



RESEARCH ARTICLE

Effect of moisture regimes and crop diversification on system productivity and soil health under North Bihar conditions

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Abstract

A field experiment was conducted in a split-plot design and replicated thrice. The treatments comprised 5 cropping systems as the main plot, viz. C₁: rice - wheat - fallow, C₂: rice - wheat - green gram, C₃: rice - maize - dhaincha, C₄: rice - maize + potato - dhaincha, C₅: rice - maize + green pea - dhaincha and moisture regimes I₁ - IW/CPE = 0.6, I₂ - IW/CPE = 0.8, I₃ - IW/CPE = 1 as sub plot. Residues of crops were incorporated after the harvest of the crop. Experimental results revealed that the maximum REY (27.56 t/ha) production efficiency (83.05 kg/ha/day), Profitability (962.46 ₹/ha/day) and higher N, P, K uptake (399.97, 93.15, 343.14 kg/ha) were recorded under the C₄ cropping system, which were significantly superior to other cropping systems. The highest relative production efficiency (175.18 %) and land use efficiency (91.64 %) were observed in C₄ and C₂ treatments. Maximum addition of nitrogen, phosphorus and potassium (153.66, 36.93, 227.66 kg/ha) through residue, MWD (3.540 mm), organic carbon content (0.497 %), available N, P₂O₅, K₂O in soil (245.88, 37.10, 153.58 kg/ha) and minimum bulk density (1.361 mg/m³) were observed in C₅ which was significantly superior to other. The nutrient balance sheet shows a negative value, with the least losses of nitrogen, phosphorus and potassium (61.95, 31.19, 24.69) observed in C₅. In moisture regimes, maximum REY (17.21 t/ha) production efficiency (53.26 kg/ha/day), profitability (603.94 ₹/ha/day) and N, P, K uptake by crops (303.61, 82.72, 265.08 kg/ha) were recorded under I₃ which was significantly superior to I₂ and I₁. Maximum N, P, K (116.35, 35.14, 196.39 kg/ha) addition to soil and least losses of nitrogen, phosphorus and potassium (162.63, 45.55, 48.96) kg/ha were observed at I₃ in the nutrient balance sheet.

Keywords: crop diversification; nutrient balance sheet; profitability; relative production efficiency

Introduction

The burgeoning Indian population, along with decreasing per capita agricultural land threaten the agricultural production system (1). Global population is increasing at an alarming rate and has reached approx 9.2 billion by 2050, necessitating a substantial increase in food production through diversification and sustainable agricultural practices (2, 3). Sustainability through crop diversification is therefore essential for ensuring long-term food security. The Indo-Gangetic plains of India are dominated by a conventional Rice-wheat cropping system, which is associated with yield reduction, soil and environment degradation. Continuous monocropping, intensive tillage and residue burning have adversely affected soil health and system productivity. Thus, the conventional rice-wheat system should be diversified with legumes and vegetables. In this direction, crop diversification, a part of conservation agriculture, plays a vital role.

Conservation agriculture is an innovative approach to farming that emphasises sustainability and environmental stewardship by minimising soil disturbance, maintaining permanent soil cover and enhancing crop diversity (4). It is designed to optimise the benefits of agricultural productivity while preserving the natural

resources that support it, such as soil, water and diversity. With the growing global demand for food, CA has gained significant attention as a solution to the challenges of soil degradation, climate change and declining agricultural productivity (5). However, complete adoption of conservation agriculture is often constrained by technical and socioeconomic factors, necessitating the adoption of partial conservation agricultural practices that integrate key conservation agriculture components such as reduced tillage, residue retention and crop diversification (6, 7). It offers a pathway toward more sustainable and resilient agricultural systems, ensuring food security for future and present generations and also improves the degraded soil.

