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NUTRIENT UPTAKE, SOIL PROPERTIES AND YIELD OF CAULIFLOWER (*Brassica oleracea* L. Group Botrytis L.) AS AFFECTED BY NATURAL AND CHEMICAL FARMING SYSTEMS

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ABSTRACT

Cauliflower (*Brassica oleracea* L. var. botrytis L.) is one of the most important cole crops cultivated worldwide for its high nutritional value and economic significance. Sustainable crop production depends largely on farming systems that not only ensure higher yields but also maintain soil fertility and ecological balance. Chemical farming practices, though highly effective in boosting productivity, often lead to soil degradation, nutrient imbalances, and environmental concerns due to excessive reliance on synthetic fertilizers and agrochemicals. In contrast, natural farming practices emphasize the use of on-farm inputs, natural formulations and biological processes to sustain soil health and crop productivity in an eco-friendly manner.

The present investigation was started in 2023-2024 which was again repeated in 2024-25 at Jadari Farm, HRTS and KVK, Solan Himachal Pradesh, India during the winter season. For natural farming practices, fresh preparations of beejaamrut, jeevamrut and ghanjeevamrut were prepared using desi cow dung and cow urine. Cauliflower was intercropped with fenugreek (*Trigonella foenum-graecum*) and oat (*Avena sativa*) as border crops. Prior to sowing, cauliflower seeds were treated with beejamrut (10-20%). Ghanjeevamrut was applied at the time of field preparation @ 1.5 t/ha before sowing. During field preparation, drenching with fermented jeevamrut (10%) was carried out, and repeated at 7-day intervals up to harvesting. In addition, jeevamrut foliar spray (5%) was applied every 5 days starting from the third week after transplanting until harvest. For plant protection agniastra and bramhastra were sprayed alternately at 5% concentration on a fortnightly basis, while khatti lassi (5%) was sprayed thrice during the crop cycle. Under the chemical farming practices, recommended doses of fertilizers were applied, consisting of FYM (250 q/ha), Urea (250 kg/ha), SSP (475 kg/ha), and MOP (120 kg/ha).

Natural farming practices has higher number of beneficial microorganisms, enzymes and organic carbon which help to improve the physico-chemical properties and enzymatic activity of cauliflower rhizosphere soil after 2 years of continuous cropping. The nutrient uptake efficiency of crops like cauliflower is strongly influenced by soil physical, chemical, and biological properties, which in turn are shaped by the farming system adopted. While chemical farming may provide immediate nutrient availability, natural farming systems enhance soil fertility through organic matter buildup, improved microbial activity, enzymatic activity and balanced nutrient cycling. Higher main crop equivalent yield was found 294.49q/ha under natural farming practices while the cauliflower yielded 261.73 under chemical farming system. Intercropping with fenugreek had Land equivalent ration (LER) values above unity (2.09), thus suggesting a considerable benefit for intercropping fenugreek with cauliflower.

Natural farming practices significantly influence soil properties, nutrient uptake, yield and performance of cauliflower (*Brassica oleracea* var. botrytis). Different natural farming practices viz. application of natural farming inputs, mulching, intercropping and Vapor-Aided Plant Soil Air condition improved soil fertility, enhanced microbial activity, and ensured better nutrient availability compared to chemical farming practices. These improvements translated into higher nutrient uptake and stable yields, demonstrating the potential of sustainable farming systems to balance productivity with improved soil health

***Keywords*:** Biological activity, Cauliflower, Nutrient Uptake, Soil properties, Intercropping, Yield

Introduction

Farming systems play a crucial role in shaping soil properties, nutrient dynamics, and crop productivity. The choice of management practices, whether conventional, organic, or natural, directly influences soil fertility, microbial activity, and nutrient availability, which in turn affect crop growth and yield. Cauliflower (*Brassica oleracea* var. botrytis), a nutrient-rich and high-value vegetable, is highly responsive to soil health and nutrient management. Cauliflower (*Brassica oleracea* var. botrytis L.) is a nutritionally rich and commercially valuable vegetable whose productivity is deeply influenced by soil health, nutrient availability, and farming practices. In Himachal Pradesh, it is grown as a cash crop that brings remunerative returns to the small and marginal hill farmers. In 2021–22, India cultivated 0.48 million hectares (m ha) of cauliflower, producing 9.53 million metric tonnes (MT) at a productivity rate of 19.6 MT per hectare. This represents 32.5% of global cauliflower production, making India the largest producer worldwide, significantly boosts farmers' income and generates employment opportunities (Pavithra and Singh, 2020).Cauliflower in Himachal Pradesh serves as a primary source of income for smallholder farmers (Bhandari *et al*., 2014; Paul *et al*., 2020) with cultivation spanning 5.92 thousand hectares and a production output of 139.14 thousand metric tonnes, cauliflower holds significant economic importance in the state. Particularly in the Solan district, cauliflower is a key crop, cultivated on 0.17 thousand hectares with a production of 4.37 thousand metric tonnes (Anon., 2021).

The indiscriminate use of pesticides and chemical fertilizers is a widespread practice among cauliflower growers seeking higher marketable yields. While this approach may boost short-term productivity, it has led to serious long-term challenges, particularly for soil health and fertility. Overuse of chemical inputs contributes to declining agricultural productivity, depletion of natural resources, and reduced soil fertility. Moreover, it poses significant threats to terrestrial and aquatic ecosystems, exacerbates climate change, and endangers human health and well-being (Bharucha *et al*., 2020; Kitamura *et al*., 2021). The presence of pesticide residues multi-times higher than the prescribed limit in contaminated drinking water and air, biodiversity losses, nitrate leaching and pollution of groundwater, and heavy metal accumulation in the soil are quite common in intensive agriculture regions (John and Babu, 2021). Pesticides' easy availability has led to suicidal deaths in rural India, and its indiscriminate application has resulted in the decline of pollinators (Baron *et al*., 2017). Studies reveal that the sole application of synthetic fertilizers depletes the microbial population in the rhizosphere, diminishes soil respiration, and reduces enzymatic activities like dehydrogenase, acid phosphatase, and β-glucosidase, along with microbial biomass carbon (Dinesh *et al*., 2013).

