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Long-term Experiment on Fennel-cluster Bean Cropping System as Affected by Production Systems: A Strategy for Improving Yield, Quality and Soil Fertility

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ABSTRACT

Background: The rise in unprecedented pressure of producing enough food for an ever-growing human population resulted in the use of considerable amounts of agrochemicals in crop production. To overcome this, inclusion of annual pulse crops such as cluster beans (*Cyamopsis tetragonoloba* L.) in cropping systems is an alternative technique for enhancing output while minimising environmental impact. Therefore, to assess the influence of different crop production systems on yield, quality and soil fertility attributes of fennel (*Foeniculum vulgare* L.)-cluster bean (*Cyamopsis tetragonoloba* L.) crop sequence, a long term field experiment was conducted.

Methods: A field experiment was conducted on fennel (*Foeniculum vulgare* L.) cluster bean (*Cyamopsis tetragonoloba* L.) crop sequence under AI-NPOF Project during 2016-17 to 2020-21 at ICAR-National Research Centre on Seed Spices, Ajmer (Rajasthan), India. The experiment was laid out as a factorial design based on randomized complete blocks (RCBD) with three replications. The first factor consisted of six production systems *viz*., (PS_1) - 100% organic, (PS_2) - 75% organic + 25% innovative practice (Compost extract, cattle urine), (PS_3) - Integrated (50% organic + 50% inorganic), (PS_4) - Integrated (75% organic + 25% inorganic), (PS_5) -100% inorganic nutrient sources and (PS_6) - State recommendation] including fennel (*Rabi* season) - cluster bean (*Kharif* season) cropping sequence, whereas the second factor included the environment over the period.

Result: The outcomes of study revealed that production system (PS_4) - Integrated (75% organic + 25% inorganic) resulted in the maximum seed yields and yield attributes of cluster bean (1501.87 kg ha^{-1}) and fennel (1970.19 kg ha^{-1}). The study shows that the production system (PS_4) had a 17.29 and 30.75% increment of protein as compared to PS_5 and PS_1 in fennel and cluster beans, respectively. Under production system PS_1, the per cent increment of soil organic carbon (~25.2%) and readily available N (~9%), P (~38.5%) and K (~Non-significant) were noted over the years respectively, compared with production system (PS_5). A significant positive association was observed between fennel and cluster bean grain yield and soil organic carbon ($P<0.01$) and the Shannon-Wiener indexes (R^2 = 0.75, R^2 = 0.69), respectively. The combined assessment of yield, quality, soil organic carbon and soil sustainability shows that rotations based on legume crops performed better and provided a model of sustainable crop intensification. Thus, adding legume to the cropping system and implementing integrated nutrient management (INM) could gradually improve soil quality in agro-ecologies where fennel predominates.

Key words: Cluster bean, Fennel, Production system, Soil organic carbon, Sustainable, Yield.

INTRODUCTION

The rise in unprecedented pressure of producing enough food for an ever-growing human population resulted in the use of considerable amounts of agrochemicals in crop production. (FAO, 2017). Although this approach can augment farm output and reduce yield gaps, yet has potential adverse impacts on the soil, water and air. Using annual pulse crops such as cluster beans (*Cyamopsis tetragonoloba* L.) in cropping systems is an alternative technique for enhancing output while minimising environmental impact. Cluster bean, is primarily grown in dry and semi-arid parts of India, Pakistan and the United States. Legume crops provide several distinctive and key ecosystem services, such as resource utilisation (Kumar *et al*., 2023), improved soil health and increased nitrogen use efficiency (Jangir *et al*., 2017b), reduce carbon footprint and positive effects on soil properties (Liu *et al*., 2020), water conservation (Ding *et al*., 2018), reduced N_2O emission, enhanced biodiversity (Guiguitant *et al*., 2020) and production sustainability (Sahruzaini *et al*.,

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(Sahruzaini *et al*., 2020). Based on studies conducted worldwide, crops cultivated after pulse crops yielded more than crops grown after non-pulse crops (Mann *et al*., 2020). Legume crops add large amount of organic residues through leaf fall and rhizodeposition and the intermediate acids produced during organic residue decomposition also solubilise fixed forms of nitrogen and phosphorus in soil resulting in increased available nitrogen and phosphorus (Lal *et al*., 2022). As a result, adding pulse crops to cropping systems may boost system stability and on-farm profitability (Nath *et al*., 2023). In India, fennel (*Foeniculum vulgare* Mill.) is commonly grown as an annual and spice crop which is mainly cultivated in the states of Gujarat and Rajasthan (almost 80% production of India). The main components of fennel seeds essential oil are (E)-anethole (increases prolactin hormone), methyl chavicol (anti-spasmodic properties), fenchone (treats gastrointestinal diseases) and limonene (anthelmintic effect), which make it feasible in the pharmaceutical, food and cosmetic industries (Abdellaoui *et al*., 2020). The demand for seed plants having medicinal and nutraceutical properties has been increased across the globe and consumers become now more aware about natural products and their health benefits. However, given the potential negative effects of excessive use of herbicides and chemical fertilisers on the profile of active ingredients in medicinal and aromatic plants, the majority of food, pharmaceutical and cosmeceutical companies prefer materials derived from sustainable and organic systems (Rezaei-Chiyaneh *et al*., 2020). Based on the numerous research outcomes, it has been determined that integrated use of organic and inorganic agro-inputs and fertilisers has proven to be a right source of nutrients (Kumar and Dhar 2010; Gezahegn, 2021). With the addition of pulse to the fennel crop cycle, soil fertility has enhanced, particularly the quantity of accessible nitrogen and soil organic carbon. The increased fennel output after leguminous crops may be due to the residual effects of legumes on biological N fixing and the addition of root biomass by legumes to successive fennel crops (Rathore *et al*., 2011; Jangir *et al*., 2017a).

In view of above, the key objective of the present study was to diversify fennel cropping systems with pulse crops and to assess the impact of different production systems on the quality, yield, yield attributes of fennel-cluster bean *viz-a-viz* soil quality over the study period.