Soil health can be improved by adopting partial conservation agriculture, which includes residue incorporation, zero till wheat and direct-seeded rice. Along with improving the soil health, it also increases the productivity of the system. Compared to direct seeded, puddled transplanted rice reduces the wheat yield by 8–9 %. It not only causes early planting of the rabi crop with lower production costs but also enhances the yield of the crop. Residue incorporation brings a significant change in the quality and quantity of soil nutrients. In Haryana and Punjab, in

situ residue burning of rice and wheat leads to annual losses of about 10 million tonnes of carbon equivalence of CO₂. Its losses affect the microflora of the soil, which further hampers the health of the soil and nutrient use efficiency (8). Incorporation of residues and adoption of leguminous crops improve the overall health of the soil. Availability of primary, secondary and micronutrient also enhanced. The nitrogen-fixing capacity of leguminous crops, by forming an association with bacteria, improved the nitrogen content of the soil. Phosphatase activity also improved with increasing micro-organism count, which increases the phosphorus content of soil. Apart from the cropping system and soil health, water management is also an important factor which affect the productivity and sustainability of the soil.

Water scarcity and climatic variability further threaten agricultural sustainability. Residue incorporation with the adoption of zero-till-wheat and direct-seeded rice improves the moisture-retaining capacity of soil. Thus, it saves irrigation water. Un-puddled condition in direct seeding saves 60 % of water compared to transplanting rice, which requires approximately. 800 to 5000 L/kg of rice production (9). Apart from adopting a suitable method for water saving, a proper water management system needs to be identified for different crops. Most of the research was done by taking soil and plant condition for deciding proper irrigation scheduling for the rabi crop. Climate is also an important parameter while deciding irrigation scheduling. Irrigation water: cumulative pan evaporation (IW: CPE) ratio is one of the approaches to deciding irrigation as it incorporates all soil, plant and atmospheric conditions. Hence, this study was planned to determine the effect of moisture regimes and crop diversification on soil health under the North Bihar conditions.

Materials and Methods

Site description

The study site belongs to Dr Rajendra Prasad Central Agricultural University, Pusa farm of Samastipur district, Bihar state, which is situated at 25°59' N and 85°48' E, on the bank of Budhi Gandak River. The climatic condition of Pusa is a subtropical and sub-humid type. It received an annual rainfall of 1234.7 mm. Out of the total rainfall, about 89.7 % received from June to September. This zone also received some showers from December to February. The average temperature of this zone is 19-30 °C with a mean maximal and minimal temperature of 35.4 to 36.6 °C during April to June and 7.9 °C during January. Monsoon showers are an important meteorological parameter affecting the cropping sequence, with maximum rainfall received in August, with 388.4 mm in 2018-19 and 403.0 mm in 2019-20. The quantum of rainfall is less, but the distribution of showers is uniform throughout the year. The soil belongs to the order Entisol with sandy loam in texture. The initial soil analysis reveals that pH 8.34, EC 0.417 dS/m, bulk density 1.44 g/cc, Mean weight diameter of water stable aggregate 2.67 mm, Organic carbon (%) 0.390, available nitrogen 158.45 kg/ha, phosphorus 28.35 kg/ha and potassium 134.56 kg/ha.

Treatment details and layout

A field experiment was conducted during three seasons of 2018-19 and 2019-20. The experiment was conducted in a split-plot design and replicated thrice. Experiment was performed by taking two factors. One factor is the rice-based system in main plot and moisture regimes as a sub-plot. Five level of cropping

system includes, C₁: Rice - Wheat - Fallow, C₂: Rice - Wheat - Green Gram, C₃: Rice - Maize - Dhaincha, C₄: Rice - Maize + Potato - Dhaincha, C₅: Rice - Maize + Green Pea - Dhaincha and three moisture regimes as sub-plot viz- I₁ - IW/CPE = 0.6, I₂ - IW/CPE = 0.8 and I₃ - IW/CPE = 1.0 in rabi season.