To counter these adverse effects, Natural farming emphasizes cultivating crops in harmony with nature by avoiding synthetic chemicals and depending on locally available resources. The approach focuses on building and maintaining soil health through organic matter, beneficial microbes, and minimal soil disturbance. It promotes biodiversity, intercropping, and integration of livestock to create resilient ecosystems. Water conservation practices such as mulching and efficient irrigation are central to reducing input costs and preserving resources. Overall, natural farming seeks to ensure sustainability, self-reliance, and ecological balance while enhancing crop productivity and farmer income. The foundation of natural farming rests on four main pillars: Jeevamrut, beejamrut, acchadana (Mulching) and VAPSA lines. Jeevamrut is a natural fertilizer and soil enhancer often called the "elixir of life" for its role in rejuvenating farmland. It is a microbial culture fermented from cow dung, cow urine, jaggery, pulse flour, water, and soil. This mixture enhances microbial activity in the soil, boosts soil fertility, and encourages earthworm proliferation (Joshi, 2012). Beyond supplying nutrients, Jeevamrut acts as a catalyst, stimulating soil microorganisms and improving plant health. It also helps prevent bacterial and fungal plant diseases, making it a vital component of sustainable farming. Beejamrut is a traditional seed treatment method derived from cow dung, urine, and locally available materials. Mentioned in ancient texts like the Vedas, this practice was historically used to protect seeds from diseases. Unlike modern chemical treatments, which can introduce toxic residues into the plant and food systems, beejamrut provides a natural and effective alternative. It reduces health risks for consumers and lowers production costs for farmers, making it both an economical and environmentally friendly option. Mulching, or Acchadana, plays a critical role in natural farming by promoting humus formation, suppressing weeds, and maintaining stable moisture levels in the soil. Mulching creates a favorable microclimate, with soil temperatures ranging from 25°C to 32°C and moisture levels between 65% and 72%. This environment supports the growth of soil organisms and plant roots. Additionally, Acchadana reduces water loss through evaporation, stabilizing the water needs of crops and enhancing overall soil health. This equilibrium minimizes irrigation requirements and provides optimal conditions for the growth of roots and soil organisms. By ensuring sufficient aeration and moisture, VAPSA supports sustainable crop production and reduces the risk of waterlogging or drought stress.

The principle of natural farming is to cooperate with nature to generate nutritious food to keep ourselves and the land healthy. Natural Farming is also termed as "Do Nothing Farming", because the farmer is considered as only to be a facilitator - the real work is done by nature itself without practicing the application of chemical fertilizers, herbicides and pesticides. It is a comprehensive management approach to improve soil health as well as the ecosystem. Natural Farming is based on the principle of promoting beneficial microorganisms without the use of external manures or chemical fertilizers and it employs several techniques or methods to improve soil fertility including the application of jeevamrut which is one of the most important components of nutrient management and ghanjeevamrut, also known as dry form of jeevaamrut which improves the plant's temperature and disease resistance, as well as the appearance of the fruits became shiny and attractive, effective nutrients uptake and seed productivity (Palekar, 2006). These are low-cost improvised preparation that enriches the soil with indigenous micro-organisms necessary for the mineralization of the soil and provides all necessary nutritional requirements for growth and yield of a crop.

Natural farming inputs act not only as a source of nutrients but also influenced the physical, chemical and biological properties of soil and increased the biodiversity and activity of the microbial population. The application of organic inputs provides enough nutrient requirements for proper growth of the crop plant and may enhance the uptake of nutrients, increases the assimilation capacity which stimulated the hormonal activity.

Understanding the impact of different farming systems on soil quality, nutrient uptake, and yield performance of cauliflower is essential for developing sustainable production strategies that ensure higher productivity while maintaining ecological balance. To achieve sustainable crop productivity without degrading soil health, significant role is played by natural farming formulation like ghanjeevamrut and jeevamrut these sources of nutrients are directly involved in the increased uptake of nitrogen, phosphorus and potassium and also help to control soil-borne disease of cabbage and cauliflower under field/controlled conditions (Boraiah *et al.*, 2017). Considering the above facts, the present study was planned and undertaken with the objective to assess the role of natural farming practices in enhancing sustainability and biodiversity under cauliflower cv. Pusa Snowball K1cropping sequence.

Material and Methods

The experimental farm of this station is located in the hilly regions of Western Himalayas at an altitude of 1460 m above mean sea level having latitude of 30°57'21"N and longitude 77°06'48"E. The average annual rainfall received during 2023 and 2024 was133.78 mm and 71.95 mm, respectively with average annual temperature of 18.63°C and 19.10°C, respectively. Figure 1 displays the meteorological data collected during the experiment.

