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Long-term effects of organic manure and inorganic fertilization on sustainability and chemical soil quality indicators of soybean-wheat cropping system in the Indian mid-Himalayas

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ABSTRACT

A long-term field study was commenced in 1995-96 to assess the impact of continuous application of inorganic fertilizers and organic manure on sustainability, productivity and chemical indicators of soil quality in an irrigated soybean-wheat cropping system (SWCS). Six treatments comprised inorganic fertilizers (NPK) and manure (M) either alone or in combination. Soybean yield indicated declining trend −22.50, −56.0 and −25.0 kg ha^{-1} year^{-1} under unfertilized control, sole nitrogen and NPK treatments, respectively while addition of organic manure resulted in a positive yield trend. Plot receiving NPK had positive yield trend of 118 kg ha^{-1} year^{-1} in wheat crop. The highest positive yield trend was obtained with manure (M) and NPK treatment, values being 17.60 and 191 kg ha^{-1} year^{-1} in soybean and wheat, respectively. Significantly ($p < 0.05$) the highest grain yield was also observed under the MNPK treatment, soybean and wheat reporting 2.56 and 4.31 Mg ha^{-1}, respectively which was ~ 30 and 25% higher than NPK treatment, respectively. Significantly higher yield sustainability was observed in the plots receiving manure either alone (0.77 and 0.51) or in combination with N fertilizer (0.79 and 0.79) or with NPK, MNPK (0.89 and 0.92) compared to the treatment, which did not receive the manure in both soybean and wheat crops. Due to continuous cropping and fertilization over the years, available N increased from initial values in all the plots except CK (−3.89 and −3.59%) under 0–15 and 15–30 cm soil depths. Negative trends for available P were observed in all treatments except MNPK over the years of continuous cropping. A significantly decreasing trend for the available K was observed under CK, N, NPK and M treatments, whereas a significant accumulation was estimated under MN and MNPK treated plots in both soil depths. Significantly higher accumulation of available N, P and K were observed under MNPK treatment compared to the rest of the treatments. The treatment MNPK had the highest soil DTPA-extractable Fe, Mn, Zn and Cu after 21-years of cropping and fertilization. The sustainable yield index (SYI) values indicated that soybean yield was more sustainable compared to the wheat. The SYI and grain yield of soybean had significantly higher correlation with available N, P, Fe, Mn, Zn and Cu. Soil available N had significantly higher values of coefficient of regression (r^2) for wheat (0.98; $p = 0.001$ and 0.97; $p = 0.001$) compared to soybean (0.74; $p = 0.029$ and 0.74; $p = 0.027$) under 0–15 and 15–30 cm soil depths, respectively. The SYI was strongly positively correlated with chemical indicators of soil quality. Hence, SYI could potentially be used for assessment of agricultural productivity and soil sustainability elsewhere.

1. Introduction

Long-term fertilizer experiments (LTFEs) have been valuable resources for investigating nutrient dynamics and overall assessment of fertilization (Shahid et al., 2016). The LTFEs also provide greater opportunities for scrutinizing crop yield trends, productivity, soil quality and identification of factors associated with such changes to help in evaluating the agricultural sustainability (Rasmussen et al., 1998). The irrigation and fertilization are the two important factors for obtaining higher productivity and sustainability around the world (Liang et al., 2016). However, some other factors such as cultivar, climate, insect pests, soil types and crop management practices are also responsible for

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changing the yield and sustainability over the years for continuous cropping (Singh et al., 2017). The SWCS is one of the profitable cropping systems in the mid-Himalayas (Kundu et al., 1990). Maintaining higher productivity and sustainability over a long-period may be a challenge to farmers because of limited resources availability and degradation in soil quality due to imbalanced replacement of organic manures by inorganic fertilizer in an intensive cropping system (Bi et al., 2014). Results from several LTFEs at different locations have indicated a declining trend in the productivity of wheat-maize (Bhattacharyya et al., 2016; Sharma et al., 2017), rice–rice (Shahid et al., 2013) and rice-wheat (Ram et al., 2015) cropping systems after a few years of continuous cropping. With the increased cultivation of input responsive high yielding varieties, farmers are compelled to use heavy doses of inorganic fertilizers. To meet nutrient needs, imbalanced chemical fertilizers were commonly applied to these crops. LTFEs have indicated that prolonged use of chemical fertilizers accelerated the degradation of soil quality and declined crop sustainability (Kumari et al., 2013; Das et al., 2014).