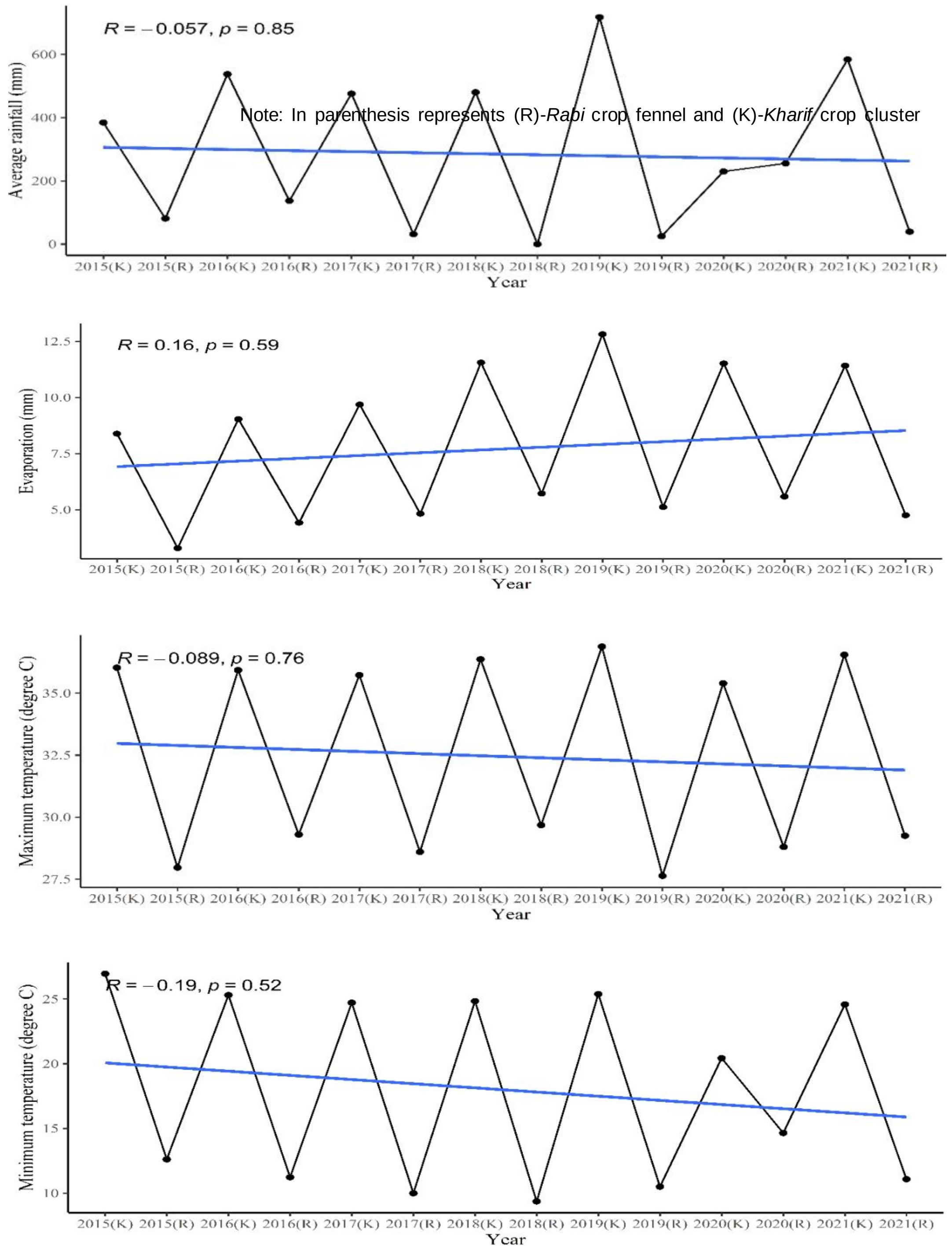
MATERIALS AND METHODS

The field experiment was conducted under AI-Network Programme on Organic Farming (AI-NPOF) Project during 2016-17 to 2020-21 at the ICAR-National Research Centre on Seed Spices, Ajmer (Rajasthan), which is located in the Northwest of India (26.3661°N, 74.5933°E). The experiment was conducted in sandy soil having loamy sand texture. A two-factor RBD experiment (three replicates) with fennel (*Rabi*) - cluster bean (*Kharif*) crop sequence grown under (1st factor) six production systems *viz*., (PS_1) 100% organic, (PS_2) 75% organic + 25% innovative practice (Compost extract, cattle urine), (PS_3) Integrated (50% organic + 50% in organic), (PS_4) Integrated (75% organic + 25% inorganic), (PS_5) 100% inorganic nutrient sources and (PS_6) State recommendation], the environment of five years in 2016-2020 was considered as (2nd factor). The size of the plot was (10×6 m^2) and spacing (Row to row, plant to plant) was kept 50×30 cm, 30×10 cm for fennel-cluster bean respectively. Observations on seed yield (kg ha^{-1}) and crop attributes such as days to initiation of seed germination, days to germination, plant height (cm) at different stages (45 and 90 DAS), number of primary and secondary branches $plant^{-1}$, number of umbel $plant^{-1}$, number of umbellate $umbel^{-1}$, days to flowering initiation, days to 50% flowering, biomass yield (kg ha^{-1}), harvest index and quality characteristics such as essential oil (%), seed nitrogen (%), seed phosphorus (%) and seed protein content (%) were recorded in *Rabi* fennel. Similarly, seed yields (kg ha^{-1}) and yield attributes such as plant height (cm), number of primary branches $plants^{-1}$, number of pods, number of seeds $pods^{-1}$ and biomass yield (kg ha^{-1}), seed index, seed nitrogen (%) and total protein content (%) were recorded in *Kharif* cluster bean. The environmental data for the year 2015-16 to 2020-21 have been recorded at meteorological unit of ICAR-NRCSS, Ajmer and their patterns over the period were analysed. The Kjeldahl method was used to calculate available nitrogen, which was then reported as percentage of protein content. The availability of P and K was assessed using the molybdate blue method and the flame photometry method, respectively, whereas the amount of soil organic matter was estimated using the dichromate-sulfuric acid (K_2CrO_7-H_2SO_4) oxidation method. The concentrations of soil-available N, P and K were measured using the methods explained by Olsen *et al.* (1954) and Page *et al.* (1982), respectively. Analysis of variance (ANOVA) was used to assess the study results compiled from 2016 to 2020 and Tukey's test at a significance level of <0.05 was used to determine the significance of differences. Calculations were performed using R statistical program, version 4.2.2. The findings were subjected to a 2-way analysis of variance in a randomised block design and data synthesis was performed using the mixed model. The effect of the environment on seed yield and quality characteristics of fennel-cluster bean was examined year after year. Furthermore, the coefficient of determination (R^2) was computed to evaluate dependencies and relationships between the selected parameters (Yield, yield components and soil parameters).

RESULTS AND DISCUSSION

Environmental data

Analysis pertaining to various attributes of environmental data revealed that throughout the experiment period, decreasing pattern of total average rainfall (R=-0.057; p=0.85) was recorded from the years 2015-16 to 2019-20 (Fig 1). During the growing season of 2018, the fennel growing (*Rabi*) season received the least average rainfall (0 mm) while, the maximum average rainfall (741 mm) occurred during the cluster bean growing (*Kharif*) season of 2019. The increasing pattern of evaporation (R=0.16; p=0.59) was recorded (non-significant) in the years 2015-16 to 2019-20. In all experimental years, a maximum temperature was recorded during the cluster bean growing season (*Kharif*) of 2019 and the *Rabi* season of fennel at 39.2°C and 27.5°C, respectively. While, the minimum temperature recorded in 2018 for *Rabi* fennel and 2015 for



Note: In parenthesis represents (R)-*Rabi* crop fennel and (K)-*Kharif* crop cluster bean.

Fig 1: Total precipitation, evaporation and temperature in the growing season of the fennel-cluster bean, recorded by the Meteorological Station at ICAR-NRCSS, Ajmer.

the *Kharif* season were 3.5 and 28.3°C, respectively. The decreasing pattern of maximum and minimum temperature (R=-0.089; p=0.76 and R=-0.19; p=0.52, respectively) was recorded in the years 2015-16 to 2019-20.

