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Productivity and profitability of sesame (*Sesamum indicum*)-chickpea (*Cicer arietinum*) organic cropping system as influenced by nutrition and planting geometry

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ABSTRACT

An experiment was conducted during 2021–22 and 2022–23 at the research farm of Punjab Agricultural University, Ludhiana, Punjab to optimize organic nutrition and planting geometry for improved productivity and profitability of sesame (*Sesamum indicum* L.)-chickpea (*Cicer arietinum* L.) organic cropping system. The experiment was conducted in a split-plot design (SPD) with three organic nutrition management practices in main plots, viz. Application of farmyard manure (FYM) to supply recommended doses of nitrogen (RDN) i.e. 52.5 kg/ha for sesame and 15 kg/ha for chickpea; Application of FYM to supply RDN + natural farming concoctions (NFCs) i.e. *beejamrit*, *ghanjeevamrit* and *jeevamrit*; and Control i.e. without application of FYM and NFCs. In sub-plots, four planting geometries were evaluated for sesame (30 cm × 15 cm, 45 cm × 10 cm, 60 cm × 10 cm, and paired rows) and chickpea (30 cm × 10 cm, 45 cm × 7 cm, 60 cm × 7 cm, and bed planting). Application of FYM significantly improved growth, yield attributes and seed yield of sesame and chickpea compared to the control, whereas the addition of NFCs along with FYM did not further enhance these parameters significantly during both the years. Paired row sowing followed by (*fb*) bed formation led to notably higher seed yield in sesame, while chickpea sown at 30 cm × 10 cm spacing achieved the highest seed yield, statistically equivalent to sowing at 45 cm × 7 cm and bed planting. The most productive system, recorded a sesame equivalent yield of 18.1 q/ha, net returns of ₹1,06,224/ha, and a benefit cost (B:C) ratio of 1.51, achieved through paired row sowing of sesame and bed planting of chickpea. Conclusively, the optimized organic nutrition and planting geometry significantly enhanced the productivity and profitability of the sesame-chickpea cropping system, with paired row sowing and bed planting emerging as the most effective strategies.

Keywords: Farmyard manure, Natural farming concoctions, Organic inputs, Spacing

Organic agriculture is a sustainable farming model recognized globally. India leads in the number of organic producers and ranks 2nd in organic farming area. In Punjab, organic farming gains attention due to the adverse effects of intensive agriculture and the growing demand for organic produce (Aulakh and Gill 2013). Increased purchasing power and health concerns boost demand for organic oilseeds and pulses. The sesame (*Sesamum indicum* L.)-chickpea (*Cicer arietinum* L.) cropping system is prevalent in states like Andhra Pradesh, Bihar, and Punjab, often managed by small farmers due to its low input needs and pest manageability, making it compatible with organic farming (Ranganatha *et al.* 2013). Before the green revolution, it was a traditional system in Punjab (Kalkat 2018, Anonymous 2023). Organic farming should target niche areas and crops with minimal yield penalties and high product prices.

Enhancing productivity and profitability involves fulfilling crop nutritional requirements through organic sources and optimizing agronomic practices. Organic systems rely on organic matter management for soil fertility. In India, natural farming practices improve soil biological properties and nutrient availability. Integrating natural farming concoctions (NFCs) with conventional organic inputs needs evaluation for better crop productivity, profitability, and soil health. The Centre for Science and Environment (CSE) highlighted the benefits of organic and natural farming from 2004–2020 (Khurana *et al*. 2022). Ravisankar (2023) also documented the agro-ecological benefits of these practices. About 2.7% of India's farming area uses organic or natural methods (Sharma *et al.* 2023).

Optimal planting density and geometry are crucial for maximizing production by improving aeration and light penetration for photosynthesis. Widening crop rows minimizes labour for weeding but requires assessing yield penalties and weed management costs (Gallandt *et al.* 2018). Bed planting, a resource-conserving technique, offers mechanical weed control and optimal organic input placement (Bhargav *et al.* 2018). This study aims to evaluate natural and organic farming inputs to identify the best

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nutrient management practices and planting geometry for maximizing yield and profitability in the sesame-chickpea organic cropping system.

