International Journal of Agriculture Sciences
ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 10, Issue 23, 2018, pp.-7559-7565.
Available online at https://www.bioinfopublication.org/jouarchive.php?opt=&jouid=BPJ0000217

Research Article

EFFECTS OF INTEGRATED USE OF INORGANIC FERTILIZER, FARMYARD MANURE AND CROP RESIDUE ON CROP PRODUCTION, NUTRIENT UPTAKE AND PROTEIN IN SOYBEAN-RAPESEED CROPPING SYSTEM UNDER CONVENTIONAL TILLAGE AND CONSERVATION AGRICULTURE IN SUBTROPICS

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Received: November 29, 2018; Revised: December 11, 2018; Accepted: December 12, 2018; Published: December 15, 2018

Abstract: Soybean (*Glycine max* L.) and rapeseed (*Brassica napus* L.) are important crops grown for protein and edible oil in semiarid subtropical soils. Information on integrated use of inorganic N and P fertilizer, farmyard manure (FYM) and crop residue (CR), and their complimentary effects is needed under Conventional Tillage (CT) as well as fast-expanding Conservation Agriculture (CA) for the development of a sustainable annual soybean (summer-grown) – rapeseed (winter-grown) system. A field experiment was conducted for 4 years to evaluate the effects of 16 treatment combinations consisting of different rates of fertilizer N and P with or without FYM, and CR under CT and CA system on yield, nutrient uptake and protein content. While 10 t FYM ha^{-1} was applied to soybean each year, its residual effect was studied in rapeseed. Crop residues of soybean (3 t ha^{-1}) and rapeseed (4 t ha^{-1}) were incorporated in CT and retained on the soil surface in CA system. All through the 4 years, the grain yield of soybean increased significantly over control with the applications of fertilizer N and P. The combined applications of FYM and CR in conjunction with 20 kg N and 60 kg P_2O_5 ha^{-1} (otherwise recommended rates) produced soybean grain yield under CT (2567 kg ha^{-1} averaged over 4 years) and CA (2440 kg ha^{-1}) that were statistically at par with 25% higher application of inorganic N and P (25 kg N and 75 kg P_2O_5 ha^{-1}). The results clearly revealed that soybean yield was comparable in CT and CA in different treatments with and without CR. Similar to grain yield, significantly higher uptake of N by soybean with the combined applications of FYM and CR with 20 kg N and 60 kg P_2O_5 ha^{-1} in CT (166 kg ha^{-1} averaged over 4 years) and CA (159 kg ha^{-1}) that were statistically at par with 25% higher applications of inorganic N and P. In succeeding rapeseed, the effects of fertilizer N and P on seed yield, N and P uptake, and protein were similar to those in soybean, however, the complimentary effects of CR and residual FYM were not consistent. Further, the rapeseed seed yield in all the 4 years was significantly lower (9-30%) under CA system than CT, both with and without CR. Total N and P uptake followed the patterns of seed yield in various treatment combinations. The reduced yield and uptake of N and P by winter-grown rapeseed in no-till CA was presumably due to poor and delayed germination of its small-sized seed, root proliferation and plant growth because of its shallow-seeding, hard soil surface layer, and cooler environment in surface soil layer during initial period after seeding created by the retention of CR on soil surface. Our study demonstrated that soybean could be grown in CT and CA with either 20 kg N, 60 kg P_2O_5 and 10 t FYM ha^{-1} + CR or 25 kg N + 75 kg P_2O_5 ha^{-1} + CR for its highest yield, nutrient uptake and protein. However, the cultivation of rapeseed and similar small-seeded crops may not perform well under no-till, soil-surface retained crop residue CA system.

Keywords: Conservation agriculture, Nitrogen, Phosphorus, Rapeseed, Reduced tillage, Integrated nutrient management

Citation: Garg A.K., *et al*., (2018) Effects of Integrated Use of Inorganic Fertilizer, Farmyard Manure and Crop Residue on Crop Production, Nutrient Uptake and Protein in Soybean-Rapeseed Cropping System under Conventional Tillage and Conservation Agriculture in Subtropics. International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 10, Issue 23, pp.- 7559-7565.

Introduction

Removal or burning of crop residue (CR) after crop harvest and conventional tillage (CT) involving intensive tilling of soil for raising 2-3 crops in a year under irrigated subtropical conditions of South Asia cause losses of organic matter and nutrients from agricultural soils [1, 2]. The combine-harvested residues, rice residue in particular, are difficult to collect and take away from the field for other purposes; the feasible option for the farmers is in situ burning that further ascertains quick seed-bed preparation for the next crop and avoid any risk of reduced crop yield associated with the incorporation of CR having wider C: N ratio that immobilize N during decomposition [3]. Adversely, the field burning of CR is a major contributor to reduced air quality (particulates, greenhouse gases), and human respiratory ailments in intensive rice-production areas. Furthermore, paddy (rice crop) being the water guzzling crop, dominance of paddy-wheat crop rotation has led to over-exploitation of ground water resulting in rapid decline of water table in the entire state [4]. These unfavorable features have led to explore the substitute crops and cropping systems, which are environment-friendly and efficient in utilizing natural resources [5].

While soybean (*Glycine max* L.) offers a good alternative to rice, providing oil and protein, has significantly less water requirement than rice. It will not only meet its own N requirement to a great extent through biological nitrogen fixation (BNF) but it will also leave considerable amounts of N in soil and in CR for utilization for the succeeding crops [6]. Our recent study has demonstrated that soybean in this region could obtain 81-125 kg N ha^{-1} (equivalent to 68-85% of total N uptake) by BNF depending upon tillage and crop management [7], and significantly improve soil health [8], and more so under conservation agriculture (CA). Therefore, rice cultivation could be partially replaced by soybean in summer, in rotation with winter-grown crops including rapeseed (*Brassica napus* L.). Soybean and rapeseed are important crops as source of protein and edible oil, and their cultivation and production would help to enhance the availability of edible oil as India is producing only 40% of its required edible oil and the rest is imported from other countries. CA system maintains a continuous soil cover through surface retention of CR, with no or reduced tillage, and the use of leguminous cover or green manure crops in rotations, and is increasingly adopted to enhance food security for millions of small holders in the developing world [9] and India [10].