Crop management

Rice crop (cultivar Sahbhagi Dhan) was grown by direct-seeded rice during the rainy season. After the harvest of the crop, crop residue was incorporated into the soil. Fertilisers were applied in the form of DAP, MOP and urea. Irrigation was applied as per the treatments. In rice, it was applied three days after the disappearance of ponded water and in the rabi season, it was applied as per treatments with 6 cm of water. There is no incidence of pest and disease attack during the two years of the experiment. Another intercultural operation was done as per the requirement. Irrigation was measured through a Parshall flume. The time required to irrigate the plot was calculated by the following formula (10):

$$\text{Time required for irrigation (t)} = \frac{A \times D}{Q} \quad (\text{Eqn. 1})$$

Where, A = Area in cm², D = Depth of irrigation water (cm), Q = Discharge cc/sec

Soil sampling and analysis

Soil samples were collected from the top 0-15 cm of the topsoil. The soil samples were processed and stored in clean cotton bags for transport. Soil nutrient analysis was conducted as follows: available nitrogen (N) was quantified via the alkaline potassium permanganate method to measure ammonia liberation (11). Available phosphorus (P) was extracted using the Olsen method, while available potassium (K) was determined using the neutral ammonium acetate extraction technique and measured via flame photometry (12, 13).

Estimation of system productivity and nutrient balance sheet

System productivity was determined in terms of rice equivalent yield (REY). Yield was taken from net plot size, discarding the border area. The gross plot size of plot was 5 × 2 m² and the net plot size varies from crop to crop. Nutrient balance sheet was prepared based on total input nutrients used and total output gain REY and the nutrient balance sheet was calculated by using the following formula:

$$\text{REY (q/ha)} = \frac{\text{Economic yield of crop} \times \text{price of respective crop}}{\text{Price per quintal of rice}} \quad (\text{Eqn. 2})$$

The nutrient balance sheet was calculated by using formula (14):

$$B = Y - (X - A) - N$$

Where, B = Balance sheet of nutrients, Y = Nutrient uptake by crop, X = Initial nutrient status of soil, A = Final nutrient status of soil, N = Nutrient added through chemical fertiliser and green manuring.

Data analysis

The raw data was collected from the field and statistically analysed in order to reduce the error of different treatments and find the best one. Similarly, the soil and nutrient data were analysed after physical and chemical analysis (15).

Results and Discussion

System productivity

Cropping system and moisture regimes recorded a significant effect on system productivity (Table 1). The maximum REY (27.56) was recorded in C₄, which was significantly superior to other cropping systems. The percentage increase in rice equivalent yield was of C₄ (254.69 %), C₅ (150.84 %), C₃ (85.33 %) and C₂ (55.85 %) over C₁ cropping systems, respectively. This might be due to the yield of rice being higher in the C₅ cropping system, but the intercrop of maize with potato is complementary in nature, with higher production potential, which increased the yields along with higher market prices, increasing the rice equivalent yield. In moisture regimes, the maximum REY (17.21) was recorded under I₃, which was significantly superior to I₂ and I₁. In terms of percentage, I₃ (12.41 %) and I₂ (6.27 %) were higher than I₁, respectively. This is because, with increasing moisture levels, the yield of rabi crops increased because of more translocation of nutrients, which provides substrate for photosynthesis, more translocation of photosynthate from source to sink, thus, more grain yield.

Maximum production efficiency (83.05) was recorded in C₄, which was significantly superior to C₅ (58.76), C₃ (43.43), C₂ (36.19) and C₁ (30.18) cropping systems. Production efficiency is directly related to the yield of the crops; the higher the yield, the higher the production efficiency. Maize and potato intercropping have higher yield potential, thus, have high production efficiency (16). Data on moisture regimes reveal that maximum production efficiency (53.26) was recorded at I₃, which was significantly superior to I₂ (50.34) and I₁ (47.36). This is due to soil moisture along with residues, which increased the yield of winter crops.