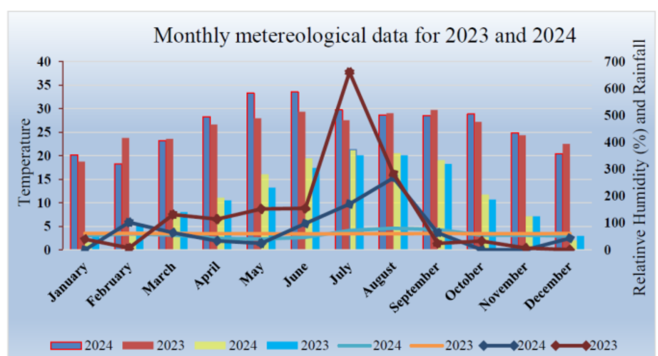

Fig. 1: Monthly meteorological data for year 2023 and 2024

Field preparation

The present investigation was started in 2023-2024 which was again repeated in 2024-25 at Jadari Farm, HRTS and KVK, Solan Himachal Pradesh, India during the winter season. The experimental farm of the department is located in the hilly regions of the Western Himalayas at an altitude of 1446 m above mean sea level, with a latitude of 30◦57′21′N and a longitude 77◦06′48′ E. The main crop (Cauliflower) variety was 'Pusa Snowball K1'. The intercrop was

Fenugreek. Planting distance of main crop was 60cm x45cm while fenugreek was sown at 60 cm x 7.5 cm between the two rows of main crop. The core of natural farming practices is the application of ghanjeevamrut, jeevamrut and beejamrut. Before sowing, seeds were treated with beejamrut@10-20%. Ghanjeevamrut was applied before sowing @ 1.5t/ha. Jeevamrut was used after five days of fermentation, at different times. At the time of filed preparation, drenching of fermented jeevamrut @ 10% (10 L in 90 L water) was done and was repeated five times at seven days interval and continued till harvesting. Similarly, fermented jeevamrut diluted @5% (5L in 95L water) was sprayed again at 5 days interval on cauliflower cropping system starting from third week of plantation till harvesting. VAPSA (Vapor-Aided Plant Soil Air) condition were created which leverages capillary action to ensure plants get sufficient moisture while minimizing water wastage. Mulching with dry grass enhances capillary action and ensure plants get enough water under VAPSA conditions. It helps in retaining soil moisture by reducing evaporation and improving the soil's ability to hold water, which supports capillary movement. Agniastr and bramhastr were sprayed at alternate weeks @ 5% and khatti lassi @ 5% was sprayed three times, first before curd initiation, second at curd development and third spray was given at maturity stage. These three sprays were taken as plant protection measures under natural farming (NF). Recommended doses of fertilizers including 250q/ha FYM, Urea-250kg/ha, SSP-475kg/ha and MOP-120kg/ha) were applied under conventional farming.

Fresh samples of jeevamrut and ghanjeevamrut were prepared by using desi cow dung and cow urine. The inputs required for jeevamrut and ghanjeevamrut along with method of preparation are mentioned in Table 1and were prepared after following the standard procedure of preparation (Lai *et al*., 2022; Rameshwar *et al*., 2021).

Table 1 : Ingredients and method of preparation of Jeevamrut, ghanjeevamrut and beejamrut

Sr. No.	Input	Ingredients	Method of preparation
1.	Jeevamrut	Cow dung – 10 kg Cow urine – 10 L urine Jaggery– 2 kg Gram flour – 2 kg Water – 200 L Handful of soil (from forest tree basin/crop bunds/virgin land)	➢ Whole quantity of cow urine, cow dung, jaggery gram flour and handful of soil was added in 200 L water ➢ All the contents were mixed with wooden stick and stirred in *clockwise direction* ➢ Stirring was done thrice a day in clockwise direction only ➢ Kept for 5-7 days in shade till the fermentation process
2.	Ghanjeevamrut	Cow dung – 200 kg Jeevamrut -4L	➢ Shade dried the 200 kg cowdung for four to five days (till removal of moisture) ➢ Grinded the shade dried cowdung to powder form ➢ Sieving of powder was done ➢ Added 4 L Jeevamrut, shade dried for 2-4 hours
3.	Beejamrut	Cowdung-5 kg Cow Urine – 5L Lime -250 g Water - 20 L Handful of soil (from forest tree basin/crop bunds/virgin land)	➢ Cow dung was wrapped in a cloth, tied with a rope, and suspended in 20 liters of water for 12 hours. ➢ One liter of water was mixed with 50 grams of lime and allowed to settle overnight. ➢ After 12 hours, the lime water and cow urine were added to the mixture ➢ All the ingredients were thoroughly mixed using a wooden stick, stirring in a clockwise direction

Jeevamrut and ghanjeevamrut were analyzed in the laboratory to determine their nutrient contents and microbial properties. Parameters such as moisture content, pH, electrical conductivity (EC), and nutrient levels were assessed on a fresh weight basis, while bulk density, organic carbon, and ash content were measured on a dry weight basis. Total nitrogen, phosphorus, potassium and micronutrient contents of jeevamrut and ghanjeevamrut were determined using standard procedures as detailed in Table 2. Observations on various yield attributes and overall yield were recorded at the time of harvest.