Under the umbrella of multi-regional FAO-IAEA Coordinated Research Project on "Integrated soil, water and nutrient management for conservation agriculture", we investigated the comparative effects of integrated use of inorganic fertilizer, farmyard manure (FYM), and CR on crop production, nutrient-use efficiency, water conservation, BNF and soil health in soybean-wheat and soybean-rapeseed cropping systems under CT and CA [11]. The results on crop yields, nutrient-use efficiency, water conservation, and BNF and soil health in soybean-wheat system were reported earlier [7, 8, 12]. In case of soybean-rapeseed system, Kumar *et al*. [13] presented results on soil health parameters. In the present paper, we report the effects of integrated use of inorganic fertilizer, FYM and CR on crop yields, nutrient uptake and protein content in a four-year field study with soybean-rapeseed cropping system under CT and CA practices in subtropical region. As rapeseed has seeds of smaller size than soybean and wheat, it is seeded at a shallow soil depth. This study investigated the feasibility of growing rapeseed under CA where no-till surface soil poses hardness and lower moisture for the germination and proliferation of seedlings.

Materials and Methods

Experimental Site, Treatments and Field Operations

A four-year field experiment on annual soybean-rapeseed rotation was established at Punjab Agricultural University Research Farm, Ludhiana, India, located in subtropical region at 30°54'N and 75°48'E (247 m asl) on Fatehpur loamy sand soil (*Typic haplustept*). The soil was loamy sand up to 60 cm, sandy loam at 60-90 cm, clay loam at 90-120 cm and silty clay loam at 120-150 cm soil depth, and had soil pH of 8.1-8.3, organic C (2.6-3.0 g C kg^{-1} soil), low in available P (12.0-12.5 kg P ha^{-1}) and high in available K (72-92 kg K ha^{-1}). There were 16 treatment combinations with respect to CT and CA system, inorganic fertilizer N and P, rapeseed residue (RR) and soybean residue (SR) in individual plots of 3.15 × 8.30 m size. All treatments were replicated thrice in split-split plot design [14]. The details of treatments, field operations, etc. were reported earlier by Kumar *et al*. [13], and therefore, only a brief description is given here. Fertilizer N (0, 20 and 25 kg N ha^{-1} to soybean and 0, 100 and 125 kg N ha^{-1} to rapeseed) and P (0, 60 and 75 kg P_2O_5 ha^{-1} to soybean and 0, 30 and 38 kg P_2O_5 ha^{-1} to rapeseed) consisted of recommended rates for soybean (20 kg N and 60 kg P_2O_5 ha^{-1}) and rapeseed (100 kg N and 30 kg P_2O_5 ha^{-1}) and 25% higher rates [15,16]. In CR treatments, 4 t RR ha^{-1} and 3 t SR ha^{-1} were incorporated in CT and spread on the soil surface in CA system. In CT treatments, soil was tilled to a layer of 10-12 cm by one pass of disking followed by two passes with a tine cultivator and planking to create a well pulverized seedbed. In CA plots, soil was not tilled. All crops were seeded by using manually-operated plough taking care to minimize the soil disturbance. After pre-sowing irrigation, soybean (cv SL 295) was seeded 4-5 cm soil depth during first fortnight of June each year in rows 45 cm apart with application of respective fertilizer N and P rates through urea and di-ammonium phosphate. Each year, before seeding, soybean seed was inoculated with Rhizobium culture (*Bradyrhizobium japonicum*) obtained from Department of Microbiology of the Punjab Agricultural University. After harvesting soybean, rapeseed (cv PGSH 51) was seeded at a shallow depth of 1-1.5 cm during last week of October to second week of November in different years in rows 45 cm apart at a plant to plant distance of 10 cm. In rapeseed crop, while whole of fertilizer P was applied at seeding, fertilizer N was applied in two equal splits *i.e*. at seeding and one day after first irrigation. The crops were irrigated as and when required. At harvesting of each crop, the CR was either removed or incorporated in CT, and was either removed or retained on the soil surface in CA in respective treatments.

Collection and Analyses of Plant Samples

At harvesting of each soybean and rapeseed crop, representative samples of straw and grain were collected from each individual plot. Straw samples were ground in Wiley Mill whereas whole grain samples were used for chemical analysis. The concentration of N in these samples was determined by the micro-Kjeldahl method [17]. Another set of sub-samples was digested in a 2:1 mixture of HNO_3 and $HClO_4$, and total P was determined in the aliquots by molybdo-phosphoric acid method [18]. Total uptake of N and P by each crop (grain+straw) was computed from crop yield and nutrient contents. The protein content of soybean grain and rapeseed seed was calculated from the total N content multiplying it by 6.25.

Statistical Analysis

Statistical analysis of data of crop yield, N and P uptake, and protein content was carried out by ANOVA in split-split plot design [14] to analyze the effects of individual factors (tillage, crop residue, fertilizer treatment and year) and their interactions. The comparative yield response of both soybean and rapeseed to different treatments in CT and CA was calculated. For the sake of assessing the feasibility of CA in relation to crop productivity in soybean-rapeseed cropping system as compared to CT, the grain yield response to various treatments was computed over CT–Control only as under:

% Response = 100 [Grain yield in treatment (kg ha^{-1}) − Grain yield in CT-Control (kg ha^{-1})] / [Grain yield in CT-Control (kg ha^{-1})]

Similarly, response in terms of N and P uptake and protein content was computed.