The maximum relative production efficiency (175.18) was found under C₄ and the minimum observed under C₂ (19.91) cropping systems. This is because both potato and maize have high yields. Among the moisture regimes, the highest relative production efficiency (12.45) was observed under I₃, followed by I₂ (6.29). This might be due to the higher yield of different crops as compared to other levels of moisture regimes (17). The maximum land use efficiency (91.64) was observed in C₂ and the minimum was observed under C₁ (70.55) cropping systems. Land Use efficiency was directly related to the duration of crops occupying the land. Rice was the base crop under all the cropping systems. Land Use Efficiency varies with variation in the duration of summer and rabi crops. Wheat with moong in the summer season and wheat in the rabi season occupied the utmost duration of 362 days from sowing to harvesting

of all crops in the C₂ cropping system, thus having the utmost Land Use Efficiency. Moisture regimes showed 86.93 % of land use efficiency. Highest profitability (962.49) observed under C₄ cropping system, which was significantly superior to C₅ (725.31), C₃ (491.92) and C₂ (341.31) and C₁ (250.60) cropping systems. Profitability was calculated on the basis of net return. A system having potato and maize intercropping has a higher net return because of higher production along with a higher market price, thus leading to higher profitability. In terms of moisture regimes, maximum profitability (603.94) was observed at I₃, which was significantly superior to I₂ (554.68) and I₁ (504.33). This is because the moisture level with a higher net return has higher profitability (17).

Nutrient uptake

Cropping system and moisture regimes had a significant impact on nutrient uptake (Table 2). The maximum uptake (399.97, 93.15 and 343.14) of nitrogen, phosphorus and potassium was noticed in C₄, which was significantly superior to other cropping systems. This is due to the higher yield of maize and potatoes. Both are nutrient exhaustive crop. C₅ (358.46, 85.57 and 272.86) showed the second order. The yield of maize with the garden pea cropping system was higher, causing more nutrient uptake. Lowest uptake in C₁ (150.38, 59.05 and 165.73) is due to less biomass yield as compared to other cropping systems. There was significant variation in total nutrient uptake due to moisture regimes. Total nutrient uptake was maximum (303.61, 82.72 and 265.08) at I₃ and minimal at I₁. Uptake is directly correlated with the yield of the crop. Moisture level receiving more frequent irrigation had more nitrogen and potassium uptake. Addition of nutrients through fertiliser, crop residue and green manuring, which increased the concentration of nutrients in the soil solution, leading to effective root growth of crops

Nutrient addition

Cropping system and moisture regimes had a significant impact on nutrient addition (Table 3). Maximum (153.66, 36.93 and 227.66) kg/ha nitrogen, phosphorus and potassium addition was observed in the C₅ cropping system, which was significantly superior to other cropping systems. This might be due to the higher yield of maize and garden pea. The biomass of garden pea adds more nutrients to the soil compared to cereals and tuber crops. In the subplot, the highest nitrogen, phosphorus and potassium addition was observed in I₃, which was significantly superior to I₂ and I₁. Moisture regimes with higher yields lead to more addition of crop residue.

Table 1. Pooled data of rice equivalent yield, production efficiency, relative production efficiency, land use efficiency and profitability as affected by different treatments

Treatments	REY (q/ha)	Production efficiency (kg/ha/day)	Relative production efficiency (%)	Land use efficiency (%)	Profitability (₹/ha/day)
Cropping system					
C ₁	7.77	30.18	-	70.55	250.60
C ₂	12.11	36.19	19.91	91.64	341.31
C ₃	14.40	43.43	43.90	90.82	491.92
C ₄	27.56	83.05	175.18	90.82	962.46
C ₅	19.49	58.76	94.69	90.82	725.31
S.Em(±)	0.34	1.04	-	0.00	18.53
CD (5 %)	1.02	3.11	-	-	55.53
Moisture regimes					
IW:CPE- 0.6	15.31	47.36	-	86.93	504.33
IW:CPE-0.8	16.27	50.34	6.29	86.93	554.68
IW:CPE-1.00	17.21	53.26	12.45	86.93	603.94
S.Em(±)	0.18	0.57	-	0.00	10.17
CD (5 %)	0.53	1.62	-	-	29.07