Table 2: Methods followed for the analysis of Total NPK and micronutrients content in jeevamrut and ghanjeevamrut

S.No.	Parameters	Method
1.	Total Nitrogen	Microkjeldhal method (Rana *et al.*, 2023)
2.	Total Phosphorous	Vando-molybdate phosphoric yellow colour method (Rana *et al.*, 2023)
3.	Total Potash	Flame photometer method (Rana *et al.*, 2023)
4.	Micronutrients	Atomic absorption spectrophotometer (Sarma *et al.*, 1987)

Collection of soil samples

Composite soil samples from 0-15 cm depth were collected before laying out the experiment and after the final harvest of crop under both natural and chemical farming systems during both the year. Collected soil samples were air dried in shade and grind with the help of pestle and mortar. These grind samples were passed through 2 mm sieve and stored in plastic box and analyzed as per methods mentioned in Table 3:

Table 3: Methods for the analysis of physico-chemical and biological properties of soil

S.No.	Parameters	Method
1.	Moisture content	Gravimetric method (Pikul, 2003)
2.	pH and EC	1:2 Soil: water suspension method (Jackson, 2005)
3.	Organic carbon	Wet digestion method (Walkley and Black, 1934)
4.	Available N	Alkaline potassium permanganate method (Subbiah and Asija, 1956)
5.	Available P	Olsen's method (Olsen *et al.*, 1954)
6.	Available K	Ammonium acetate method (Hanway and Heidel, 1952)
7.	Total microbial count	Serial dilution method (Rao, 1999)
8.	Phosphatase enzyme	Casida *et al.*, 1964
9.	Urease enzyme	Tabatabai and Bremmer, 1972
10.	Microbial activity	CO_2 evolution method (Parmer and Schmidt, 1964)

Nutrient (N, P or K) uptake (kg/ha)

Nutrient uptake is calculated by multiplying the dry matter yield (kg/ha) with the nutrient content (%) of each treatment as follows

$$\text{Nutrient uptake (kg/ha)} = \frac{\left[\begin{array}{l}\text{Dry matter yield (kg/ha)} \times \\ \text{Nutrient (N, P or K) content (\%)}\end{array}\right]}{100}$$

Yield, crop equivalent yield and land equivalent ratio (LER)

Fenugreek was used as intercrop and oat as a border crop in Cauliflower under natural farming system. Francis described crop equivalent yield (CEY) to the sum of equivalent principal and intercrop yields (Francis, 1986). The differing yield intercrops were transformed into the equivalent yield of any crop depending on the commodity price. So, a comparison was made based on economic returns and crop equivalent yield (CEY) of multiple cropping sequences was calculated by converting the yield of different intercrops/crops into equivalent yield of any one crop based on price of the produce. Mathematically, the CEY is represented as:

$$CEY = Cy+Cy1\ (P1/P0)+Cy2\ (P2/P0)+.......+Cyn\ (Pn/P0)$$

Where,

Cy =Yields of the main crop

P0 =Price of the main crop

(Cy1, Cy2, Cy3.....Cyn) = Yields of intercrop, which are to be converted to equivalent of main crop yield

(P1, P2, P3... Pn) = Price of the respective intercrops.

LER (land equivalent ratio) was determined as per the following formula:

LER= yab/yaa× yba/ybb

Where

yaa= sole yield of "a" intercrop

ybb= sole yield of "b" intercrop

yab= relative yield of a intercrop when growing along with b intercrop

yba= relative yield of b intercrop when growing along with a intercrop

Benefit cost ratio (B:C)

Benefit cost ratio was calculated by considering the cost of variable as well as fixed inputs and prevailing marketing rates, the expenditure incurred on various natural farming inputs and operations. Similarly, gross returns were worked out for both natural and chemical farming based on quality and market prices of the produce.

Statistical analysis

Only two treatments were compared having 10 replications each; therefore, an independent t-test was applied to evaluate the significance of differences in parameters between natural and chemical farming. No specific experimental design was used, as designs are typically applied for comparisons involving more than two treatments. Prior to the test, the assumption of homogeneity of variances was examined using an F-test (var.test (natural, chemical)), and based on the result, the appropriate form of the t-test was applied.)). If the F-test indicated unequal variances ($p > 0.05$), independent t-test was used (t-test (natural, chemical, var. equal = FALSE)) otherwise pooled-variance independent t-test was applied (t-test (natural, chemical, var. equal = TRUE)). This analysis was done using software R (version 4.5.1) and R Studio. The graphs were prepared in MS Excel (Microsoft Office standard 2013).

Results and Discussion

Nutrient composition of jeevamrut and ghanjeevamrut

Jeevamrut is slightly acidic in nature (6.34) and good source of macro and micro nutrients (N 0.93%, P 0.60%, K 0.75%, Zn 3.26 mg/kg and Cu 1.64 mg/kg) (Fig 2).It has also been reported that more number of beneficial microorganisms were recorded under higher acidic conditions (Somasundaram *et al*., 2003). It not only enhances the microbes in the environment but also act as catalyst with a synergistic effect to promote all the useful microbes of the environment. Results of the analysis presented in Fig 3 reveal that jeevamrut is enriched consortia of native soil micro-organisms and enzymes. Maximum CFUs of bacteria (216), fungi (64) actinomycetes (8), dehydrogenase (51.38 mg TPF g-124-1), phosphatase (77.33 µg PNP $g^{-1}h^{-1}$) and urease (46.42 µg PNP $g^{-1}h^{-1}$per 10 g sample) (52) were recorded on the 10thday of preparation of jeevamrut. Ghanjeevamrut is found to have higher number of beneficial microorganisms, enzymes, macro and micro nutrients, organic carbon and high particle size. The presence of beneficial microorganisms in natural farming formulations like beejamrut, jeevamrut and ghanjeevamrut are due to their constituents such as: cow dung, cow urine, legume flour, jaggery and handful of soil. A handful of soil collected from the forest land and added at the time of preparation of jeevamrut serve as an initial inoculums of bacteria, fungi, actinomycetes, N-fixers and P-solubilizes. Hence, high beneficial microorganism count found in jeevamrit and ghanjeevamrut. (Papen *et al*., 2002) and (Kumar *et al*., 2023) also reported the presence of naturally occurring beneficial microorganisms predominantly bacteria, yeast, actinomycetes and certain fungi in organic liquid manures. It has been reported by Reddy and Menon (2021) that the beneficial microorganisms present in jeevamrut ensures mineralization of humus and organic matter to mobilize fixed nutrients. Jeevamrut and ghanjeevamrut also contains important amino acids, growth-promoting compounds like gibberelic acid (GA) and indole acetic acid (IAA), vitamins, both essential macro and micronutrients (Nileema *et al*., 2011; Sreenivasa *et al*., 2010). The availability of soil microbes is optimal in pH range of 5.5 to 6.5. According to Msimbira and Smith (2020) plants produce more root exudates which is a source of carbon for multiplication and survival of microbes. Zifcakova (2020) reported that bacterial and fungal activities are higher under slightly acidic to acidic soils.