Results

Soybean and Rapeseed Yield

Grain yield of soybean for the all four years of soybean-rapeseed rotation increased significantly with the application of 20 kg N + 60 kg P_2O_5 ha^{-1} that is the previously recommended rate of N and P [Table-1]. In the absence of RR, the recommended rate of N and P (T_2), 25% higher N and P rate (T_3) and recommended N and P rate in conjunction with 10 t FYM ha^{-1} (T_4) resulted in 331-474 (17-25%), 376-860 (17-52%) and 432-830 (22-50%) kg ha^{-1} increase in soybean grain yield over CT-Control (T_1), respectively in CT system during 4 years. In case of CA, the increase in soybean grain yield over CT-Control (T_1) with corresponding treatments (T_{10}, T_{11} and T_{12}) was 264-433 (13-26%), 408-810 (18-49%) and 358-743 (17-45%) kg ha^{-1}, respectively. With the addition of 4 t RR ha^{-1}, the increase in soybean grain yield over CT-Control (T_1) with T_6, T_7 and T8 treatment in CT was 318-413 (14-25%), 389-837 (17-51%) and 448-820 (23-50%), and T_{14}, T_{15} and T_{16} treatments in CA was 265-530 (12-32%), 386-860 (17-52%) and 303-797 (13-48%) kg ha^{-1}, respectively. On an average of 4 years, without RR, the application of 20 kg N + 60 kg P_2O_5 ha^{-1}, 25 kg N + 75 kg P_2O_5 ha^{-1}, and 20 kg N + 60 kg P_2O_5 ha^{-1} in conjunction with 10 t FYM ha^{-1} increased soybean grain yield over CT-Control by 21, 30 and 32% in CT and 17, 28 and 25% in CA, respectively. Similarly with RR, the soybean yield response over CT-Control with respective treatments was 19, 30 and 32% in CT, and 19, 29 and 25% in CA. In case of succeeding rapeseed, the impact of fertilizer applied at different rates in both CT and CA showed trends similar to those observed in soybean but the magnitude of seed yield increase was much higher [Table-2]. In the absence of SR, the recommended rate of N and P (T_2), 25% higher N and P rate (T_3) and recommended N and P rate in conjunction with 10 t FYM ha^{-1} (T_4) resulted in 358-749 (50-96%), 588-740 (67-129%) and 531-663 (60-126%) kg ha^{-1} increase in rapeseed yield over CT-Control ($N_0P_0RR_0 – N_0P_0SR_0$) in CT. In three of four years of experimentation, the seed yield of rapeseed in CA was significantly lower than CT in respective treatments. The yield change with T_9, T_{10} and T_{11} treatments in CA over CT-Control was minus 72 to 467 (minus 7 to 46%), 43-543 (4-54%) and 101-510 (10-50%) kg ha^{-1}, respectively. The addition of crop residue during four cycles in $N_{20}P_{60}RR_4$ – $N_{100}P_{30}SR_3$ (T_6), $N_{25}P_{75}RR_4$ – $N_{125}P_{38}SR_3$ (T_7) and $N_{20}P_{60}RR_4$ + FYM10 – $N_{100}P_{30}SR_3$ (T_8) treatments resulted in 42-57, 65-85 and 53-73% increase in rapeseed grain yield over CT-Control in CT [Table-2]. The yield increase with corresponding treatments (T_{14}, T_{15} and T_{16}) in CA over CT-Control was 15-50, 44-78 and 25-72%, respectively. On an average of 4 years, $N_{20}P_{60}RR_4$ – $N_{100}P_{30}SR_3$, $N_{25}P_{75}RR_4$ – $N_{125}P_{38}SR_3$ and $N_{20}P_{60}RR_4$ + FYM_{10} – $N_{100}P_{30}SR_3$ treatments increased rapeseed yield over CT-Control by 49, 77 and 66% in CT and 34, 60, and 46% in CA, respectively. Similarly, on an average of 4 years, $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$, $N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} – $N_{100}P_{30}SR_0$ treatments increased rapeseed yield over CT-Control by 64, 82 and 74% in CT and 15, 34, and 28% in CA, respectively. Further, the rapeseed seed yield in all the 4 years was significantly lower (9-30%) under CA system than CT, both with and without CR.

Nitrogen Uptake by Soybean and Rapeseed

The results of nitrogen uptake in the absence of crop residue revealed that $N_{20}P_{60}RR_0$, $N_{25}P_{75}RR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} resulted in 16-28, 28-44 and 35-40% increase in N uptake by soybean (grain + vegetative parts) over CT-Control ($N_0P_0RR_0$ – $N_0P_0SR_0$) in CT [Table-3]. The corresponding increase with these treatments in CA was 5-31, 23-54 and 20-43%, respectively. On an average of 4 years, $N_{20}P_{60}RR_0$, $N_{25}P_{75}RR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} increased N uptake by soybean over CT-Control by 24, 38 and 38% in CT and 19, 38 and 33% in CA, respectively. However, with the addition of crop residue during four cycles of soybean-rapeseed rotation revealed that $N_{20}P_{60}RR_4$, $N_{25}P_{75}RR_4$ and $N_{20}P_{60}RR_4$ + FYM_{10} resulted in 20-32, 31-51 and 35-50% increase in N uptake by soybean over CT-Control in CT [Table-3]. The corresponding increase with these treatments in CA was 17-31, 28-46 and 21-42%, respectively. On an average of 4 years, $N_{20}P_{60}RR_4$, $N_{25}P_{75}RR_4$ and $N_{20}P_{60}RR_4$ + FYM_{10} increased N uptake by soybean over CT-Control by 24, 41 and 41% in CT and 26, 41 and 35% in CA system. In case of succeeding rapeseed, the impact of fertilizer applied at both the rates showed trends similar to those observed in soybean but the magnitude of increase in N uptake was much higher. In the absence of crop residue, $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$, $N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} – $N_{100}P_{30}SR_0$ treatments resulted in 74-97, 109-148 and 102-116% increase in N uptake by rapeseed over CT-Control ($N_0P_0RR_0$ – $N_0P_0SR_0$) in CT [Table-3]. The corresponding change with these treatments in CA was minus 2 to 49, 28-73 and 10-73%, respectively. On an average of 4 years, $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$, $N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} – $N_{100}P_{30}SR_0$ treatments increased N uptake by rapeseed over CT-Control by 88, 121 and 102% in CT and 16, 49 and 40% in CA system, respectively. However, with the addition of crop residue during four cycles of soybean-rapeseed rotation revealed that $N_{20}P_{60}RR_4$ – $N_{100}P_{30}SR_3$, $N_{25}P_{75}RR_4$ – $N_{125}P_{38}SR_3$ and $N_{20}P_{60}RR_4$ + FYM_{10} – $N_{100}P_{30}SR_3$ treatments resulted in 58-90, 100-160 and 74-120% increase in N uptake by rapeseed over CT-Control in CT [Table-3]. The corresponding increase with these treatments in CA was 6-55, 52-114 and 26-100%, respectively. On an average of 4 years, $N_{20}P_{60}RR_4$ – $N_{100}P_{30}SR_3$, $N_{25}P_{75}RR_4$ – $N_{125}P_{38}SR_3$ and $N_{20}P_{60}RR_4$ + FYM_{10} – $N_{100}P_{30}SR_3$ treatments increased N uptake by rapeseed over CT-Control by 72, 121 and 91% in CT and 37, 91 and 58% in CA system. Further, the N uptake by rapeseed in all the 4 years was significantly lower (14-38%) under CA system than CT, both with and without CR.