MATERIALS AND METHODS

The study was carried out during 2021–22 and 2022–23 at research farm of Punjab Agricultural University, Ludhiana (30°54′ N latitude and 75°52′ E longitude; altitude of 247 meters amsl) Punjab. The soil was loamy sand with a *p*H of 7.6, EC of 0.43 dS/m and soil organic carbon 0.56%. The soil was low in available N (184 kg/ha), medium in available P (19.6 kg/ha) and medium in available K (145 kg/ha).

The experiment was conducted in split plot design (SPD) comprised three organic nutrition treatments in the main plots, viz. Application of farmyard manure (FYM) to provide the recommended dose of nitrogen (RDN) at 52.5 kg/ha for sesame and 15 kg/ha for chickpea; Application of FYM to supply RDN along with natural farming concoctions (NFCs) consisting of seed treatment with *beejamrit*, application of *ghanjeevamrit* at 1000 kg/ha before sowing and *jeevamrit* at 500 litres/ha thrice in sesame and four times in chickpea, along with irrigation or adequate rainfall events; and Control-without FYM and NFC application. The total quantities of (NFCs) used were: *Beejamrit*-500 ml for sesame and 8 litres for chickpea, *Jeevamrit*-1500 litres/ha for sesame and 2000 litres/ha for chickpea, and *Ghanjeevamrit*-1000 kg/ha for both crops. The sub-plots were assigned to four different planting geometries-for sesame: 30 cm × 15 cm, 45 cm × 10 cm, 60 cm × 10 cm and paired row sowing (47.5:20 × 15 cm) followed by *(fb)* bed formation; and for chickpea, the planting geometries were: 30 cm × 10 cm, 45 cm × 7 cm, 60 cm × 7 cm, and bed planting (37.5 cm bed top and 30 cm furrow, two rows/bed at 20 cm × 10 cm).

Well decomposed FYM with a *p*H of 7.4, EC of 0.35 dS/m, available N (0.59%), available P (1.12%) and available K (0.61%) was applied as per the treatments before the pre-sowing irrigation to crops. Quantity of FYM was calculated based on the N content on dry weight basis to supply recommended dose of nitrogen (RDN). *Beejamrit* was made by fermenting 5 kg of fresh cow dung in 20 litres of water with 50 g lime, 5 litre cow urine, 1 kg virgin soil, and 1 litre lime water, sufficient to treat 100 kg of seeds. *Ghanjeevamrit* was prepared by mixing 100 kg cow dung, 10 litre cow urine, 1 kg jaggery, 1 kg gram flour, and 1 kg virgin soil, and fermenting for 48 h. *Jeevamrit* was made from 10 kg fresh cow dung, 10 litre cow urine, 2 kg jaggery, 2 kg gram flour, and 1 kg virgin soil in 200 litres of water, fermented for 3 days under shade (Das *et al.* 2024).

Sesame variety Punjab Til No. 2 was sown on July 16, 2021, and July 11, 2022. The succeeding chickpea variety PBG 8 was sown on November 13, 2021, and November 10, 2022. Crops were sown in definite row spacing as per the treatment whereas the desired plant to plant spacing was maintained by thinning after the complete emergence of crops [15 DAS (days after sowing) for sesame and 22 DAS for chickpea]. Sesame was sown in paired rows having 20 cm spacing in-between and 47.5 cm spacing between two paired-rows. At 20 DAS, partial beds were made by running hand-held ridger between the paired rows which opened the soil and formed furrows and partial beds. This manual operation was repeated at 35 DAS to complete earthing up and formation of ideal beds having 37.5 cm of bed top and 30 cm wide furrows. These two operations in sesame simulated two runs of tractor operated wheat bed planter (without seeding attachment) used in larger fields to create raised beds and furrows for better drainage and mechanical weeding concurrently.

Weed management also differed in different planting geometries to keep the entire plots weed free but followed the same schedule: 20 and 35 DAS for sesame, and 30 and 60 DAS for chickpea. For 30 cm rows, manual weeding with *khurpa* was used. In 45 cm rows, mechanical weeding with a brush cutter and manual intra-row weeding were done initially. For 60 cm rows, a power weeder was used with manual intra-row weeding initially. In paired row/bed planting, weeding with a hand-held ridger was done between rows in sesame and furrows in chickpea simulating mechanical weeding using tractor-operated wheat bed planter, with manual weeding on bed tops initially. System productivity of the sesame-chickpea organic cropping system was calculated in terms of sesame equivalent yields.