Yield and yield attributes

Over the period, long-term integrated fertilization has significantly increased fennel and cluster bean yield compared to the solely organic fertilization however, in the year 2017 and 2018 reduced yield was recorded due to variations in climate variables such as temperature and rainfall. Fennel yield increased over the years, especially under the PS_4 and PS_6 treatments while, cluster bean yield showed irregular patterns due to unfavourable climatic conditions, particularly in the *Kharif* season. On an average across the years from 2015-16 to 2019-20, compared to the PS_5, fennel seed yield increased by 2.53%, 4.32%, 11.97%, 19.62% and 19.72%, respectively and cluster bean yield increased by 3.48%, 4.75%, -1.00%, 19.09% and 14.43%, respectively, under the PS_1, PS_2, PS_3, PS_4 and PS_6 production system, respectively (Fig 2a). In the year or temporal factor, the fennel seed yield in 2016–2020 ranged between 1148 (2017) and 2207 (2019) kg ha^{-1}. In the production system factor, the highest fennel grain yield (1971 kg ha^{-1}) was observed in PS_6 completely at par with PS_4 (1970 kg ha^{-1}). However, the lowest seed yield (1646 kg ha^{-1}) was observed in PS_5 completely at par with PS_1 (1688 kg ha^{-1}). Similarly, the highest cluster bean yield (1501 kg ha^{-1}) was observed in PS_4 completely at par with PS_6 (1443 kg ha^{-1}) (Fig 2c). The study showed that PS_4 was the most suitable production system for seed yield in both crops. The highest annual biological yields of fennel (6817 kg ha^{-1}) and cluster beans (6799 kg ha^{-1}) were observed in the years 2019 and 2017 respectively (Fig 2b and 2d).

The yield-year interaction analysis data was previously tested for normality using the Shapiro-Wilk test (W=0.983; p-value=0.3012, R^2=0.995 and W=0.989; p-value=0.8383, R^2=0.998) for fennel and cluster bean, respectively. The two-way analysis of variance (ANOVA) detected that the differences between the evaluated seed yield of fennel and cluster bean were highly significant (p<0.001), which proved that the production system used in this study had great differences in seed yield (Fig 2). High significance (p<0.001) was also observed between the seed yield and year (Y).

The days to germination in fennel depended significantly on the production system used for the raising of the crop and the interaction between the year and the production system (Fig 3a). Significantly, the highest days to

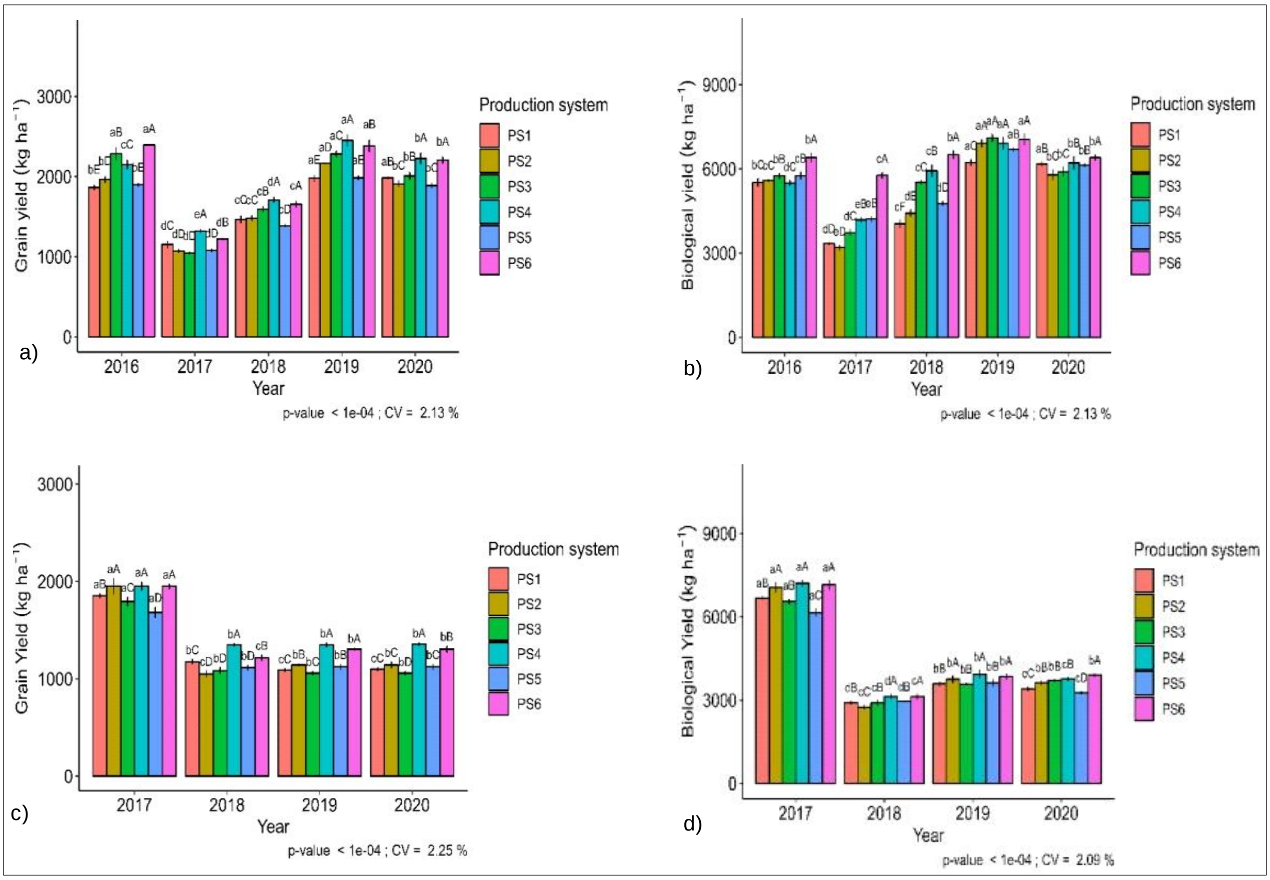


Fig 2: The interaction effect of year and production system on; (a) fennel seed yield, (b) fennel biological yield, (c) cluster bean yield, (d) cluster bean biological yield.

germination initiation were characteristic of the seed with significantly highest in the PS_4 production system (8 days) and the pattern was almost similar to days to complete germination (12 days) (Fig 3b) in the year 2016. While, plant height at different stages (45 DAS and 90 DAS) had observed lowest in the year 2016 and highest observed in the year 2020 in the production system PS_4 (43.24 cm and 118.56 cm, respectively) (Fig 3c, 3d).