Sustainable yield index (SYI) is a derivative of actual yields over a long-period and a higher SYI indicates a better management practice capable for producing acceptable yields over the years (Das et al., 2014; Ram et al., 2015). However, limited information is available on the impact of long-term field application of NPK and farm yard manure (FYM) on yield trend, sustainability and chemical indicators of soil quality in sub-temperate irrigated SWCS in the mid-Himalaya. The SWCS has been assessed using various parameters by many researchers (Kundu et al., 2007; Sharma et al., 2017; Singh et al., 2017), but to date, few attempts have been made to assess the sustainability, yield trends and chemical indicators of soil quality in the irrigated SWCS. Information regarding assessment of SYI based on chemical indicators of soil quality and especially its relationships with crop productivity and yield sustainability is limited. In this study, an attempt has been made to quantitatively estimate SYI as affected by fertilization and its relationship with 21-year long-term SWCS in the mid-Himalayas with the following objectives: (i) to determine the effects of long-term organic and inorganic nutrient management on yield trends, grain yield and SYI of irrigated SWCS on a silty clay loam soil after 21-years of cropping; (ii) to assess the chemical indicators of soil quality that influences SYI of the cropping system; and (iii) to establish relationships between yield trends (21-years) and long-term nutrient management.

2. Materials and methods

2.1. Experimental site and soil description

The experiment was started in 1995-96 at the experimental farm, Hawalbagh of the ICAR-Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, Uttarakhand, India (29°36′N; 79°40′E at 1250 m above mean sea level). The climate of the experimental site is sub-temperate with mean annual temperature of 18 °C (mean annual minimum and maximum temperature varied from 0.1 to 21 °C and 19 to 31 °C, respectively). Mean temperature during *kharif* (wet) and *rabi* (winter) season were 23 °C and 18 °C, respectively. Mean annual precipitation is 1005 mm, of which, 70–71% is received during June to September. Other climatic parameters during the study period are presented in Table 1. Initial soil properties of the experimental site are summarized in Table 2.

2.2. Treatment details and experimental design

The experiment included two crops per year i.e. soybean (June-October) and wheat (November-April) with six treatment combinations viz. CK (No fertilizer), N (120 kg nitrogen ha^{-1}); NPK (120-26–33 kg nitrogen-phosphorous-potassium ha^{-1}); Manure (10 Mg FYM ha^{-1}); MN (120 kg N ha^{-1} + 10 Mg FYM ha^{-1}); MNPK (120-26-33 kg N-P-K ha^{-1} + 10 Mg FYM ha^{-1}), laid out in randomized block design (RBD) with four replications. Net plot size (15 m^2) was used for harvesting the crop to minimize the border effects on the crop productivity. Treatments details are given in Table 3.

Table 1
Mean climatic data during the experimental period (1995–2016).

Months	Mean temperature (°C)	Rainfall (mm)	Mean RH (%)	Evaporation (mm day^{-1})	Sunshine (h)
Soybean growing season (kharif)					
June	25	129.0	70	3.8	6.3
July	25	217.0	81	2.6	4.2
August	25	200.0	82	2.7	4.7
September	24	137.0	78	2.9	5.9
October	19	29.0	69	2.7	7.8
Wheat growing season (Rabi)					
November	14	4.7	67	1.9	7.7
December	10	15.5	67	1.3	7.0
January	9	37.0	69	1.2	6.4
February	12	56.7	69	1.4	6.7
March	15	32.3	64	2.3	7.7
April	19	34.8	59	3.4	8.2

Table 2
Initial soil characteristics of long-term field experiment.

Soil characteristic	Soil depth (cm)	
	0–15	15–30
Soil texture	Silty clay loam	Silty clay loam
pH (Soil:water, 1:2.5)	6.4	6.3
EC (dS m^{-1})	0.12	0.11
CEC [cmol (p^+) kg^{-1}]	13.5	11.9
Bulk density (Mg m^{-3})	1.33	1.34
Total soil organic carbon (g kg^{-1})	7.31	6.09
Total soil nitrogen (g kg^{-1})	0.82	0.79
Available N (kg ha^{-1})	295	278
Available P (kg ha^{-1})	9.2	9.1
Available K (kg ha^{-1})	164	142

2.3. Crop management

All the plots were ploughed (~ 15 cm deep) after each harvest. Inorganic N, P and K were applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP), respectively. FYM (10 Mg ha^{-1} on fresh weight basis) and inorganic fertilizer were applied as per treatments and incorporated in the soil with a hand hoe after first ploughing during field preparation. At the commencement (1995-96) of experiment, recommended dose of fertilizers (NPK) and manure (FYM) were applied in soybean crop and after two years onwards (since 1997-98) continuous fertilization was done in wheat crop only to see its residual effect on soybean crop (Table 3). Half of the amount of N along with full P and K were applied in wheat crop at the time of sowing while; the remaining half N was top-dressed after first irrigation (35 days after sowing). Wheat cultivars: VL-421 during 1995-96 to 2000-01; VL-616 during 2002–03 to 2004–05 and VL-804 during 2004–05 to 2015-16 was sown with a seed rate of 100 kg ha^{-1} in rows of 20 cm apart and 5–6 cm deep by hand during the first fortnight of November each year and was harvested in May at ~ 5 cm above soil surface.

Soybean (cultivar: Bragg during 1996–2000 and VL Soy-2 during 2001-16 was seeded at a rate of 80 kg seed ha^{-1} during the second fortnight of June each year in rows 45 cm apart to a depth of 3 to 4 cm by hand. Soybean was harvested manually at physiological maturity during the first week of October and grain yield was reported at 12% moisture content.