Irrigation depth was 55 mm for bed planting and 75 mm for flat sowing for both crops, resulting in total water usage of 397.5 mm for bed planting and 487.5 mm for flat sowing, regardless of spacing variations, in the sesame-chickpea cropping system. The weather data were obtained from Meteorological Observatory, Punjab Agricultural University, Ludhiana, Punjab located at experimental site. During 2021–22 and 2022–23, total rainfall was 654 and 475 mm for sesame, and 157 and 112.5 mm for chickpea, respectively. Maximum temperatures were 39.9°C (April 2022) and 43.1°C (July 2023). Winter temperatures ranged from 13.6–24.2°C and 13.2–23.8°C. Relative humidity ranged from 44–84%, lowest in April–May and highest in January. Weekly sunshine hours varied from 0.5–10.8/day. Apparent water productivity, the ratio between grain yield produced by a crop and the irrigation water applied during the entire growing season, were computed following the method of Rodrigues and Pereira (2009). Total water productivity, the seed yield of crop that can be produced per unit of total water use (irrigation water applied + rainfall), were computed as per the method suggested by Rodrigues and Pereira (2009). Analysis of variance was performed for split-plot design and significant mean differences were tested using Fisher's protected test at 5% level of significance.

RESULTS AND DISCUSSION

Yield attributes and yield of sesame: Sole application of FYM increased the number of capsules per sesame plant by 47% whereas the application of NFCs + FYM increased it by 50% as compared to the control (Table 1). Similarly, the number of seeds per capsule increased by 36% with the sole application of FYM and by 41% with the application of NFCs

Table 1 Effect of organic nutrition and planting geometry on yield attributes and yield of sesame at harvest (pooled mean of 2021–22 and 2022–23)

Treatment	Plant population at harvest (plants/ha)	Capsules/ plant	Seeds/ capsule	1000-seed weight (g)	Seed yield (q/ha)	Stalk yield (q/ha)	Harvest index
Organic nutrition							
Control	189725	33.6	29.7	2.8	5.81	10.46	0.36
FYM	190501	49.3	40.3	3.1	9.41	13.86	0.40
FYM + NFCs	190805	50.3	41.9	3.2	9.62	14.24	0.40
CD (*P*=0.05)	-	4.0	4.5	NS	0.42	1.19	0.02
Planting geometry							
30 cm × 15 cm	206044	43.2	35.5	2.9	8.31	13.03	0.39
45 cm × 10 cm	210615	42.2	34.2	3.0	8.23	13.02	0.38
60 cm × 10 cm	159566	46.6	40.9	3.1	7.52	11.87	0.39
Paired row sowing (47.5:20 cm) *fb* bed formation	185148	45.6	38.6	3.1	9.05	13.47	0.40
CD (*P*=0.05)	-	2.7	3.2	NS	0.25	0.75	NS

FYM, Farmyard manure to supply 52.5 kg N/ha; NFCs, Natural farming concoctions (*beejamrit*, *ghanjeevamrit*, *jeevamrit*).

+ FYM compared to the control. As a result, application of NFCs along with FYM resulted in a significantly higher seed yield (9.6 q/ha) of sesame as compared to the control (5.8 q/ha), however, it remained statistically at par with the alone application of FYM (9.4 q/ha). The addition of organic manure and its decomposition slowly released essential nutrients, meeting crop demand and improving growth and yield attributes. Application of NFCs in addition to FYM resulted in marginal increase of 2.2% in the seed yield of sesame as compared to alone application of FYM.

Sesame sown at planting geometry of 60 cm × 10 cm resulted in a significantly higher number of capsules/plant (46.6) as compared to the planting geometry of 30 cm × 15 cm (43.2), 45 cm × 10 cm (42.2), although, it remained statistically at par with paired row sowing of sesame *fb* bed formation (45.6). The per cent decrease in the number of capsules/plant with planting geometries of paired row sowing *fb* bed formation, 30 cm × 15 cm and 45 cm × 10 cm was 2.1, 7.3 and 9.4%, respectively over the planting geometry of 60 cm × 10 cm. Likewise, sesame sown at planting geometry of 60 cm × 10 cm resulted in a significantly higher number of seeds/capsule (40.9) as compared to the planting geometry of 30 cm × 15 cm (35.5) and 45 × 10 cm (34.2), although, it remained statistically at par with paired row sowing of sesame *fb* bed formation (38.6). Higher nutrient availability and more light interception under wider spacing lead to better translocation of photosynthates from source to sink.