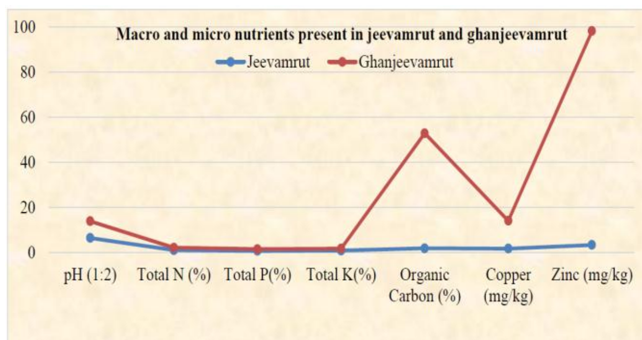

Fig. 2: Macro and micro nutrients present in jeevamrut and ghanjeevamrut

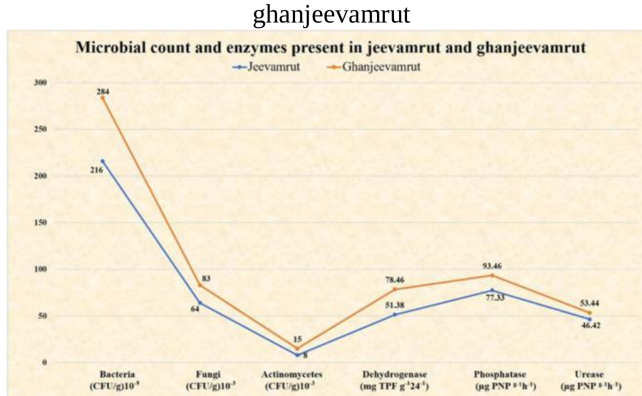

Fig. 3: Microbial count and enzymes present in jeevamrut and ghanjeevamrut

Physico-chemical properties of soil

The soil samples were analyzed in the laboratory as per standard procedure mentioned in Table 3. The results of soil properties before planting (initial value) and after harvesting of cauliflower-fenugreek crops is listed below in Table 4. The physical attributes of soil viz. bulk density, porosity, moisture content and chemical attributes of soil including pH, EC, OC, available N, P, and K were estimated under both natural farming and chemical farming system.

Before the start of experiment

The soil samples collected and analysed before the start of the experiment having cauliflower-fenugreek cropping system was having normal pH (7.15) and EC (0.29 dS/m), medium soil organic carbon (11.80%), available nitrogen (N) (319.16 kg/ha), high available phosphorus (P) (62.70 kg/ha) and medium in available potassium (K) (306.52 kg/ha) under natural farming system (Table 4). Experimental plot of the chemical farming system was having pH (7.34) and EC (0.22 dS/m), medium soil organic carbon (10.58%). Although available N (321.08 kg/ha), available P (70.91 kg/ha) and available K (313.80 kg/ha) was statistically higher in chemical farming as compared to natural farming fields. Soil porosity (47.66%) and moisture content (48.91%) in NF fields were statistically higher compared to CF fields. Soil under NF field were having low bulk density (1.30 Mg/m3) which is better for agriculture crops as it has more pore space, which allows roots to grow more easily and stores more water.

After harvest of crop

Soil physico-chemical properties calculated under cauliflower–fenugreek cropping system are tabulated in Table 4. The bulk density 1.28 Mg/m3 and 1.31 Mg/m3, porosity 51.21 % and 44.69 %, moisture content 56.06% and 47.88% and OC 13.54 and 10.95g /kg were recorded in natural farming and chemical farming, respectively. Soil pH and EC was found under normal range in both natural and chemical farming system. Although available N (345.77 kg/ha), P (84.78 kg/ha), K (328.00 kg/ha) was statistically higher in chemical farming as compared to available N (323.99 kg/ha), P (67.83 kg/ha), K (316.25 kg/ha) under natural farming fields.

The initial soil OC before applying jeevamrut and ghanjeevamrut was reported as 11.80 and 10.58 g/kg under natural farming and chemical farming, respectively (Table 4),which increased significantly after the application of jeevamrut and ghanjeevamrut to 13.54 and 10.95 g/kg, natural farming and chemical farming, respectively. The available nitrogen was reported to be 319.16 and 321.08 kg ha^{-1} (Table 4) before planting which significantly increased to 325.24 and 346.15 kg ha^{-1} under natural farming and chemical farming, respectively. A significant increase in available phosphorus (85.66 kg ha^{-1}) was observed in chemical farming fields compared to available phosphorous (68.56 kg ha^{-1}) in natural farming field as compared to initial values of 70.91 kg ha^{-1} and 62.70 kg ha^{-1}, respectively. Similar trends were observed with available K where an increase of 11.16 kg ha^{-1} and 15.34 kg ha^{-1} was observed in natural and chemical farming, respectively, at the end of the experiment.