Phosphorus Uptake by Soybean and Rapeseed

The results of P uptake in the absence of crop residue revealed that $N_{20}P_{60}RR_0$, $N_{25}P_{75}RR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} resulted in 15-44, 32-60 and 37-57% increase in P uptake by soybean over CT-Control ($N_0P_0RR_0$) in CT [Table-4]. The corresponding increase with these treatments in CA was 2-43, 24-57 and 24-40%, respectively. On an average of 4 years, $N_{20}P_{60}RR_0$, $N_{25}P_{75}RR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} increased P uptake by soybean over CT-Control by 28, 47 and 46% in CT and 25, 47 and 35% in CA, respectively. However, with the addition of crop residue during four cycles of soybean-rapeseed rotation revealed that $N_{20}P_{60}RR_6$, $N_{25}P_{75}RR_4$ and $N_{20}P_{60}RR_4$ + FYM_{10} resulted in 21-27, 39-56 and 25-51% increase in P uptake by soybean over CT-Control in CT [Table-4]. The corresponding increase with these treatments in CA was 29-40, 43-57 and 31-52%, respectively. On an average of 4 years, $N_{20}P_{60}RR_4$, $N_{25}P_{75}RR_4$ and $N_{20}P_{60}RR_4$ + FYM_{10} increased P uptake by soybean over CT-Control by 23, 46 and 37% in CT and 34, 51 and 39% in CA system. In case of succeeding rapeseed, the impact of fertilizer applied at both the rates showed trends similar to those observed in soybean but the magnitude of increase in P uptake was much higher. In the absence of crop residue, $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$, $N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} – $N_{100}P_{30}SR_0$ treatments resulted in 61-91, 60-167 and 80-147% increase in P uptake by rapeseed over CT-Control ($N_0P_0RR_0$ – $N_0P_0SR_0$) in CT [Table-4]. The corresponding change with these treatments in CA was minus 3 to 66, 6-87 and 31-99%, respectively. On an average of 4 years, $N_{20}P_{60}RR_0$–$N_{100}P_{30}SR_0$, $N_{25}P_{75}RR_0$–$N_{125}P_{38}SR_0$ and $N_{20}P_{60}RR_0$+FYM_{10}–$N_{100}P_{30}SR_0$ treatments increased P uptake by rapeseed over CT-Control by 70, 96 and 100% in CT and 30, 53 and 60% in CA, respectively. However, with the addition of crop residue during four cycles of soybean-rapeseed rotation revealed that $N_{20}P_{60}RR_4$–$N_{100}P_{30}SR_3$, $N_{25}P_{75}RR_4$ – $N_{125}P_{38}SR_3$ and $N_{20}P_{60}RR_4$ + FYM_{10} – $N_{100}P_{30}SR_3$ treatments resulted in 48-69, 49-129 and 49-95% increase in P uptake by rapeseed over CT-Control in CT [Table-4]. The corresponding increase with these treatments in CA was 6-78, 54-98 and 23-108%, respectively. On an average of 4 years, $N_{20}P_{60}RR_4$ – $N_{100}P_{30}SR_3$, $N_{25}P_{75}RR_4$–$N_{125}P_{38}SR_3$ and $N_{20}P_{60}RR_4$ + FYM_{10} –$N_{100}P_{30}SR_3$ treatments increased P uptake by rapeseed over CT-Control by 56, 85 and 75% in CT and 44, 83 and 66% in CA system. Further, the P uptake by rapeseed in all the 4 years was significantly lower under CA system than CT, both with and without CR.

Protein Content of Soybean and Rapeseed

The results of protein content in the absence of crop residue revealed that $N_{20}P_{60}RR_0$, $N_{25}P_{75}RR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} resulted in 1.00-2.13, minus 3.34 to 4.89 and 2.34-4.78% change in protein content by soybean over CT-Control ($N_0P_0RR_0$ – $N_0P_0SR_0$) in CT [Table-5]. The corresponding change with these treatments in CA was minus 1.37 to 11.49, 1.17-12.64 and 3.41-16.09%, respectively. On an average of 4 years, $N_{20}P_{60}RR_0$, $N_{25}P_{75}RR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} increased protein content by soybean over CT-Control by 1.58, 2.21 and 4.10% in CT and 4.42, 7.26 and 8.83% in CA, respectively. However, with the addition of crop residue during four cycles of soybean-rapeseed rotation revealed that $N_{20}P_{60}RR_6$, $N_{25}P_{75}RR_4$ and $N_{20}P_{60}RR_4$ + FYM_{10} resulted in minus 4.68 to 3.16, 1.67-5.75 and minus 5.02 to 6.08% change in protein content by soybean over CT-Control in CT [Table-5]. The corresponding increase with these treatments in CA was -0.34-8.03, 1.37-6.90 and 2.39-8.05%, respectively. On an average of 4 years, $N_{20}P_{60}RR_4$, $N_{25}P_{75}RR_4$ and $N_{20}P_{60}RR_4$ + FYM_{10} increased protein content by soybean over CT-Control by 0.95, 4.10 and 3.15% in CT and 4.42, 5.68 and 5.68% in CA system. In case of succeeding rapeseed, the impact of fertilizer applied at both the rates showed trends similar to those observed in soybean but the magnitude of increase in protein content was much higher. In the absence of crop residue, $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$, $N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} – $N_{100}P_{30}SR_0$ treatments resulted in 1.55-17.87, -0.52-16.91 and 5.99-19.32% increase in protein content by rapeseed over CT-Control ($N_0P_0RR_0$ – $N_0P_0SR_0$) in CT [Table-5]. The corresponding change with these treatments in CA was minus 1.02 to 6.28, minus 3.09 to 6.76 and 2.06-14.98%, respectively. On an average of 4 years, $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$, $N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$ and $N_{20}P_{60}RR_0$ + FYM_{10} – $N_{100}P_{30}SR_0$ treatments increased protein content by rapeseed over CT-Control by 7.35, 6.86 and 10.78% in CT and 0.98, 1.47 and 6.37% in CA, respectively. However, with the addition of crop residue during four cycles of soybean-rapeseed rotation revealed that $N_{20}P_{60}RR_4$ – $N_{100}P_{30}SR_3$, $N_{25}P_{75}RR_4$–$N_{125}P_{38}SR_3$ and $N_{20}P_{60}RR_4$ + FYM_{10} – $N_{100}P_{30}SR_3$ treatments resulted in 4.12-11.06, 5.58-11.98 and 5.58-28.99% increase in protein content by rapeseed over CT-Control in CT [Table-5]. The corresponding increase with these treatments in CA was 0.00-3.86, 0.00-12.90 and 6.60-24.15%, respectively. On an average of 4 years, $N_{20}P_{60}RR_4$ – $N_{100}P_{30}SR_3$, $N_{25}P_{75}RR_4$ – $N_{125}P_{38}SR_3$ and $N_{20}P_{60}RR_4$ + FYM_{10} – $N_{100}P_{30}SR_3$ treatments increased protein content by rapeseed over CT-Control by 7.35, 7.84 and 14.22% in CT and 2.45, 7.35 and 14.22% in CA system.