The paired row sowing *fb* bed formation of sesame resulted in the highest seed yield followed by crop sown at recommended geometry of 30 × 15 cm whereas the crop sown at 60 cm × 10 cm resulted in lowest seed yield. The increase in seed yield with planting geometries of paired row sowing *fb* bed formation, 30 cm × 15 cm, 45 cm × 10 cm was 20, 10 and 9%, respectively, over the planting geometry of 60 cm × 10 cm. Although increase in row spacing from 30–60 cm in sesame increased the number of capsules/plant (43–46) and seeds/capsule (35–41) but it could not compensate the yield loss due to reduced plant population under wider planting geometry (206044–159566 plants/ha) (Table 1). Evidently, the full potential of individual plant can be achieved when sown at wider spacing and yield/plant decreases gradually as plant population/unit area is

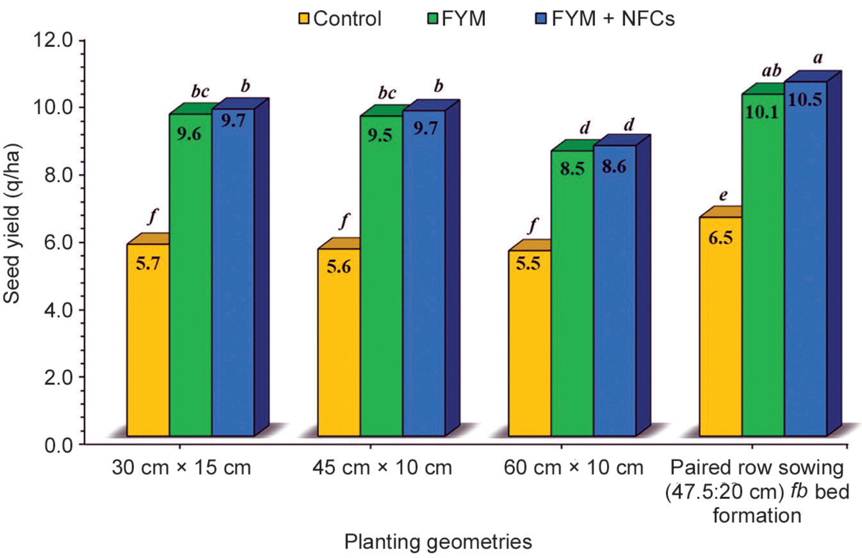

Fig. 1 Interactive effect of organic nutrition and planting geometry on seed yield of sesame (pooled mean of 2021–22 and 2022–23).
FYM, Farmyard manure to supply 52.5 kg N/ha; NFCs, Natural farming concoctions (*beejamrit*, *ghanjeevamrit*, *jeevamrit*).

increased. Maximum yield per unit area can, therefore, be obtained at optimized planting densities. Sesame sown in paired rows sowing *fb* bed formation resulted in the highest seed yield which is also evident from higher number of capsules/plant and number of seeds per capsule along with optimum plant population per unit area. In the extant study, after a rainfall event, water was drained into the furrows away from the plants grown on raised beds causing better aeration in the soil, which the crop needed. Sesame is very sensitive to water logging and does not survive well in saturated soils (Wei *et al.* 2013).

The interaction between organic nutrition and planting geometry was found significant for seed yield (Fig. 1). Sesame sown at 30 cm × 15 cm or 45 cm × 10 cm spacing when manured with FYM + NFCs showed similar seed yields to those sown in paired rows with bed formation and manured with FYM alone. Interestingly, flat-sown sesame without organic inputs showed consistent seed yields across different spacing (30 cm × 15 cm, 45 cm × 10 cm, or 60 cm × 10 cm) in both the years. However, sesame sown at 60 cm × 10 cm spacing and manured with either FYM or FYM + NFCs yielded significantly less compared to closer spacing (30 cm × 15 cm or 45 cm × 10 cm) with organic inputs. This highlights the importance of dense plant stands in utilizing soil nutrients for higher yields. Application of NFCs along with FYM resulted in significantly higher stalk yield as compared to the control, however, it remained statistically at par with the alone application of FYM (Table 1). The increase in sesame stalk yield with different planting geometries like paired row sowing *fb* bed formation of sesame, 30 cm × 15 cm, 45 cm × 10 cm was 13.5, 9.8 and 9.7%, respectively over the planting geometry of 60 cm × 10 cm.