Sims *et al*. (2020) and Walter *et al*. (2016) reveal that higher bulk density results in soil compaction and low soil porosity which negatively impacts soil health and plant growth. They further reported that bulk density is having direct correlation with a stock of carbon and nutrients in soil. Nawaz *et al*. (2013) reported that soil porosity regulates the water holding capacity, soil aeration, and root growth, microbial biodiversity which play a significant role in soil structure, texture and nutrient cycling. Compaction of soil due to high bulk density reduces infiltration rate in the soil which can lead to increased runoff and erosion. Kaushal *et al*. (2024) reported that jeevamrut application not only increased the biological properties but also significantly improved physical and chemical properties of soil. This might be due to the existence of favorable conditions in the rhizosphere region after the addition of jeevamrut. Our studies agree with the previous studies of Shang *et al*. (2020) reporting that application of organic fertilizers not only increased the nutrients in soil but also enhances microbial activity and physical properties of the soil.

Han *et al*. (2016) reported that organic manure composed of poultry and cattle manure-analogous to jeevamrut-improved the soil's physical and chemical properties significantly and gave better results than the chemical NPK treatment. Higher soil microbial activity results more stability, resistance of soil ecosystems, better plant growth and yield. Phosphorous is an essential primary macronutrient playing vital role in growth and development of plants. It has been reported by Khan *et al*. (2023) that crop productivity significantly decreases under drought, salinity and extreme temperature conditions when the phosphorus is in limited quantity. The dissolution of unavailable K to available form of K in the soil with the application of jeevamrut and vermitea in combination with biofertilizers such as PSB, Azotobacter, or VAM has been reported by Gurjar *et al*. (2024). Comparative studies on physico-chemical and biological properties of soil under natural farming and farmer's field indicated that NF field soil was rich in organic carbon, available P, available K, and other micronutrients when compared with the farmer's field. Our results agree with the previous studies reporting that organic manure composed of poultry and cattle manure analogous to jeevamrut improved the soil's physical and chemical properties significantly and gave better results than the chemical NPK treatment (Han *et al*., 2016). It has been reported that cow dung manure increased the soil organic matter and improved the soil chemical properties, i.e., N, P, K, Ca and Mg in okra significantly when compared with other manures (Adekiya *et al*., 2020).

Table 4: Physico-chemical and biological properties of soil before planting and after harvest of the crop under two farming conditions (NF and CF)

Soil properties before the start of experiment and after harvest						
Soil Properties	**Before the start of experiment**		**t-value**	**After harvesting of crop**		**t-value**
	NF	**CF**		**NF**	**CF**	
Physical properties						
Bulk density (Mg/m^3)	1.30	1.32	3.93	1.28	1.31	5.56
Porosity (%)	47.66	43.80	5.40	51.21	44.69	7.36
Moisture content (%)	48.91	47.29	2.32	56.06	47.88	9.69
Chemical properties						
pH (1:2)	7.15	7.34	6.40	7.23	7.35	3.59
EC (dS m^{-1})	0.29	0.22	6.37	0.32	0.38	4.21
Organic Carbon (g/kg)	11.80	10.58	4.64	13.54	10.95	17.85
Available N (kg/ha)	319.16	321.08	0.98	325.24	346.15	10.26
Available P(kg/ha)	62.70	70.91	12.42	68.56	85.66	12.57
Available K(kg/ha)	306.52	313.80	3.04	317.68	329.14	3.86
Biological properties						
Bacterial count (cfu x 10^{-5})	49.02	47.32	2.06	89.36	47.98	52.41
Actinomycetes count (cfu x 10^{-3})	13.19	12.77	1.25	25.65	13.99	17.16
Fungal count (cfu x 10^{-3})	7.80	6.13	4.37	19.33	7.70	31.98
Soil Enzymes						
Dehydrogenase (µg TPFg^{-1}h^{-1})	41.01	38.62	3.97	57.26	39.66	20.18
Phosphatase (µmol L^{-1}g^{-1}h^{-1})	60.46	55.66	1.9	75.99	59.73	8.90

Microbial count, enzymatic and microbial activities of soil before and after the experiment

The composition and constituents of jeevamrut and ghanjeevamrut can influence the microbial properties and enzymatic activities of the soil. To investigate it, the effect of jeevamrut and ghanjeevamrut on the microbial count and enzymes in soil was also studied. Table 4 illustrates the microbiological properties and enzymatic activities under NF and CF before and after the experiment. Before the experiment, microbiological count and enzymatic activity was relatively higher under NF and lower under CF. These trends remained consistent after the experiment. However, when comparing the overall trends before and after the experiment, the microbial count as well as enzymatic activities were generally higher post-experiment, with the highest value in NF. It was noticed that natural farming practices resulted in significant increase in bacterial (89.36x10-5cfu/g of soil), actinomycetes (25.65x10-3 cfu/g of soil) and fungal count (19.33 x10-3 cfu/g of soil) in natural farming fields when compared their count in chemical farming fields (47.98x10-5cfu/g of soil, 13.99x10-3 cfu/g of soil, 7.70x10-3 cfu/g of soil, respectively). These results indicate that the whole Jeevamrut and ghanjeevamrut are rich source for microbial inoculation and proliferation. The dehydrogenase activity also increased from 41.01 µg TPFg^{-1}h^{-1} to 57.26 µg TPFg^{-1}h^{-1} under natural farming system. Similarly increase in phosphatase enzyme from 60.46 µmol L^{-1}g^{-1}h^{-1} to 75.99 µmol L^{-1}g^{-1}h^{-1} was also observed under natural farming system. Although, the increase in chemical farming was seen but was very less as compared to natural farming systems. Application of jeevamrut and ghanjeevamrut recorded significantly higher dehydrogenase (58.98 µg TPFg^{-1}h^{-1}) and phosphatase activity (74.55 µmol L^{-1}g^{-1}h^{-1}) at harvest compared to 39.43 µg TPFg-1h-1and 58.24 µmol L^{-1}g^{-1}h^{-1}, respectively in chemical farming (Fig 3). Our studies revealed that there was per cent increase of 137.04, 66.74, 106.98, 49.58 and 28.00 % in bacterial, actinomycetes, fungal, dehydrogenase and phosphatase, respectively, enzymes under natural farming system as compared to chemical farming. Figure 4 depicts higher rate of CO_2 evolution under natural farming system which increased upto 48 hours, then followed a sudden decrease and remained in decreasing trend with increase in incubation period. In contrast, the rate of CO_2 evolution in chemical farming increased very little after 48 hours and stayed nearly constant after 96 hours.