Discussion

The results on grain yield of soybean have shown that significantly higher yields were obtained with recommended rates of N and P fertilizer ($N_{20}P_{60}RR_0$) than CT-Control ($N_0P_0RR_0$ – $N_0P_0SR_0$) in all the 4 years under both CT and CA systems [Table-1]. On an average of 4 years, application of 25% extra fertilizer ($N_{25}P_{75}RR_0$) registered further increase of 7.5% and 9.6% in soybean yield over $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$ treatment without CR in CT and CA system, respectively. Similar increase of 9.4 and 8.1% was observed with CR in the respective treatments. These results illustrates that supply of 25% extra N and P fertilizer, both without and with CR is required to produce highest soybean and rapeseed yield over previously recommended rates of N and P [15,16]. Furthermore, additional application of 10 t FYM ha^{-1} increased soybean yields by 9.2 and 10.6% without and with CR in CT and 7.0 and 5.1% in CA over respective recommended N and P rates, indicating that the application of FYM in conjunction with recommended rate of N and P to soybean proved strikingly better than the recommended rate of

Table-1 *Grain yield of soybean (kg ha^{-1}) as influenced by inorganic fertilizer, FYM and CR management practices under conventional tillage and conservation agriculture.*

Treatment Number	Treatments		Year 1	Year 2	Year 3	Year 4	*Mean*
	Soybean	Rapeseed					
	Conventional tillage						
T_1	N_0 P_0 RR_0[a]	N_0 P_0 SR_0[b]	2247	1650	1917	1976	*1948*
T_2	N_{20} P_{60} RR_0	N_{100} P_{30} SR_0	2680	2013	2391	2307	*2348*
T_3	N_{25} P_{75} RR_0	N_{125} P_{38} SR_0	2623	2510	2533	2434	*2525*
T_4	N_{20} P_{60} RR_0 + FYM_{10}[c]	N_{100} P_{30} SR_0	2857	2480	2513	2408	*2565*
T_5	N_0 P_0 RR_4	N_0 P_0 SR_3	2261	1723	1890	1965	*1960*
T_6	N_{20} P_{60} RR_4	N_{100} P_{30} SR_3	2565	2063	2277	2376	*2320*
T_7	N_{25} P_{75} RR_4	N_{125} P_{38} SR_3	2636	2487	2550	2482	*2539*
T_8	N_{20} P_{60} RR_4 + FYM_{10}	N_{100} P_{30} SR_3	2836	2470	2537	2424	*2567*
	Mean		2588	2175	2326	2297	*2346*
	Conservation agriculture						
T_9	N_0 P_0 RR_0	N_0 P_0 SR_0	2335	1667	1972	1864	*1960*
T_{10}	N_{20} P_{60} RR_0	N_{100} P_{30} SR_0	2544	2083	2216	2240	*2271*
T_{11}	N_{25} P_{75} RR_0	N_{125} P_{38} SR_0	2655	2460	2437	2399	*2488*
T_{12}	N_{20} P_{60} RR_0 + FYM_{10}	N_{100} P_{30} SR_0	2638	2393	2354	2334	*2430*
T_{13}	N_0 P_0 RR_4	N_0 P_0 SR_3	2350	1870	2030	1847	*2024*
T_{14}	N_{20} P_{60} RR_4	N_{100} P_{30} SR_3	2512	2180	2337	2253	*2321*
T_{15}	N_{25} P_{75} RR_4	N_{125} P_{38} SR_3	2633	2510	2459	2436	*2510*
T_{16}	N_{20} P_{60} RR_4 + FYM_{10}	N_{100} P_{30} SR_3	2550	2447	2403	2359	*2440*
	Mean		2527	2201	2276	2217	*2305*
	LSD (0.05)						
	Treatment		129	175	100	99	*62*
	Tillage		ns	ns	ns	ns	*ns*
	Crop residue		ns	55	ns	ns	*ns*
	Year		--	--	--	--	*97*
	Year × Treatment		--	--	--	--	*125*

[a]N = fertilizer N (kg N ha^{-1}); P = fertilizer P (kg P_2O_5 ha^{-1}); RR = Rapeseed crop residue (t ha^{-1})
[b]SR = Soybean crop residue (t ha^{-1}); [c]FYM = Farmyard manure (t ha^{-1}), ns = non-significant

Table-2 *Seed yield of rapeseed (kg ha-1) as influenced by inorganic fertilizer, FYM and CR management practices under conventional tillage and conservation agriculture.*

Treatment Number[a]	Year 1	Year 2	Year 3	Year 4	*Mean*
Conventional tillage					
T_1	1049	1010	495	716	*818*
T_2	1798	1520	970	1074	*1341*
T_3	1755	1750	1133	1304	*1486*
T_4	1712	1613	1120	1247	*1423*
T_5	905	1000	430	758	*773*
T_6	1542	1587	736	1019	*1221*
T_7	1729	1870	898	1293	*1448*
T_8	1725	1743	755	1213	*1359*
Mean	1527	1512	817	1078	*1233*
Conservation agriculture					
T_9	753	877	244	420	*574*
T_{10}	977	1477	573	741	*942*
T_{11}	1092	1553	683	1052	*1095*
T_{12}	1150	1520	605	902	*1044*
T_{13}	790	830	293	588	*625*
T_{14}	1323	1517	567	982	*1097*
T_{15}	1510	1800	820	1115	*1311*
T_{16}	1308	1733	644	1099	*1196*
Mean	1113	1413	554	862	*986*
LSD (0.05)					
Treatment	146	138	89	79	*57*
Tillage	98	ns	63	119	*41*
Crop residue	ns	ns	63	ns	*ns*
Year	--	--	--	--	*143*
Year × Treatment	--	--	--	--	*114*