In fennel, the number of primary and secondary branches (12 and 26, respectively) was highest in production system PS_4 which was at par with the production system PS_6 in the year 2018 and 2016, respectively (Fig 4a, 4b). The number of umbels per plant and umbellate per umbel was significantly higher observed in the production system PS_4 which was at par with the production system PS_6. The number of umbels per plant was highest observed in the year 2020 and was on par with the year 2018. The umbellate per umbel was highest observed in the year 2018 at par with the year 2016 (Fig 4c, 4d). The days to flower initiation and 50% flowering were longest in the year 2020 which was significantly superior to other years. It was observed that the maximum days to flowering were recorded in production system PS_4 which was completely at par with the PS_6 (Fig 4e, 4f).

In cluster bean, the plant height and number of primary branches were observed significantly highest in production system PS_4 which was at par with the PS_6. Meanwhile, the plant height and number of primary branches were observed in decreasing patterns over the year (Fig 5a and 5b). It was also observed that the lowest plant height and number of primary branches were studied in the production system PS_1. The number of pods had significantly superior in the year 2020 over to the remaining years. The production system PS_4 had significantly superior in the number of pods and seeds per pod of cluster bean. The seed per pod was significantly superior in the year 2018 over to the remaining year (Fig 5c and 5d). The seed index of cluster bean was highest observed in the production system PS_4 and PS_6 (Fig 5e).

Higher yield might be a result of increased availability of nutrients from organic manure and favourable impacts from production system PS_4 (75% organic + 25% inorganic), which supplies nitrogen and phosphorus to support plant yield and growth. In contrast to organic fertilizers, which release nutrients gradually through microbial mineralization

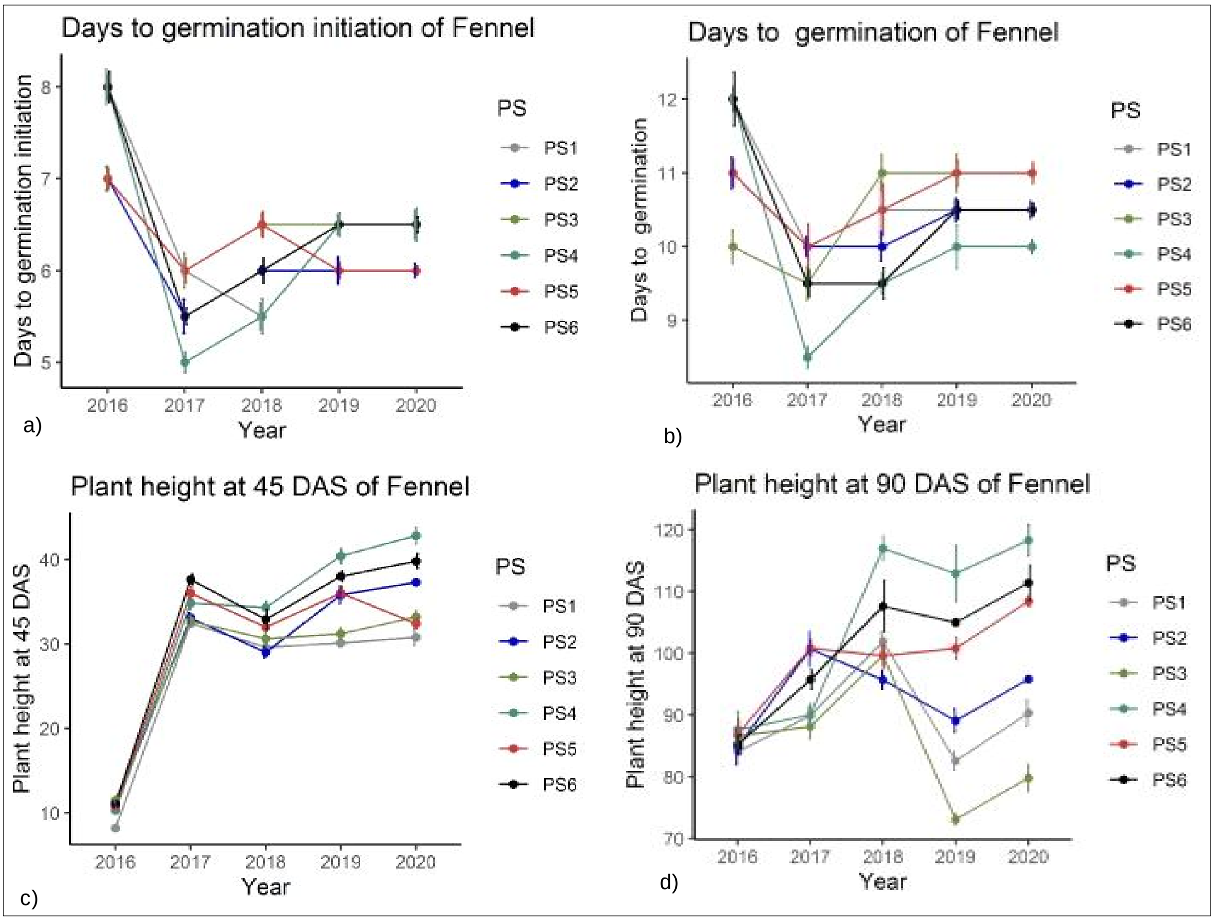


Fig 3: The interaction effects of year and production system on the yield attributes of fennel. (a) Days to germination initiation, (b) Day to germination, (c) Plant height at 45 days after sowing, (d) Plant height at 90 days after sowing.

to assure nutrient availability in the seed developmental stages of crops and even in the succeeding crops, inorganic fertilisers supply nutrients immediately after application. When compared to the combined application of organic and inorganic fertilizers, it was revealed that the single use of inorganic fertilisers was ineffective at increasing crop output. These findings are consistent with the findings of Mevada *et al*. (2017); Singh *et al*. (2018) who observed significant effects of mixed organic manure and chemical fertiliser application on yield production and growth parameter of fennel. The addition of legumes in crop sequence during the long term experiment favoured improved nutrient availability and uptake, resulting in greater source accumulation and efficient translocation of photosynthates into a sink and therefore, a higher seed production. Similarly, according to research by Kumar *et al*. (2022), the application of both organic manures and inorganic inputs had a substantial impact on the fennel crop's growth and yield characteristics metrics.

Seed quality attributes

In fennel, the highest seed nitrogen (2.92 and 5.08%, respectively) was observed in the production system PS_4 which was significantly superior to other production systems but at par with the PS_6 in the cluster bean (Table 1). The study shows that fennel following cluster bean in the PS_4