Deluz *et al*. (2020) and Dhawi (2020) reported that soil contains diverse microbial population, including bacteria, fungi, and viruses, which directly improve the plant health. According to Hartman *et al*. (2015), using products made from organic manure increases the microbial population and improves plant uptake of nutrients. Earlier studies by Sharma (2022), shown that the application of organic manure improves the microbial count and activity, and thus helps in reshaping the microbial community. The studies of Reddy and Menon (2021), revealed that jeevamrut containing amino acids can impart resistance against the pathogens. It has been reported that jeevamrut formulations are effective in suppressing mycelial growth (more than 90%) of Alternaria alternata in vitro (Pandia *et al*., 2019). The bacteria and fungi found in the natural farming field also shown potent plant growth-promoting qualities, according to earlier research, suggesting their function in improving soil chemistry and biology (Kaushal *et al*., 2024). Choudhary *et al*. (2022), also noted that applying ghanjeevamrut + jeevamrut + mulching in a wheat-gram intercropping system increased dehydrogenase activity. Our results supported the beneficial effects of jeevamrut and ghanjeevamrut treatment on soil microbiology by showing a noticeably increased microbial load and enzymatic activity in the natural farming fields as opposed to the chemical farming areas. The beneficial microbes also suppress harmful pathogens, leading to healthier plants that can efficiently utilize nutrients. Ultimately, the combined effects of increased nutrient availability, improved soil health, and enhanced microbial diversity lead to superior plant growth and yield, establishing jeevamrut and ghanjeevamrut as a powerful tool for promoting sustainable and productive farming systems.

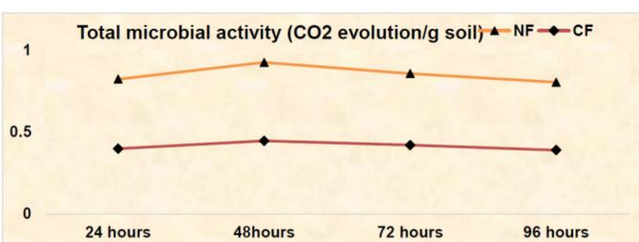

Fig 4: Microbial activity in soil under NF and CF system

Percent increase after two years under both farming systems

Figure 5 shows that the bulk density, porosity, moisture content, pH, EC, OC, increased by 1.56, 7.45, 14.62, 1.12, 10.34, 14.75 percent, respectively, under natural farming practices at the end of the experiment. When compared to natural farming system, the increase in physico-chemical attributes under chemical farming system was rather small. However, percent increase in available N (1.91), P (9.35) and K (3.64) under natural farming system was lower as compared to 7.81, 20.80 and 4.89 percent, respectively, under chemical farming system. The increases in bacterial, actinomycetes and fungal count under natural farming system were 82.29, 94.47 and 147.82 %, respectively, as compared to 1.39, 9.55 and 20.80, respectively, under chemical farming system (Figure 5). Similar trends were observed for enzymatic activity.

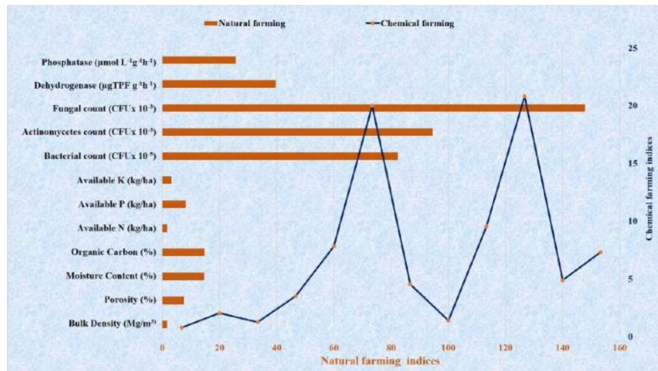

Fig. 5: Percent increase in soil properties under natural farming system compared to chemical farming system.

Nutrient Uptake (NPK)

Data on N, P and K-uptake (Fig 6) differ substantially in the above-ground part of cauliflower. The application of jeevaamrut and ghanjeevamrut, had significant influence on N, P and K-uptake. The nitrogen (76.28kg/ha), phosphorus (9.94 kg/ha), and potassium (58.16kg/ha) uptake under natural farming system were significantly higher as compared to 55.54, 7.53 and 45.68 kg/ha, respectively under chemical farming system. The amplified nitrogen, phosphorus and potassium uptake in cauliflower was reported under natural farming system in conjunction with jeevamrut and ghanjeevamrut. This may be attributed to the readily available soil nutrients with their application as it helps in enhancing the plant-available forms of nutrients in rhizosphere and also synthesizes growth-stimulating plant hormones. According to Parveen *et al*. (2024), phosphorous is associated with several vital functions, such as the proper distribution of sugar and starch and its consumption, better photosynthesis activity and root growth are achieved. Better root growth might have resulted in better uptake of nutrients. Our results are also consistent with that of Chatterjee and Bandhopadhyay (2014).