Table 2. Total N, P and K uptake of the system as affected by different treatments

Treatments Cropping system	N (kg/ha)			P (kg/ha)			K (kg/ha)		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
C ₁	148.12	152.64	150.38	56.91	61.19	59.05	160.98	170.48	165.73
C ₂	216.43	234.99	225.71	66.33	75.91	71.12	195.11	216.89	206.00
C ₃	284.32	306.19	295.25	72.18	79.71	75.95	241.59	262.77	252.18
C ₄	385.50	414.44	399.97	89.31	96.99	93.15	332.10	354.18	343.14
C ₅	343.94	372.97	358.46	81.62	89.51	85.57	262.64	283.07	272.86
S.Em(±)	5.31	7.40	4.55	1.32	2.51	1.42	5.27	7.28	4.49
CD (5 %)	17.31	24.05	13.65	4.29	8.17	4.25	17.18	23.67	13.47
Moisture regimes									
IW:CPE- 0.6	261.38	273.76	267.57	68.17	73.06	70.61	223.52	235.14	229.33
IW:CPE-0.8	275.71	297.64	286.67	73.68	81.44	77.56	239.31	259.76	249.54
IW:CPE-1.00	289.89	317.34	303.61	77.96	87.49	82.72	252.62	277.53	265.08
S.Em(±)	2.29	4.60	2.57	0.72	1.53	0.85	3.49	4.86	2.99
CD (5 %)	6.76	13.58	7.35	2.11	4.52	2.42	10.30	14.32	8.54

C₁: rice - wheat - fallow; C₂: rice - wheat - green gram; C₃: rice - maize - dhaincha; C₄: rice - maize + potato - dhaincha; C₅: rice - maize + green pea - dhaincha; IW:CPE: Irrigation water : cumulative pan evaporation.

Table 3. Total N, P and K addition by different crops through residue in the system as affected by different treatments

Treatments Cropping system	N (kg/ha)			P (kg/ha)			K (kg/ha)		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
C ₁	46.50	47.92	47.21	23.83	26.72	25.27	116.51	121.45	118.98
C ₂	72.62	78.57	75.60	29.52	33.77	31.65	145.53	159.72	152.62
C ₃	124.2	135.19	129.76	30.72	35.05	32.89	194.72	211.91	203.32
C ₄	142.24	153.00	147.62	34.26	37.84	36.05	211.69	226.69	219.19
C ₅	147.93	159.39	153.66	35.26	38.61	36.93	220.07	235.24	227.66
S.Em(±)	2.65	2.30	1.75	0.66	1.08	0.63	4.55	5.62	3.61
CD (5 %)	8.63	7.49	5.26	2.17	3.50	1.90	14.83	18.26	10.83
Moisture regimes									
IW:CPE- 0.6	102.32	106.79	104.55	28.34	30.93	29.63	167.28	174.71	170.99
IW:CPE-0.8	106.94	115.87	111.41	30.99	34.80	32.90	178.26	193.10	185.68
IW:CPE-1.00	110.91	121.78	116.35	32.82	37.46	35.14	187.57	205.20	196.39
S.Em(±)	1.68	1.51	1.13	0.50	0.71	0.43	3.48	3.58	2.50
CD (5 %)	4.94	4.45	3.22	1.47	2.09	1.24	10.28	10.55	7.13

C₁: rice - wheat - fallow; C₂: rice - wheat - green gram; C₃: rice - maize - dhaincha; C₄: rice - maize + potato - dhaincha; C₅: rice - maize + green pea - dhaincha; IW:CPE: Irrigation water : cumulative pan evaporation.