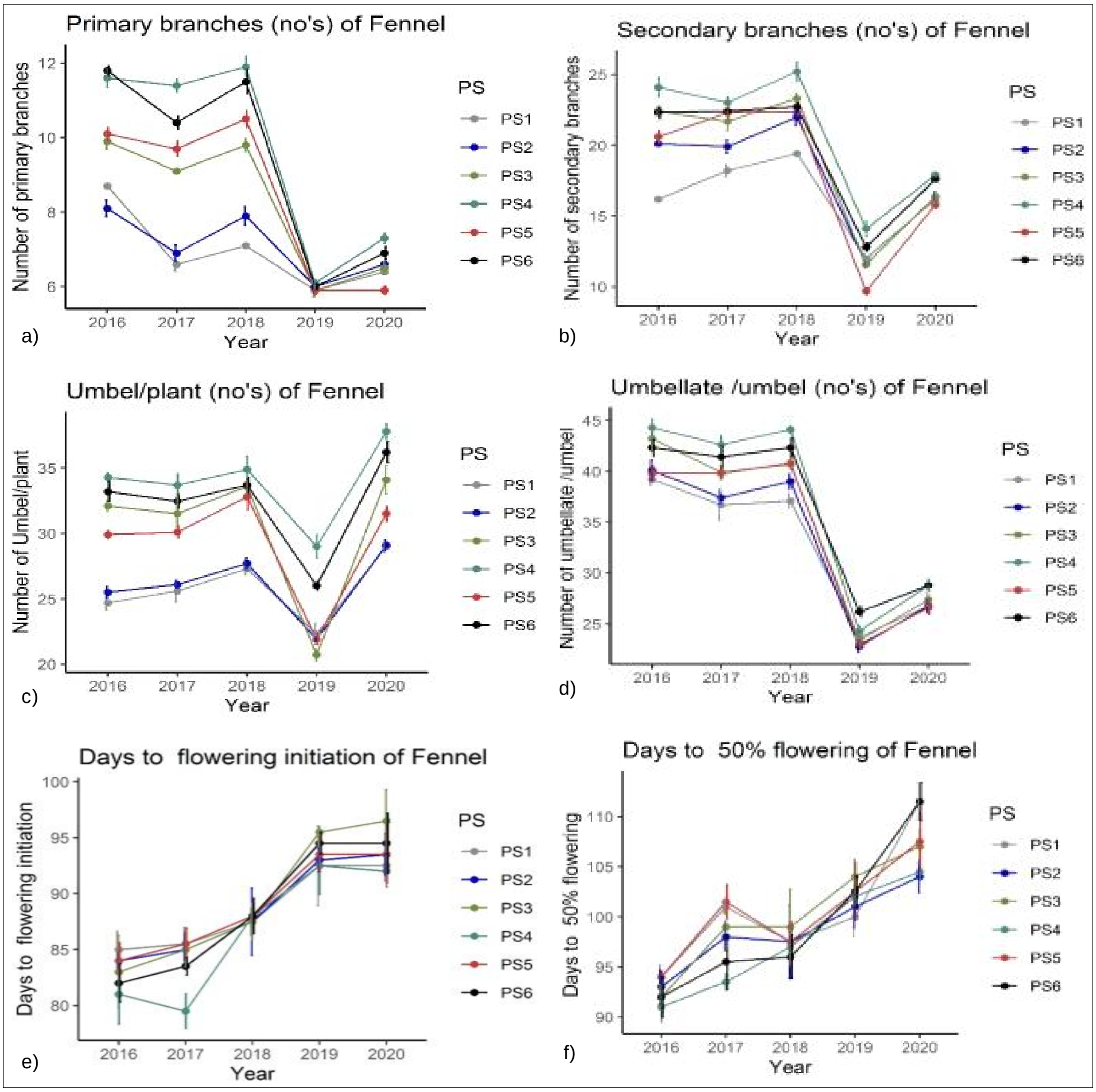
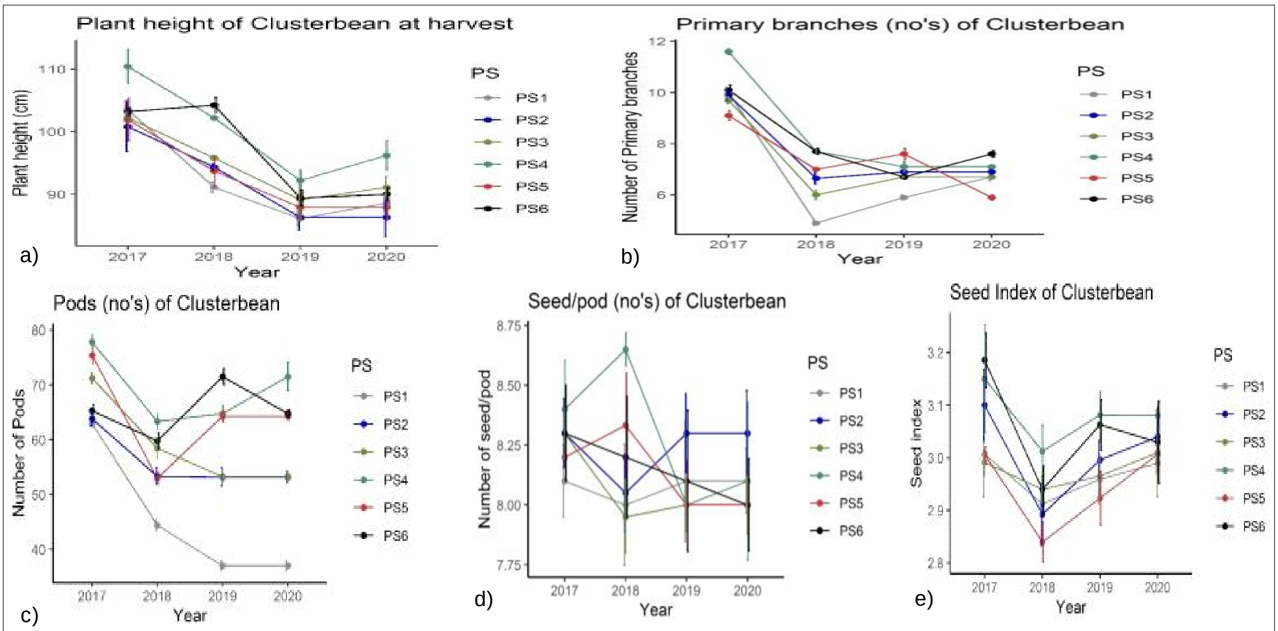


Fig 4: The interaction effects of year and production system on the yield attributes of fennel. (A) Primary branches, (B) Secondary branches, (C) Umbel/plant, (D) Umbellate/plant, (E) Day to flowering initiation, (F) Days to 50% flowering.

system had 17.29 and 30.75% increment of protein as compared to PS_5 and PS_1 in fennel and cluster bean, respectively. The protein content in fennel, as well as cluster bean, was highest observed in the year 2020 due to the inclusion of pulses in cropping systems which helps in improved plant uptake. On an average across the years, compared to the PS_2, fennel essential oil increased by 5.51%, 2.29%, 0.75%, 2.29% and 2.29%, under the PS_1, PS_3, PS_4, PS_5 and PS_6 production systems, respectively. While, the cluster bean seed index compared to the PS4 increased by 4.05%, 2.66%, 3.70%, 4.76% and 0.98%, respectively, under the PS_1, PS_2, PS_3, PS_5 and PS_6 production systems. Therefore, diversified cropping systems that include pulses in the rotation can more consistently produce high seed and protein yields than a continuous fennel monoculture system and fallow systems in semiarid prairies, regardless of growing conditions.

