finger millet + legumes (mixed)		2410	
	–	Legumes (mixed)		2446	
	–	Blackgram		1900	
	–	Soybean		3104	
	1.3	Mustard		456	
11	24	Paddy	Chandrapuri village, Rudraprayag district, Garhwal Himalaya	4946 ± 492	Dinakaran et al. (2019)
	15	Wheat + mustard		3100 ± 204	
	60	Rice		1666.67	
12	0	Rice	Langasu-Uttaron village of Chamoli district, Garhwal Himalaya	2065–2175	Present study
	16	Rice		2333–2432	
	30	Rice		2475–2602	
	60	Rice		3079–3361	

Table 9 (continued)

S. no	Quantity of FYM (t/ha)	Crop	Location	Yield (kg/ha)	References
	0	Wheat	Langasu-Uttaron village of Chamoli district, Garhwal Himalaya	865–1078	Present study
	16	Wheat		932–1182	
	30	Wheat		1481–1693	
	60	Wheat		1759–2555	
	0	Blackgram	Langasu-Uttaron village of Chamoli district, Garhwal Himalaya	1776–1808	Present study
	16	Blackgram		1822–1840	
	30	Blackgram		1894–1941	
	60	Blackgram		2084–2094	

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

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