[a]For details of Treatments, refer to Table-1, ns = non-significant

N and P alone in producing higher yield of soybean, reducing climate-induced fluctuations in yield from year to year, and enhancing uptake of both N and P in CT and CA systems. Application of FYM enhances the soil organic C content (SOC) and has direct and indirect effects on soil properties leading to improved soil health as illustrated in other studies [8, 19]. Kumar *et al.* [13] reported significant improvement in water stable aggregation and proportion of macro-aggregates, SOC content, labile C and N fractions such as water soluble C, particulate and light fraction organic matter, potentially mineralizable N and microbial biomass with the application of 10 t FYM ha^{-1} along with recommended rate of N and P to soybean in the experimental plots of the present study. Overall, soybean yields were comparable under CT and CA system, whereas rapeseed yields were significantly lower under CA system. The N uptake by soybean on an average of 4 years was 41 and 35% higher in FYM treated plots over CT-Control plots in CT and CA system, respectively.

Table-3 *Total N uptake (kg ha^{-1}) by soybean and rapeseed as influenced by inorganic fertilizer, FYM and CR management practices under conventional tillage and conservation agriculture.*

Treatment Number[a]	Soybean					Rapeseed				
	Year 1	Year 2	Year 3	Year 4	*Mean*	Year 1	Year 2	Year 3	Year 4	*Mean*
Conventional tillage										
T_1	123	106	127	115	*118*	53	51	31	35	*43*
T_2	151	123	163	146	*146*	104	99	61	61	*81*
T_3	157	147	183	164	*163*	111	113	77	80	*95*
T_4	166	148	178	158	*163*	107	103	67	72	*87*
T_5	122	114	129	112	*119*	45	50	25	38	*40*
T_6	150	127	156	152	*146*	84	97	54	62	*74*
T_7	161	143	185	174	*166*	117	111	62	91	*95*
T_8	166	159	179	161	*166*	99	96	54	77	*82*
Mean	150	133	163	148	*148*	90	90	54	65	*75*
Conservation agriculture										
T_9	120	101	143	111	*119*	34	39	17	18	*27*
T_{10}	137	111	166	148	*141*	52	76	30	43	*50*
T_{11}	151	133	195	172	*163*	68	88	41	60	*64*
T_{12}	147	139	179	164	*157*	68	88	34	50	*60*
T_{13}	107	125	140	107	*120*	38	50	18	28	*34*
T_{14}	144	139	166	148	*149*	71	79	33	54	*59*
T_{15}	157	153	185	167	*166*	99	105	47	75	*82*
T_{16}	149	151	178	159	*159*	75	87	39	70	*68*
Mean	139	132	169	147	*147*	63	77	32	50	*55*
LSD (0.05)										
Treatment	8	9	12	8	*5*	12	11	7	5	*4*
Tillage	ns	ns	ns	ns	*ns*	3	8	5	10	*3*
Crop residue	ns	6	ns	ns	*3*	ns	ns	ns	4	*3*
Year	--	--	--	--	*9*	--	--	--	--	*17*
Year × Treatment	--	--	--	--	*9*	--	--	--	--	*9*

[a]For details of Treatments, refer to Table-1, ns = non-significant

Table-4 *Total P uptake (kg ha^{-1}) by soybean and rapeseed as influenced by inorganic fertilizer, FYM and CR management practices under conventional tillage and conservation agriculture.*

Treatment Number[a]	Soybean					Rapeseed				
	Year 1	Year 2	Year 3	Year 4	*Mean*	Year 1	Year 2	Year 3	Year 4	*Mean*
Conventional tillage										
T_1	25.7	14.4	13.8	15.6	*17.4*	12.7	10.6	5.5	8.5	*9.3*
T_2	30.3	16.5	19.9	21.9	*22.2*	20.4	18.0	10.5	14.4	*15.8*
T_3	36.0	19.0	22.0	24.9	*25.5*	20.3	18.8	14.7	18.9	*18.2*
T_4	35.2	21.4	21.6	23.4	*25.4*	22.8	21.0	13.6	17.1	*18.6*
T_5	26.0	14.0	14.0	13.2	*16.8*	10.2	10.6	4.2	8.3	*8.3*
T_6	31.6	17.7	17.5	18.9	*21.4*	18.8	16.7	9.3	13.0	*14.5*
T_7	35.9	20.0	21.5	24.1	*25.4*	18.9	19.1	12.6	18.2	*17.2*
T_8	32.0	20.6	20.8	22.0	*23.9*	18.9	18.9	10.6	16.6	*16.3*
Mean	31.6	18.0	18.9	20.5	*22.2*	17.9	16.7	10.1	14.4	*14.8*
Conservation agriculture										
T_9	32.2	11.4	13.8	13.9	*17.8*	8.6	9.6	4.1	5.8	*7.0*
T_{10}	36.8	14.7	17.7	17.9	*21.8*	12.3	17.6	7.5	10.8	*12.1*
T_{11}	40.4	17.8	21.4	22.8	*25.6*	13.4	17.6	9.7	15.9	*14.2*
T_{12}	36.1	17.9	19.3	20.7	*23.5*	16.7	21.1	8.3	13.5	*14.9*
T_{13}	26.7	15.0	14.1	14.0	*17.5*	8.9	11.0	4.1	7.7	*7.9*
T_{14}	35.5	18.6	19.3	20.1	*23.4*	13.4	18.9	7.6	13.7	*13.4*
T_{15}	36.7	22.6	21.7	23.6	*26.2*	19.6	21.0	10.7	16.7	*17.0*
T_{16}	34.6	18.9	21.0	22.0	*24.1*	15.6	22.0	8.4	15.4	*15.4*
Mean	34.9	17.1	18.5	19.4	*22.5*	13.6	17.4	7.6	12.4	*12.7*
LSD (0.05)										
Treatment	2.7	1.7	1.2	1.7	*0.9*	2.5	1.9	1.2	1.5	*0.9*
Tillage	0.7	ns	ns	ns	*ns*	1.7	ns	0.9	ns	*ns*
Crop residue	ns	1.2	ns	0.6	*ns*	ns	ns	ns	ns	*ns*
Year	--	--	--	--	*2.7*	--	--	--	--	*2.9*
Year × Treatment	--	--	--	--	*ns*	--	--	--	--	*ns*