Soil properties

Soils under (PS_1) 100% organic and (PS_2) 75% organic + 25% innovative practice (compost extract, cattle urine) plots contained higher soil nitrogen at the depth of 0-20 cm, over the (PS_5) 100% inorganic nutrient sources in the year 2020 (Fig 6a). The mean estimate of N by the system was ~9% higher in the plots under (PS_1)-100% organic than that under (PS_5) - 100% inorganic nutrient sources. Soils under (PS_1)



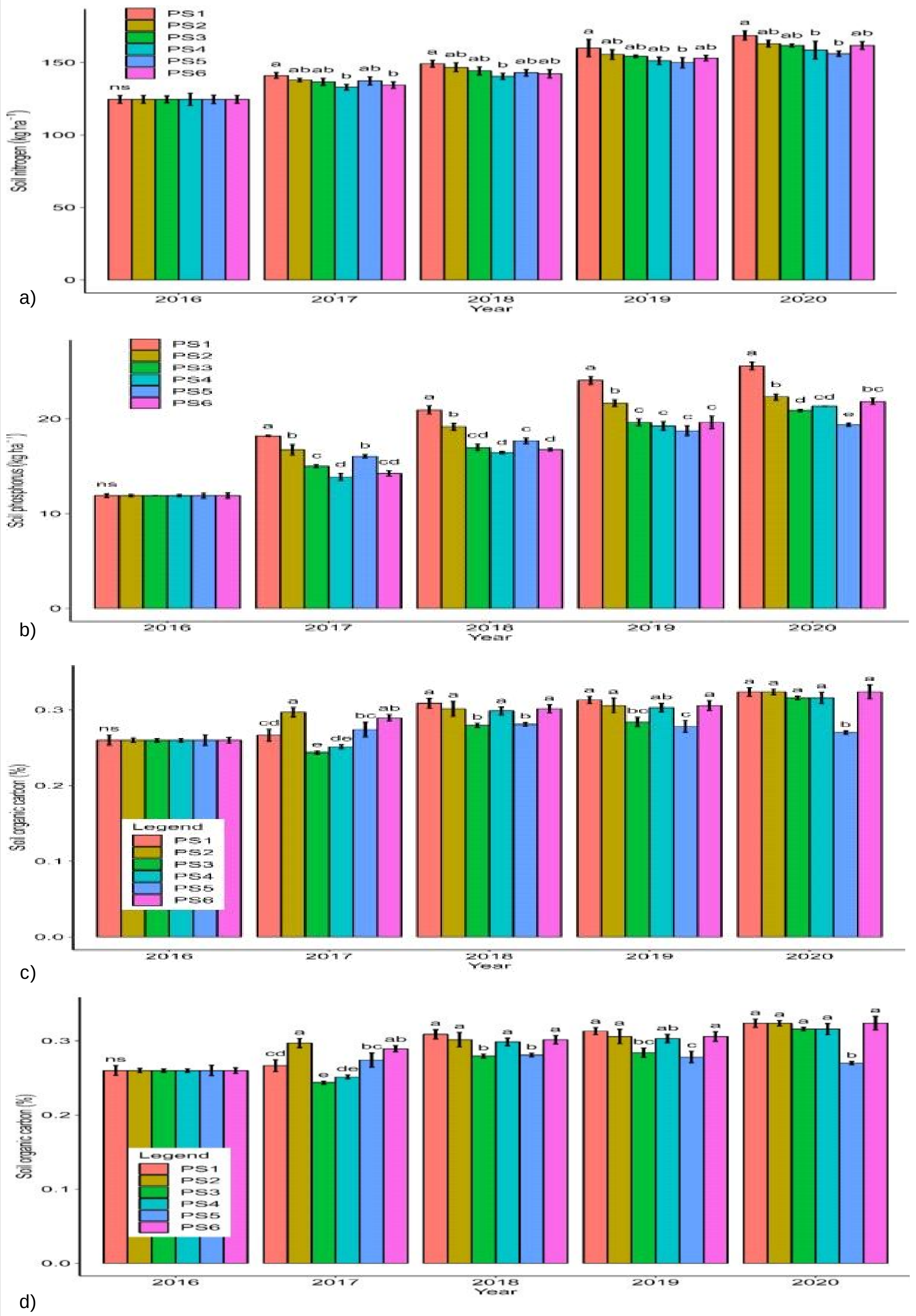
(A) Plant height at harvest, (B) Primary branches, (C) Number of pods, (D) Seed/pod, (E) Seed index.

Fig 5: The interaction effects of year and production system on the yield attributes of cluster bean.

Table 1: The effect of year and production system on seed nitrogen, protein, fennel essential oil and cluster bean seed index of the fennel-cluster bean cropping system.

Production	Seed nitrogen (%)		Protein (%)		Fennel essential	Cluster bean
system	Fennel	Cluster bean	Fennel	Cluster bean	oil (%)	seed index
PS_1	2.75c	4.13e	17.21c	25.86e	1.27d	2.96bc
PS_2	2.84b	4.70c	17.79b	29.37c	1.34a	3.00b
PS_3	2.74c	4.89b	17.18c	30.60b	1.31c	2.97bc
PS_4	2.92a	5.08a	18.29a	31.75a	1.33ab	3.08a
PS_5	2.65d	4.61d	16.56d	28.81d	1.31c	2.94c
PS_6	2.86b	5.05a	17.91b	31.58a	1.31bc	3.05a
Year						
2016	2.76c	-	17.30c	-	1.27c	-
2017	2.77c	4.67c	17.37c	29.23c	1.15d	3.07a
2018	2.79bc	4.70bc	17.44bc	29.42bc	1.28c	2.92c
2019	2.81ab	4.76b	17.61ab	29.76b	1.37b	2.99b
2020	2.83a	4.83a	17.72a	30.23a	1.48a	3.02b

100% organic plots contained higher soil phosphorus at the depth of 0-20 cm, over the remaining production system all year (Fig 6b). The mean estimate of P by the system was ~38.8% higher in the plots under (PS_1) - 100% organic than that under (PS_5)-100% inorganic nutrient sources. Over the years 2016 to 2020 it was observed that soil phosphorus had a significant increment with the application of different production systems. Soils under (PS_4) Integrated (75% organic + 25% inorganic) plots contained higher soil potassium in the 0-20 cm soil layer, which was at par with