Yield attributes and yield of chickpea: The combined application of NFCs and FYM led to a notably higher number of pods per plant and seeds per pod compared to the control. However, this increase was statistically similar to the sole application of FYM (Table 2). Specifically, the number of seeds per pod increased by 50% with the sole application of FYM and by 66% with the application of NFCs + FYM compared to the control. In consequence, application of FYM along with NFCs resulted in a significantly higher seed yield of chickpea as compared to the control, however, it remained statistically at par with the alone application of FYM. The increase in seed yield of chickpea with the application of FYM and application of NFCs + FYM was 84.2 and 94.7%, respectively over control. This could be attributed to enhanced soil physio-chemical properties and improved nutrient availability, leading to stronger root systems and increased moisture and nutrient absorption from deeper layers, consequently boosting chickpea growth and yield attributes. Key yield attributes such as pod count per plant, seeds per pod, and 100-seed weight significantly influence chickpea yield, with organic inputs enhancing these attributes (Table 3). Addition of NFCs alongside FYM marginally increased chickpea seed yield by 5.7% compared to FYM alone. NFCs, rich in diverse microorganisms, may enhance nutrient bio-availability to plants (Sharma *et al.* 2023).

Chickpea sown at 60 cm × 7 cm resulted in a significantly higher number of pods per plant as compared to the planting geometry of 45 cm × 7 cm and recommended bed planting, although, it remained statistically at par with recommended planting geometry of 30 cm × 10 cm. The lowest number of pods per plant was recorded with planting geometry of 45 cm × 7 cm. Increase in row spacing led to lower plant density per unit area and the performance of the individual plant would have been better due to low competition among plants, better light interception, more aeration, and higher photosynthetic rate. The recommended planting geometry of 30 cm × 10 cm resulted in significantly higher seed yield compared to 60 cm × 7 cm, although statistically similar to bed planting and 45 cm × 7 cm. Seed yield increased by 36.1, 32.9 and 30.9% with 30 cm × 10 cm, bed planting, and 45 cm × 7 cm, respectively, over 60 cm × 7 cm. Increasing row spacing from 45–60 cm in chickpea raised the number of pods per plant (24.5–28.3)

Table 2 Effect of organic nutrition and planting geometry on yield attributes and yield of chickpea at harvest (pooled mean of 2021–22 and 2022–23)

Treatment	Pods/ plant	Seeds/pod	100-seed weight (g)	Seed yield (q/ha)	Stalk yield (q/ha)	Harvest index
Organic nutrition						
Control	18.1	1.2	14.6	7.6	14.1	0.35
FYM	29.0	1.8	16.1	14.0	22.9	0.38
FYM + NFCs	31.3	2.0	16.5	14.8	23.2	0.39
CD (P=0.05)	4.3	0.3	NS	1.3	3.6	0.02
Planting geometry						
30 cm × 10 cm	26.7	1.5	15.7	13.2	22.0	0.37
45 cm × 7 cm	24.5	1.7	15.7	12.7	20.8	0.38
60 cm × 7 cm	28.3	1.7	15.7	9.7	16.1	0.38
Bed planting	25.1	1.7	15.8	12.9	21.3	0.37
CD (P=0.05)	2.8	NS	NS	1.0	2.1	NS

FYM, Farmyard manure to supply 15 kg N/ha; NFCs, Natural farming concoctions. (*beejamrit*, *ghanjeevamrit*, *jeevamrit*).