[a]For details of Treatments, refer to Table-1, ns = non-significant

These results confirm the earlier findings of Aulakh *et al.* [12] with soybean-wheat rotation at the same location, where soybean yield, and N and P uptake in CA system were equal to or higher than CT in different treatments without and with CR. The results on grain yield of rapeseed have shown that significantly higher yields were obtained with recommended rates of N and P fertilizer ($N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$) than CT-Control ($N_0P_0RR_0$ – $N_0P_0SR_0$) in all the 4 years [Table-2]. On an average of 4 years, application of 25% extra fertilizer ($N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$) registered increase of 10.8% and 16.2% in rapeseed yield over $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$ treatment without CR in CT and CA system, respectively. Similarly, increase of 18.6 and 19.5% was observed with CR in the respective treatments. Furthermore, additional application of 10 t FYM ha-1 increased rapeseed yields by 6.1 and 11.3% without and with CR in CT and 10.8 and 9.0% in CA, respectively. Fertilizer and residual FYM treatments significantly increased N uptake in all tillage and CR treatments [Table-3]. On an average of 4 years, $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$ treatment resulted in a large increase in N uptake over CT-Control, which ranged from 85 to 200% in different tillage and CR treatments.

Table-5 *Protein content (%) of soybean grain and rapeseed seed as influenced by inorganic fertilizer, FYM and CR management practices under conventional tillage and conservation agriculture.*

Treatment Number	Soybean grain					Rapeseed seed				
	Year 1	Year 2	Year 3	Year 4	*Mean*	Year 1	Year 2	Year 3	Year 4	*Mean*
Conventional tillage										
T_1	29.3	29.9	34.8	32.9	*31.7*	20.7	19.4	19.7	21.7	*20.4*
T_2	29.8	30.2	35.2	33.6	*32.2*	24.4	19.7	20.7	22.8	*21.9*
T_3	30.5	28.9	36.5	33.6	*32.4*	24.2	19.3	20.9	22.8	*21.8*
T_4	30.7	30.6	36.4	34.3	*33.0*	24.7	21.1	21.5	23.0	*22.6*
T_5	28.6	30.7	34.9	31.8	*31.5*	21.0	19.4	20.3	22.9	*20.9*
T_6	30.0	28.5	35.9	33.8	*32.0*	22.1	20.2	21.0	24.1	*21.9*
T_7	30.4	30.4	36.8	34.6	*33.0*	22.5	20.6	20.8	24.3	*22.0*
T_8	30.6	28.4	36.8	34.9	*32.7*	26.7	20.7	20.8	25.0	*23.3*
Mean	30.0	29.7	35.9	33.7	*32.3*	23.3	20.0	20.7	23.3	*21.8*
Conservation agriculture										
T_9	28.3	30.8	38.0	33.3	*32.6*	20.8	18.9	19.0	18.7	*19.4*
T_{10}	28.9	30.3	38.8	34.3	*33.1*	22.0	19.3	19.5	21.7	*20.6*
T_{11}	29.8	31.3	39.2	35.6	*34.0*	22.1	18.8	20.2	21.8	*20.7*
T_{12}	30.3	31.8	40.4	35.6	*34.5*	23.8	19.8	20.4	23.0	*21.7*
T_{13}	24.5	32.4	35.8	32.1	*31.2*	20.3	18.6	18.9	21.4	*19.8*
T_{14}	29.2	32.3	36.4	34.4	*33.1*	21.5	19.4	19.9	22.9	*20.9*
T_{15}	29.7	31.9	37.2	35.0	*33.5*	23.2	19.4	20.4	24.5	*21.9*
T_{16}	30.0	31.5	37.6	35.0	*33.5*	25.7	21.0	21.0	25.3	*23.3*
Mean	28.8	31.5	37.9	34.4	*33.2*	22.4	19.4	19.9	22.4	*21.0*
LSD (0.05)										
Treatment	0.86	ns	ns	0.72	*1.52*	ns	0.40	ns	1.38	*ns*
Tillage	ns	0.62	ns	0.59	*0.60*	ns	ns	ns	ns	*0.77*
Crop residue	ns	ns	ns	ns	*ns*	ns	ns	ns	1.37	*0.56*
Year	--	--	--	--	*0.62*	--	--	--	--	*0.94*
Year × Treatment	--	--	--	--	*1.24*	--	--	--	--	*ns*

[a]For details of Treatments, refer to Table-1, ns = non-significant

Application of 25% more fertilizer ($N_{25}P_{75}RR_0$ – $N_{125}P_{38}SR_0$) and residual effect of 10 t FYM ha^{-1} ($N_{20}P_{60}RR_0$+FYM_{10} – $N_{100}P_{30}SR_0$) further significantly increased N uptake. CR showed significant effect in all the 4 years and N uptake in different treatments was reduced by 14 to 20% when soybean residue was retained on surface in CA. Retaining of CR did not show any significant effect in all the 4 years and N uptake by soybean [Table-3] in CT and CA practice, however, there is significant increase in N uptake was observed in $N_{20}P_{60}RR_0$+FYM_{10} – $N_{100}P_{30}SR_0$ in CT as compared CA practice. On an average of 4 years, P uptake by rapeseed in CT increased from 9.3 kg ha^{-1} in CT-Control to 15.8 and 18.6 kg ha^{-1} with $N_{20}P_{60}RR_0$ – $N_{100}P_{30}SR_0$ and $N_{20}P_{60}RR_0$+FYM_{10} – $N_{100}P_{30}SR_0$ treatments, respectively [Table-4]. The corresponding P uptake by rapeseed in CA system increased from 9.3 kg ha^{-1} in CT-Control to 12.1 and 14.9 kg ha^{-1}, respectively. While soybean residue incorporated in CT did not influence P uptake by rapeseed, its retention on soil surface in CA system reduced P uptake by 7.6 and 5.5% in $N_{20}P_{60}RR_4$–$N_{100}P_{30}SR_3$ and $N_{20}P_{60}RR_4$+FYM_{10}–$N_{100}P_{30}SR_3$ treatment, respectively. Further, the protein concentration in rapeseed in all the 4 years was significantly lower (up to 6%) under CA system than CT, both with and without CR [Table-5]. In the present study, poor and delayed germination, root proliferation and lower plant population of rapeseed were observed under CA. In an earlier study on the same site, Aulakh *et al.* [12] recorded daily soil temperature during winter-grown wheat crop and demonstrated that the soil temperature at 4 cm depth remained lowest in plots with CR retained on soil surface in CA as compared to bare soil surface leading to relatively cooler environment created by mulching effects of surface-retained CR. Thus, the relatively cooler environment created by surface-retained CR markedly delayed the germination of rapeseed, led to relatively poor crop growth during initial period, reduced N and P uptake, protein content and resulted into significant reduction in rapeseed yield in CA than CT. In contrast to earlier findings on winter-grown wheat crop [12], in the present study, rapeseed performed poorly under CA. The most plausible reasons for poor performance of rapeseed under CA are (a) much smaller size of its seed than of soybean and wheat, which is seeded at shallower depth (1-1.5 cm) than wheat (4-5 cm), leading to lower moisture availability, (b) un-pulverized seedbed as compared to tilled soil of CT posing resistance to growing roots, and (c) crop residue retained on soil surface that acted as mulch and created cooler soil environment. Thus, with traditional field operations, winter-grown rapeseed may not perform well under no-till and surface-retained CR. Therefore the development of farm implements for different soil types and crops is required for better seed and fertilizer placement simultaneously retaining CR on the soil surface to ensure maximum crop production.