Physical properties of soil

Physical properties of soil were significantly affected by the cropping system (Table 4). Minimum bulk density (1.36) was observed under the C₅ cropping system, which was significantly superior to C₂ (1.41) and C₁ (1.42) and was statistically at par with C₄ (1.38) and C₃ (1.37) cropping systems. Soil bulk density varies with organic matter content, tillage and cropping system adopted. Higher residue recycling of pea increases the organic carbon content, which reduces the particle density than mineral density. Thus, decreases the bulk density of soil. Maximum mean weight diameter (MWD) of water stable aggregates (3.54) was observed under the C₅ cropping system, which was significantly superior to C₃ (3.41), C₄ (3.36), C₂ (3.32) and C₁ (3.10) cropping

systems. An increase in mean weight diameter of water stable aggregates was found at the end of the experiment. Residue incorporation facilitated the formation of more macro aggregates as compared to micro aggregates. It also increases the total organic carbon content, which limits the soil movement, thus accelerating the soil aggregate formation (18).

Chemical properties of soil

Changes in chemical properties of soil are presented in Table 5. pH and EC were non-significantly different and organic carbon content was significantly influenced by the cropping system. Maximum organic carbon content (0.50) was recorded under C₅, which was significantly superior to C₄ (0.47), C₂ (0.45) and C₁ (0.39) and was at par with C₃ (0.48) cropping system. This might be due

Table 4. Physical properties of soil as affected by different treatments

Treatments Cropping system	Bulk density (mg/m ³)			Mean weight diameter of water stable aggregates (mm)		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
C ₁	1.43	1.42	1.42	3.07	3.12	3.10
C ₂	1.42	1.41	1.41	3.29	3.34	3.32
C ₃	1.37	1.37	1.37	3.41	3.42	3.41
C ₄	1.38	1.38	1.38	3.35	3.36	3.36
C ₅	1.36	1.36	1.36	3.50	3.58	3.54
S.Em(±)	0.01	0.01	0.01	0.04	0.06	0.04
CD (5 %)	0.05	0.03	0.03	0.13	0.19	0.10
Moisture regimes						
IW:CPE- 0.6	1.38	1.38	1.38	3.35	3.39	3.37
IW:CPE-0.8	1.39	1.39	1.39	3.32	3.37	3.34
IW:CPE-1.00	1.40	1.39	1.39	3.30	3.34	3.32
S.Em(±)	0.01	0.01	0.01	0.03	0.04	0.03
CD (5 %)	NS	NS	NS	NS	NS	NS

C₁: rice - wheat - fallow; C₂: rice - wheat - green gram; C₃: rice - maize - dhaincha; C₄: rice - maize + potato - dhaincha; C₅: rice - maize + green pea - dhaincha; IW:CPE: Irrigation water : cumulative pan evaporation.

Table 5. Chemical properties of soil as affected by different treatments

Treatments	pH			EC (dSm ⁻¹)			Organic carbon content (%)		
Cropping System	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
C ₁	8.39	8.40	8.40	0.40	0.39	0.39	0.39	0.40	0.39
C ₂	8.32	8.30	8.31	0.39	0.38	0.39	0.45	0.45	0.45
C ₃	8.31	8.30	8.31	0.37	0.37	0.37	0.48	0.48	0.48
C ₄	8.34	8.31	8.32	0.38	0.37	0.37	0.47	0.47	0.47
C ₅	8.30	8.26	8.28	0.37	0.36	0.36	0.49	0.50	0.50
S.Em(±)	0.05	0.04	0.03	0.01	0.01	0.01	0.01	0.01	0.01
CD (5 %)	NS	NS	NS	NS	NS	NS	0.03	0.03	0.02
Moisture Regimes									
IW:CPE- 0.6	8.34	8.30	8.32	0.38	0.37	0.37	0.46	0.46	0.46
IW:CPE-0.8	8.33	8.32	8.32	0.38	0.38	0.38	0.45	0.47	0.46
IW:CPE-1.00	8.34	8.32	8.33	0.38	0.38	0.38	0.45	0.45	0.45
S.Em(±)	0.04	0.03	0.02	0.01	0.00	0.00	0.01	0.00	0.00
CD (5 %)	NS	NS	NS	NS	NS	NS	NS	NS	NS