Table 3 Effect of nutrition and planting geometry on decision making parameters of sesame-chickpea organic cropping system (pooled mean of 2021–22 and 2022–23)

Treatment	System productivity (q/ha)	Gross returns (₹/ha)	Cost of cultivation (₹/ha)	Net returns (₹/ha)	Benefit cost ratio
Organic nutrition					
Control	11.1	108789	62377	46413	0.74
FYM	19.2	187693	71592	116101	1.62
FYM + NFCs	19.9	194754	78787	115967	1.47
CD (*P*=0.05)	1.11	11490	-	11487	-
Planting geometry					
30 cm	17.5	171359	74402	96957	1.30
45 cm	17.1	167420	70336	97084	1.38
60 cm	14.3	139718	68675	71042	1.03
Paired row sowing *fb* bed formation and bed planting	18.1	176484	70260	106224	1.51
CD (*P*=0.05)	0.66	6342	-	6338	-

FYM, Farmyard manure to supply 52.5 kg N/ha; NFCs, Natural farming concoctions (*beejamrit*, *ghanjeevamrit*, *jeevamrit*).

but couldn't offset yield loss due to reduced plant population (312,292–234,208 plants/ha). Yield/plant decreases as plant population per unit area increases, thus optimizing planting densities is crucial. Altering planting geometry from 30 cm × 10 cm to 45 cm × 7 cm didn't affect seed yield, suggesting similar resource utilization by plants. Chickpea on raised beds yielded statistically similar seed yield, likely due to higher pod count, seed count per pod, and optimal plant population. Bed planting conserves water and nutrients, reduces weed emergence, soil compaction, and water logging (Mishra *et al.* 2012). In this study, rainfall water drained away from plants on raised beds, improving soil aeration, crucial for crop growth.

The stalk yield of chickpea increased by 62.4% with the sole application of FYM and by 64.5% with the application of NFCs + FYM compared to the control. Planting geometry also significantly affected stalk yield, with increases of 36.6%, 32.3%, and 29% observed with planting geometries of 30 cm × 10 cm, bed planting, and 45 cm × 7 cm, respectively, over 60 cm × 7 cm. However, the harvest index of chickpea remained unaffected by changes in planting geometries.

System productivity and profitability: Application of NFCs along with FYM in sesame-chickpea cropping system resulted in the highest system productivity (19.9 q/ha) followed by the alone application of FYM (19.2 q/ha) (Table 3). Among different planting geometries, the highest system productivity was recorded with the paired row sowing *fb* bed formation of sesame and recommended bed planting of chickpea (18.1 q/ha), followed by the 30 cm row spacing (17.5 q/ha), whereas the lowest system productivity was recorded (14.3 q/ha) with 60 cm row spacing.

Application of NFCs along with FYM in sesame-chickpea cropping system resulted in the highest gross returns, followed by alone application of FYM, however the net returns and benefit cost (B:C) ratio were higher under alone application of FYM as compared to application of NFCs + FYM. The additional cost of preparing and applying NFCs increased the overall cultivation cost, and the marginal yield gains in seed and stalk were insufficient to offset these expenses. Recommended row spacing had the highest cultivation cost, followed by 45 cm spacing, with 60 cm spacing having the lowest. These differences stemmed from the weeding methods: manual weeding in 30 cm rows incurred high labour costs, while other geometries allowed for cheaper mechanical weeding. Using brush cutters or power weeders was less expensive. Consequently, paired row sowing of sesame *fb* bed formation and bed planting of chickpea resulted the highest net returns. Although wider 60 cm spacing reduced costs and improved yield attributes per plant, it decreased plant density, leading to significant yield reductions.

Water productivity and soil organic carbon: The significantly higher apparent and total water productivity was recorded with the application of FYM along with NFCs as compared to the control due to higher system productivity (Fig. 2). Among the planting geometries, paired row sowing *fb* bed formation in sesame and bed planting in chickpea resulted significantly higher water productivity as compared to the other planting geometries. Bed planting not only increased crop productivity but also resulted in lower irrigation depth (55 mm vs 75 mm under flat planting), leading to an average 18.5% reduction in irrigation water usage. This reduction in water consumption contributed to achieving the highest water productivity. Similarly, bed planting enhanced the total water productivity of the entire cropping system. In the extant study, after a rainfall event, water drained into furrows away from plants on raised beds, improving soil aeration, which is crucial for both sesame and chickpea crops.