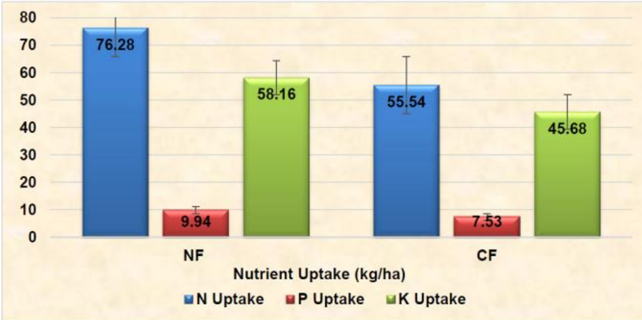

Fig. 06: Nutrient Uptake (NPK)

Growth parameters, yield, land equivalent ratio and crop equivalent yield

The results obtained with respect to the various plant growth, yield, quality, and economic characteristics have been presented and discussed with a view to find out the cause and effect of natural farming and chemical farming systems, for sorting out the information of practical value. The data on pooled values of no. of leaves, leaf area index, curd weight are enumerated in Table 6. Number of leaves (18.50 and 15.50), leaf area index (0.78 and 0.62) and curd weight (978.44 and 802.49 g) vary significantly under natural farming and chemical farming, respectively. Increase in number of leaves might be due to the adoption of all natural farming practices as the higher absorption of nutrients enhanced cell division, cell elongation, and thus concomitant increase in metabolic activity.

Data presented in table 6 reveal that CEY (294.49 q/ha) under natural farming was recorded with fenugreek as intercrop with cauliflower while the sole crop of cauliflower yielded 261.73 q/ha under chemical farming system. The results revealed that intercrops have a combined effect of better utilization of growth resources than sole cropping of main crop and more efficient conversion, resulting in higher yields per unit area than sole crops. LER was found to be 2.09 under natural farming system. LER compares the efficiency of intercropping in using environmental resources to that of monocropping. Also, the land is used more efficiently in the intercropping system. The critical value is the value of unity. When the LER is greater than one, intercropping promotes the growth and yield of the intercropped species, whereas when the LER is less than one, intercropping has a negative impact on the species' growth and yield. B: C ratio was also recorded higher (8.90) when compared with chemical farming system (5.81).

Our finding has been supported by earlier findings of Torrey 1950 and Jagriti *et al*. (2018). Better nutrient status of jeevamrut formulation (2500 litre ha^{-1}) resulted in profused growth in the form of higher dry matter accumulation and yield parameters (Kasbe *et al*., 2009). Previous researchers also found that applying organic manures in conjunction with fermented organics such beejamrut, jeevamrut, and panchagavya significantly improved plant height, dry matter accumulation, branch count, leaf area index (LAI), and seed output (Shwetha and Babala 2008). Maximum equivalent yield of pigeon pea (34.36 t ha^{-1}) was recorded when intercropped with sorghum (Vermam *et al*. 2005). Our results got support from the early findings in garden pea-fenugreek-radish cropping system; in the fenugreek-normal-leafed pea and in pea-coriander intercropping. Benefit cost ratio recorded was also higher in natural farming (6.08) as compared to chemical farming (3.06) (Abdelkader *et al*., 2019, Jamwal *et al*., 2024, Zivanov, 2018).

Table 6: Growth parameters, yield, LER and B:C ratio

Farming practice	No. of leaves	Leaf Area Index	Curd weight (g)	LER
NF	18.50	0.78	978.44	2.09
CF	15.50	0.62	802.49	
t-test	6.92*	7.46*	12.97*	
	Yield (q/ha)			
	Cauliflower	Fenugreek	Crop Equivalent Yield (CEY t/ha)	B: C ratio
NF	267.90	76.54	294.49	8.90
CF	261.73	-	-	5.81

Conclusion

Natural farming practices significantly influence soil properties, nutrient uptake, yield and performance of cauliflower (Brassica oleracea var. botrytis). Different natural farming practices viz. application of natural farming inputs, mulching, intercropping and Vapor-Aided Plant Soil Air condition improved soil fertility, enhanced microbial activity, and ensured better nutrient availability compared to chemical farming practices. These improvements translated into higher nutrient uptake and stable yields, demonstrating the potential of sustainable farming systems to balance productivity with improved soil health. Thus, adopting resource-conserving and biologically driven farming practices can serve as a viable strategy for enhancing cauliflower production while safeguarding ecological sustainability. Based on our findings, farmers might successfully adopt natural farming practices with lower production costs and greater financial returns than chemical farming. Establishing the efficacy and use of natural farming formulations in agriculture will be aided by expanding study into different regions or crops. To optimize its effects on crop yields and environmental sustainability, more research can look into the best ways to formulate. Further research should be directed toward the extension of this study to other crops and areas, especially in the mid-hill agro-climatic zone of Himachal Pradesh.

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Competing interest The authors have no competing interests to declare that are relevant to the content of this article.

Authors' Contributions

AS carried out the experiment, took observations. MD collected and analyzed the soil samples. AS carried out the experiment and took observations. AV supervised the experiments and provided the important guidance to conduct the experiment. JC supervised the experiments and provided the important guidance to conduct the experiment. BB helped in analyzing the data. RR helped in securing research funds and providing technical support. RK managed the literature searches.

All authors read and approved the final manuscript.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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