C₁: rice - wheat - fallow; C₂: rice - wheat - green gram; C₃: rice - maize - dhaincha; C₄: rice - maize + potato - dhaincha; C₅: rice - maize + green pea - dhaincha; IW:CPE: Irrigation water : cumulative pan evaporation.

to the addition of the organic matter through the adoption of leguminous crops in the cropping system and residue incorporation improved the soil organic carbon content. Data clearly show (Table 6) that available soil nitrogen, phosphorous and potassium were significantly affected by the cropping system. Maximum available nitrogen, phosphorus and potassium (245.88, 37.10, 153.58) was observed under the C₅ cropping system, which was significantly superior to other cropping systems. This may be due to the favourable effect of organic carbon and legume inclusion. Organic matter prevents nitrogen losses by allowing the slow release of nutrients bound in aggregates. Dhaincha and garden pea are leguminous crops that can fix nitrogen in soil by forming an association with nitrogen-fixing bacteria, which enhances the available nitrogen content in soil. An increase in available P was due to an increase in microbial population, which solubilised the fixed phosphorus in soil. Available phosphorus is directly related to soil organic matter. Hydrolysis of organic matter produces aliphatic acid, which competes with phosphorus for binding sites. Apart from that, organic anion chelates Al³⁺, Fe³⁺ and decrease phosphorous precipitation with these cations. Thus, improved available P in soil. Breakdown of organic matter released low molecular weight organic acid, which caused mineralisation of fixed K. It is also found that humus retained more divalent cations as compared to monovalent cations & thus enhanced the available potassium in soil.

Nutrient balance sheet

The nutrient balance sheet shows loss of nutrients irrespective of treatments after 2 years of study (Table 7). Maximum losses of nitrogen were observed in the C₄ cropping system and minimum (61.95) losses of nutrients were observed in the C₅ cropping system. This might be due to more nutrient removal by crops as compared to applied through fertiliser and residue incorporation. The phosphorus balance sheet also shows a negative trend like nitrogen, with minimal (31.19) losses of phosphorous was observed in the C₅ cropping system. This is due to the higher biomass yield of garden pea in the maize and green pea cropping system led to more addition of nutrients to the soil. Potassium balance sheet also follows a similar trend to nitrogen. The minimum losses of potassium were observed in the C₅ cropping system. In the moisture regimes with the least (162.63) deficiency of nitrogen was observed in I₃, followed by I₂ and I₁. The phosphorus balance sheet in moisture regimes also shows a negative trend like nitrogen, with minimal (45.55) losses of phosphorous was observed in I₃. Potassium balance sheet also follows a similar trend, with the least (48.96) losses observed in I₃, followed by I₂ and I₁.

Table 6. Chemical properties of soil as affected by different treatments

Treatments	Available N (kg/ha)			Available P ₂ O ₅ (kg/ha)			Available K ₂ O (kg/ha)		
Cropping system	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
C ₁	190.42	203.09	196.75	23.82	30.36	27.09	137.31	138.93	138.12
C ₂	204.25	222.28	213.27	28.41	34.41	31.41	139.74	149.42	144.58
C ₃	219.08	242.90	230.99	33.44	37.05	35.25	143.67	151.08	147.38
C ₄	215.29	234.60	224.94	31.01	36.71	33.86	140.99	148.61	144.80
C ₅	229.85	261.91	245.88	35.25	38.95	37.10	149.67	157.50	153.58
S.Em(±)	3.37	3.76	2.52	0.62	0.68	0.46	2.37	2.57	1.75
CD (5 %)	11.0	12.26	7.57	2.02	2.21	1.38	7.74	8.37	5.25
Moisture regimes									
IW:CPE- 0.6	214.53	235.39	224.96	31.17	36.50	33.84	144.73	152.178	148.4
IW:CPE-0.8	210.67	232.30	221.49	30.33	35.26	32.79	142.29	148.8	145.59
IW: CPE-1.00	210.14	231.17	220.65	29.65	34.73	32.19	139.79	146.26	143.03
S.Em(±)	2.35	2.98	1.90	0.75	0.63	0.49	2.12	2.43	1.61
CD (5 %)	NS	NS	NS	NS	NS	NS	NS	NS	NS