Conclusions and Agronomic Implications

The results of the present 4-year field study with annual irrigated soybean-rapeseed system under CT and CA practices in subtropical region support several conclusions that may have useful implications for development of sustainable cropping systems, improving soil health, formulation of recommendations for N and P fertilization of crops, and integrated nutrient management, while minimizing land degradation in the Indo-Gangetic Plains of Northwestern India where soils are extremely poor in SOM and low in fertility.

1. Our results revealed comparable and highest soybean grain yield obtained both under CT and CA with the application of inorganic 25 kg N and 75 kg P_2O_5 ha^{-1} on a soil low in available N and P, which is 25% higher than the earlier recommended rate of 20 kg N and 60 kg P_2O_5 ha^{-1} [12].
2. The results further illustrated that application of 10 t FYM ha^{-1} and incorporation of CR in conjunction with earlier recommended rate of 20 kg N and 60 kg P_2O_5 ha^{-1} could be a better choice to obtain greater soybean grain yield both under CT and CA as it minimized the climate-induced fluctuations in yields from year to year, and enhanced the uptake of both N and P. Optimized balanced supply of nutrients through the integrated use of N and P fertilizer, FYM and incorporation of CR played a significant role in harnessing crop yield potentials on sustained basis and building up/restoring soil productivity by improving physical, chemical and biological soil health parameters in the present study as reported earlier [13].
3. The seed yield of succeeding winter-grown rapeseed obtained with the application of 125 kg N and 38 kg P_2O_5 ha^{-1} (25% higher than recommended N and P rate without crop residue) was 36% higher (average of four years) under CT than CA system. Furthermore, the seed yields in CA system were 9-30% lower than CT showing poor performance of rapeseed under CA.
4. Both soybean and rapeseed are important crops grown for edible oil and protein. Earlier studies on the similar subtropical sites have shown significant increase in oil content as well as oil yield of oilseed crops

including soybean and rapeseed with balanced fertilization [15, 20]. The present study has further demonstrated significantly enhanced protein content in both crops with integrated nutrient management. These findings would encourage the increase in area and production of these crops in this region in order to reduce the import of edible oil from other countries and improve the edible oil economy of the country.

5. These results confirm the previous findings of Aulakh *et al.* [12] with soybean-wheat rotation that soybean yield, and N and P uptake in CA system were equal to or higher than CT in different treatments without and with CR. These as well as former findings of improvement in soil health, and great benefits of BNF [7, 8, 13], would lead to the adoption and enhancement in area under CA for improving crop production, agricultural sustainability and environmental quality.
6. Fractional replacement of rice crop by soybean under irrigated environment helps in increasing edible oil production that will subsequently meet substantial portion of the oilseed need of the region and minimize the fast depletion of groundwater resources.

Application of research

1. The results illustrated that application of 10 t FYM ha^{-1} and incorporation of CR in conjunction with earlier recommended rate of 20 kg N and 60 kg P_2O_5 ha^{-1} could be a better choice to obtain greater soybean grain yield both under CT and CA as it minimized the climate-induced fluctuations in yields from year to year, and enhanced the uptake of both N and P.
2. Optimized and balanced supply of nutrients through the integrated use of N and P fertilizer, FYM and incorporation of CR played a significant role in harnessing crop yield potentials on sustained basis. The present study has further demonstrated significantly enhanced protein content in both soybean and rapeseed with integrated nutrient management. These findings would encourage the increase in area and production of these crops in this region in order to reduce the import of edible oil from other countries and improve the edible oil economy of the country.
3. While the cultivation of soybean under CA system showed several benefits over CT, relatively lower seed yields of rapeseed obtained in CA system suggested the need for the future development of farm implements for different soil types and crops is required for better seed and fertilizer placement simultaneously retaining CR on the soil surface to ensure maximum crop production.

Research Category: Conservation agriculture

Abbreviations: CA: Conservation Agriculture, CT: Conventional Tillage, FYM: Farmyard Manure, CR: Crop Residue, BNF: Biological Nitrogen Fixation, LSD: Least Significant Difference, SOC: Soil Organic Carbon

Acknowledgement / Funding: Authors are thankful to FAO/IAEA Coordinated Research Project D15009 on "Integrated soil, water and nutrient management for conservation agriculture", through Research Contract No. IND/12980 (http://www-naweb.iaea.org/nafa/swmn/applied-research.html) for financial support. Authors are also thankful to Punjab Agricultural University, Ludhiana, India for providing the field and laboratory facilities.

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Research project name or number: FAO/IAEA Coordinated Research Project D15009 on "Integrated soil, water and nutrient management for conservation agriculture", through Research Contract No. IND/12980

Author Contributions: First author (corresponding author) has collected the soil and plant samples from the experimental plots and performed their laboratory analyses. First and third author compiled the results of laboratory analyses and prepared the manuscript after doing all the requisite statistical analyses. Second author received the grant from funding agency *i.e.* FAO/IAEA and established the experiment and guided the other authors in organizing the manuscript in current shape.

Author statement: All authors read, reviewed, agree and approved the final manuscript

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

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