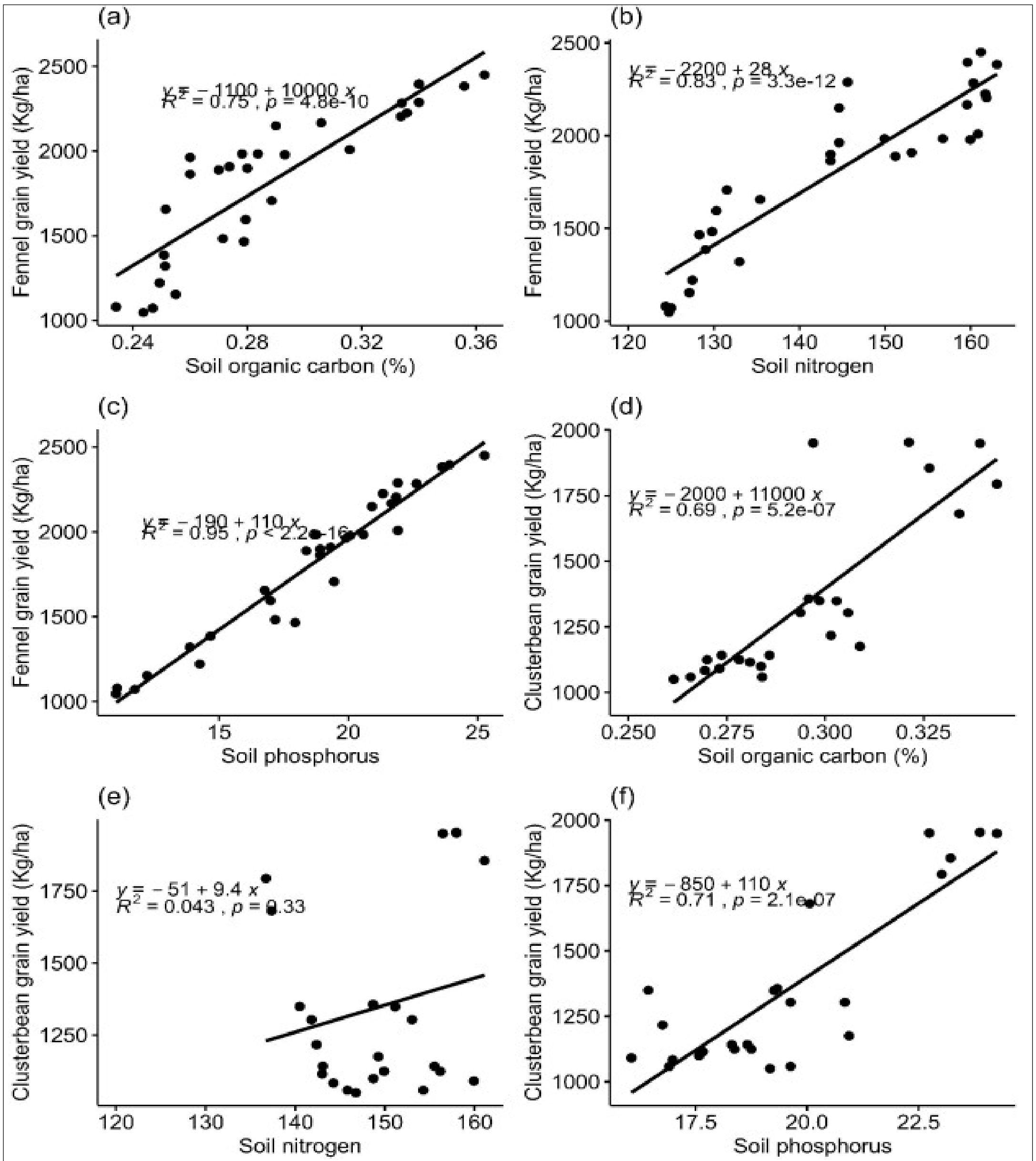


(A) Soil nitrogen, (B) Soil phosphorus, (C) Soil potassium, (D) Soil organic carbon.

Fig 6: The effects of year and production system on the soil properties over time.

(PS_2) - 75% organic + 25% innovative practice (Compost extract, cattle urine) in all years (Fig 6c). The potassium concentration in the soil had not much variation in the production system. Over the years 2016 to 2020 it was observed that soil potassium had a non-significant increment with the application of different production systems.

The soil organic carbon (SOC) ranged from 0.27% to 0.34% for different production systems at the beginning of the experiment in 2016-2020 (Fig 6d). All the field plots were low in soil fertility as the organic carbon was less than 0.27%. All production systems had significant differences in SOC in year 2020. The SOC increased with the continuous application of organic and inorganic fertilizers for 5 years among all production systems. The soil fertility in 100% organic (PS_1) was the highest significant increment in SOC ranging between 0.27% and 0.34% at par with all other production systems except the PS_5 production system in the year 2020. The SOC in production system PS_1 was completely at par with PS_2 (75% organic + 25% innovative practice (Compost extract, cattle urine) all year. The lowest SOC was observed in the production system PS_5 (100% inorganic nutrient sources) in all years of the experiment.



(a) Fennel grain yield and soil organic carbon; (b) Fennel grain yield and soil nitrogen; (c) Fennel grain yield and soil phosphorus; (d) Cluster bean grain yield and soil organic carbon; (e) Cluster bean grain yield and soil nitrogen; (f) Cluster bean grain yield and soil phosphorus.

Fig 7: Simple linear regression analysis of yield and soil parameters.

The quantitative relations between yield and soil parameters

The data included 30 yield data (fennel and cluster bean each) and 30 soil data of three soil variables (soil organic carbon, soil nitrogen and soil phosphorus each). A significant positive relationship was observed between fennel grain yield and soil organic carbon, soil nitrogen and soil phosphorus (Fig 7a-7c) and also the Shannon-Wiener indexes (R^2 = 0.75, P<0.01, R^2 = 0.83, P<0.01 and R^2 = 0.95, P<0.01). Similarly, in cluster bean, a significant positive relationship between cluster bean grain yield and soil organic carbon and soil phosphorus (Fig 7d and 7f) and also the Shannon-Wiener indexes (R^2 = 0.69, P<0.01 and R^2 = 0.71, P<0.01). However, the relationships between cluster bean grain yield and soil nitrogen were found not significant for the evenness index (R^2 =0.04, NS) (Fig 7e).

Under production system PS_1, the per cent increment of readily available N (~9%), P (~38.5%) and K (~non-significant) were noted over the years respectively, compared with PS_5. Long-term use of organic manures could effectively stop applied nitrogen from leaching and raise the N and SOC content of the ploughed layer (Meng *et al*., 2005). After 5 years, the rise in SOC was greatest (~25.2% increment) in production system PS_1 (100% organic) and lowest for production system PS_5 (100% inorganic nutrient sources). In a similar study, rice-wheat cropping systems based on pulse systems outperformed in terms of available nitrogen (8-29%), phosphorus (3-35%), potassium (6-15%) and sulphur (3-13%) at the surface soil (Nath *et al*., 2023). The pulse-based cropping system and organic manures both work wonders for improving the soil's physical, chemical and biological qualities as well as its fertility gradient. These findings are consistent with the findings of (Brar *et al*., 2015), who studied continuous pulse farming systems, as well as combined effects of organic and inorganic fertilizers, boosted soil carbon sequestration and crop yields. Higher carbon input through organic supplements (farmyard manure and above-ground biomass) and biological nitrogen fixation resulted in increased SOC and accessible N under organic manure and pulse-based systems, respectively (Rob *et al*., 2022). The study resulted that the inclusion of pulse crops in the cropping pattern, the addition of organic amendments and a reduction in chemical fertiliser could gradually restore soil fertility and soil health according to higher SOC in the fennel-cluster bean (PS_1) than the fennel-cluster bean (PS_5).