C₁: rice - wheat - fallow; C₂: rice - wheat - green gram; C₃: rice - maize - dhaincha; C₄: rice - maize + potato - dhaincha; C₅: rice - maize + green pea - dhaincha; IW:CPE: irrigation water : cumulative pan evaporation.

Table 7. Total nutrient uptake, nutrient removal and the balance sheet of nutrients as affected by different treatments

Treatments	Uptake of nutrients by crop (kg/ha)			Initial nutrient status of soil (kg/ha)			Final nutrient status of soil (kg/ha)			Nutrient added through fertiliser and residue incorporation (kg/ha)			Nutrient balance sheet (kg/ha)		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Cropping system															
C ₁	300.76	118.10	331.46	173.45	8.09	113.34	203.09	13.24	115.31	588.96	169.80	388.99	-258.56	-47.30	-55.56
C ₂	451.42	142.24	412.00	173.45	8.09	113.34	222.28	15.00	124.02	687.00	227.42	456.92	-186.75	-78.27	-34.24
C ₃	590.51	151.89	504.36	173.45	8.09	113.34	242.90	16.15	125.40	799.51	183.49	556.03	-139.55	-33.54	-39.62
C ₄	799.94	186.30	686.28	173.45	8.09	113.34	234.60	16.01	123.35	1135.24	268.30	770.71	-274.15	-74.09	-74.43
C ₅	716.91	171.13	545.71	173.45	8.09	113.34	261.91	16.98	130.73	867.32	211.21	587.78	-61.95	-31.19	-24.69
Moisture regimes															
IW:CPE- 0.6	535.14	141.23	458.66	173.45	8.09	113.34	235.39	15.91	126.31	797.11	200.10	517.95	-205.09	-56.13	-60.03
IW:CPE-0.8	573.35	155.12	499.07	173.45	8.09	113.34	232.30	15.37	123.50	810.81	206.62	547.32	-184.87	-50.50	-54.91
IW:CPE-1.00	607.23	165.45	530.15	173.45	8.09	113.34	231.17	15.14	121.40	820.69	211.11	568.73	-162.63	-45.55	-48.96

C₁: rice - wheat - fallow; C₂: rice - wheat - green gram; C₃: rice - maize - dhaincha; C₄: rice - maize + potato - dhaincha; C₅: rice - maize + green pea - dhaincha; IW:CPE: Irrigation water : cumulative pan evaporation.

Conclusion

The present study concluded that integrating high-value intercropping systems, such as maize with potato, under adequate moisture regimes increases the productivity of the system, while inclusion of legume-based cropping systems is essential for improving soil quality and ensuring long-term productivity of rice-based cropping systems. In the north zone of Bihar, Rice - Maize + Garden Pea - Dhaincha cropping system is good in terms of soil health and profitability.

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Authors' contributions

AK performed this experiment under the guidance of VK. SK and GK participated in a useful discussion on theoretical frameworks. NP provided the agrometeorological data, which helps in the calculation of the IW/CPE ratio for irrigation. PP and SK turned it into advanced research. SS and PK¹ participated in the design of the study and performed the statistical analysis. PK² performed the publication work. All authors read and approved the final manuscript. [SK¹ stands for Sweeti K and SK² stands for Shweta K; PK¹ stands for Pankaj Kumar and PK² for Pradeep Kumar].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

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