The soil organic carbon (SOC) content was 0.56 and 0.64%, respectively at the initial and after two years of the

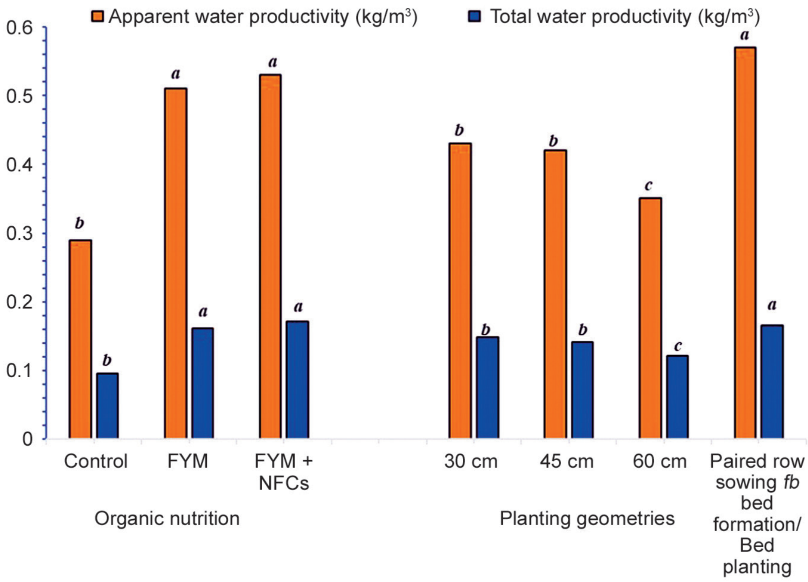

Fig. 2 Effect of nutrition and planting geometry on apparent and total water productivity of sesame-chickpea organic cropping system.
FYM, Farmyard manure to supply 52.5 kg N/ha; NFCs, Natural farming concoctions (*beejamrit*, *ghanjeevamrit*, *jeevamrit*).

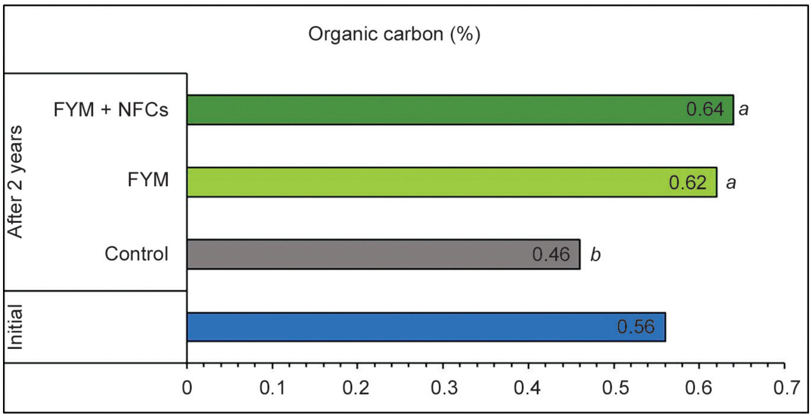

Fig. 3 Effect of organic nutrition on soil organic carbon.
FYM, Farmyard manure to supply 52.5 kg N/ha; NFCs, Natural farming concoctions (*beejamrit*, *ghanjeevamrit*, *jeevamrit*).

experiment (Fig. 3). The incorporation of organic inputs increased the SOC content from its initial status. The application of FYM + NFCs and alone application of FYM increased SOC content by 14.3 and 10.7%, respectively over initial SOC content. Addition of NFCs to FYM did not significantly enhance the SOC compared to alone application of FYM after two years of study. Organic inputs provide energy for soil microorganisms, are known to increase microbial biomass carbon and organic carbon content.

Conclusively, to enhance productivity of sesame-chickpea organic cropping system and promote soil health, it is advisable to apply farmyard manure (based on N content) equivalent to supply 52.5 kg N/ha for sesame and 15 kg N/ha for chickpea. Innovative practices such as sowing of sesame in paired rows (47.5:20 × 15 cm) *fb* bed formation (earthing up at 15 and 25 DAS) and bed planting of chickpea (37.5 cm bed top and 30 cm furrow, two rows/bed at 20 cm × 10 cm) facilitate effective mechanical weed control and soil aeration, leading to improved system productivity, water productivity and profitability.

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