CONCLUSION

From the study it could be inferred that seed yields and their attributes of the fennel and cluster bean were observed to augment over time with the production system PS_4 (75% organic + 25% inorganic). Even after many years of experimentation, the field trial's soil carbon concentrations are not in a steady-state condition due to the changing environmental conditions. The production system (PS_1-100% organic) receiving manure had both the greatest overall SOC contents and the steepest growth throughout the experimental period. SOC, available N and P contents grew by 25.2%, 9% and 38.5% over the examined 5-year period.

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Conflict of interest: None.

REFERENCES

Abdellaoui, M., Bouhlali, E.D.T., Derouich, M., El-Rhaffari, L. (2020). Essential oil and chemical composition of wild and cultivated fennel (*Foeniculum vulgare* Mill.): A comparative study. South African Journal of Botany. 135: 93-100.

Brar, B.S., Singh, J., Singh, G., Kaur, G. (2015). Effects of long term application of inorganic and organic fertilizers on soil organic carbon and physical properties in maize-wheat rotation. Agronomy. 5(2): 220-238.

Ding, D., Zhao, Y., Guo, H., Li, X, Schoenau, J., Si, B. (2018). Water footprint for pulse, cereal and oilseed crops in Saskatchewan, Canada. Water. 10(11): 1609. https://doi.org/10.3390/w10111609.

Food and Agriculture Organization of the United Nations (Ed.) (2017). The future of food and agriculture: Trends and challenges. Food and Agriculture Organization of the United Nations 2017.

Gezahegn, A.M. (2021). Role of integrated nutrient management for sustainable maize production. International Journal of Agronomy. pp 1-7.

Guiguitant, J., Vile, D., Ghanem, M.E., Wery, J., Marrou, H. (2020). Evaluation of pulse crops' functional diversity supporting food production. Scientific Reports. 10(1): 3416. https://doi.org/10.1038/s41598-020-60166-4.

Jangir, C.K., Kumar, S., Lakhran, H., Meena, R.S. (2017b). Towards mitigating malnutrition in pulses through biofortification. Trends Biosciences. 10: 2999-3002.

Jangir, C.K., Panghaal, D., Kumar, S., Meena, R.S., Prince. (2017a). Enriching soil carbon stock through mitigating soil erosion, in agricultural. Allied Sciences and Biotechnology for Sustainability of Agriculture, Nutrition and Food Security (Jaipur: Mahima Publications). pp. 415-419.

Kumar, A., Dhar, S. (2010). Evaluation of organic and inorganic sources of nutrients in maize (*Zea mays*) and their residual effect on wheat (*Triticum aestivum*) under different fertility levels. Indian Journal of Agricultural Sciences. 80(5): 364-371.

Kumar, S., Gopinath, K.A., Sheoran, S., Meena, R.S., Srinivasarao, C.H., Bedwal, S., Jangir, C.K., Mrunalini, K., Jat, R., Praharaj, C.S. (2023). Pulse-based cropping systems for soil health restoration, resources conservation and nutritional and environmental security in rainfed agroecosystems. Front Microbiology. 13: 1041124. https://doi.org/10.3389/fmicb.2022.1041124.

Kumar, V., Singh, P., Malik, T. P., Kumar, V., Richa, R., Sharma, N., Kumar, A. (2022). Effect of Integrated nutrient management on growth and yield of fennel (*Foeniculum vulgare*). Indian Journal of Agriculture Sciences. 92(1): 131-135.

Lal, G., Lal, S., Chaudhary, N., Choudhary, M.K., Meena, S.S. and Kumar, N. (2022). Performance of green gram varieties under organic production system. Legume Research. 1-6. DOI: 10.18805/LR-4970.

Liu, K., Bandara, M., Hamel, C., Knight, J.D., Gan, Y. (2020). Intensifying crop rotations with pulse crops enhance system productivity and soil organic carbon in semi-arid environments. Field Crops Research. 248: 107657. DOI: 10.1016/j.fcr.2019.107657.

Mann, A., Kumar, A., Kumar, S.S., Sharma, P.C. (2020). Sustainable production of pulses under saline lands in india. In Legume Crops [Working Title]. Intech Open. pp. 1-18.

Meng, L., Ding, W., Cai, Z. (2005). Long-term application of organic manure and nitrogen fertilizer on N_2O emissions, soil quality and crop production in a sandy loam soil. Soil Biology and Biochemistry. 37(11): 2037-2045.

Mevada, K.D., Gamar, P., Ombase, K.C., Bhadane, R.S., Patel, P.D. (2017). Influence of integrated nutrient management on yield, quality and nutrient status of drilled *rabi* fennel (*Foeniculum vulgare* Mill.). Journal of Pure and Applied Microbiology. 11(3): 1559-1565.

Nath, C.P., Kumar, N., Dutta, A., Hazra, K.K., Praharaj, C.S., Singh, S.S., Das, K. (2023). Pulse crop and organic amendments in cropping system improve soil quality in rice ecology: Evidence from a long-term experiment of 16 years. Geoderma. 430: 116334. https://doi.org/10.1016/j.geoderma.2023.116334.

Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, A. (1954). Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate, (USDA Circ. 939). Government Printing Office, Washington, US. 1954. pp. 939.

Pages, A.L., Miller, R.H., Dennis, R.K. (1982). Methods of Soil Analysis. Part 2 Chemical Methods. Madison: Soil Science Society of America Inc. 1982.

Rathore, V.S., Singh, J.P., Soni, M.L., Beniwal, R.K. (2011). Effect of nutrient management on growth, productivity and nutrient uptake of rainfed clusterbean (*Cyamopsis tetragonoloba*) in arid region. Indian Journal of Agricultural Sciences. 77(6): 3411. https://epubs.icar.org.in/index.php/IJAgS/article/view/3411.

Rezaei-Chiyaneh, E., Amirnia, R., Amani Machiani, M., Javanmard, A., Maggi, F., Morshedloo, M. R. (2020). Intercropping fennel (*Foeniculum vulgare* L.) with common bean (*Phaseolus vulgaris* L.) as affected by PGPR inoculation: A strategy for improving yield, essential oil and fatty acid composition. Scientia Horticulturae. 261: 108951. https://doi.org/10.1016/j.scienta.2019.108951.

Rob, C.L., Baumecker, M., Ellmer, F. and Kautz, T. (2022). Organic manure increases carbon sequestration far beyond the “4 per 1000 initiative” goal on a sandy soil in the thyrow long-term field experiment div. 2. Agriculture. 12(2): 170. https://doi.org/10.3390/agriculture12020170.

Sahruzaini, N.A., Rejab, N.A., Harikrishna, J.A., Ikram, N.K.K., Ismail, I., Kugan, H.M., Cheng, A. (2020). Pulse crop genetics for a sustainable future: Where we are now and where we should be heading. Frontiers in Plant Science. 11: 531. https://doi.org/10.3389/fpls.2020.00531.

Singh, Y.V., Singh, S.K., Srivastava, D.K., Singh, P., Jatav, H.S. (2018). Soil test crop response based integrated plant nutrient management system for fennel (*Foeniculum vulgare* mill.) in an inceptisol. Journal of the Indian Society of Soil Science. 66(4): 420-424.