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Integrating natural farming for enhanced seed yield, soil health and profitability in onion seed production

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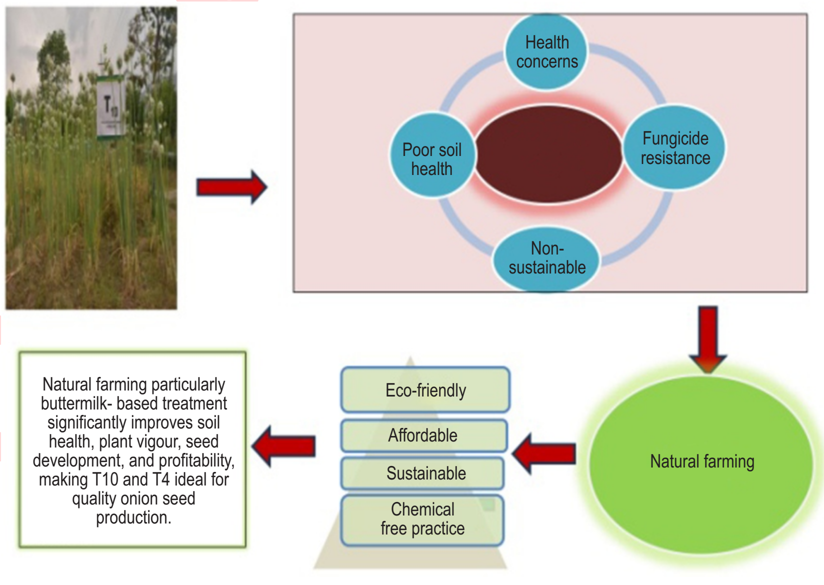
Abstract

Aim: The study conducted from 2022–2024 aimed to study the impact of natural farming on the growth, yield, seed quality and economics on onion seed production and, to identify natural treatments that could serve as sustainable alternatives to conventional farming.



Methodology: Thirteen treatments involving different cropping systems and natural sprays such as buttermilk and *Sounthaster* were evaluated, including a conventional control. Plant height, leaf count, umbel diameter, seeds per umbel, 1000-seed weight and disease incidence, severity were among the field metrics that were noted. Seed quality traits, soil parameters were assessed using standard procedures and economic returns were expressed in terms of Benefit: Cost ratio.

Results: Maximum plant growth, days to flowering, highest seed yield, minimum days to seed harvest, and lowest disease incidence was recorded in T_{10}- Onion sole crop with 4 sprays of Butter milk. T_4 - Onion+Fenugreek with 4 sprays of Butter milk performed statistically at par with T_{10} and T_{13}. Both T_{10} and T_4 also recorded superior seed quality and higher Benefit: Cost ratio.

Interpretation: The results showed that the natural farming, particularly buttermilk-based treatments, improves soil health, plant growth, and seed vigour, resulting in increased yield and quality. Hence, for the production of high-quality onion seeds, treatments T_{10} and T_4 are therefore appropriate and profitable choices.

Key words: Buttermilk, *Jeevamrit,* Natural farming, Onion seed

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Introduction

Onion (*Allium cepa* L.) is a globally important spice crop valued for enhancing food with its distinct flavours and aromas (Nissa *et al*., 2024). It is abundant in nutrients, including vitamins, minerals, and flavonoids, providing many health advantages, including anti-inflammatory and cardiovascular benefits (Jaggi, 2005). India is the 2^{nd} largest onion producer, with Maharashtra leading in cultivation, while Gujarat has the highest productivity (NHB, 2022). Onion seeds are produced through bulb-to-seed and seed-to-seed methods, each with benefits and drawbacks, but seed quality deteriorates quickly under environmental changes (Ranjan *et al.,* 2016). Due to their seasonal and semi-perishable quality, onions are vulnerable to infections that lower their yield, quality, and shelf life (Das *et al.,* 2025). Chemical pesticides and fertilizers are used in conventional seed production which degrades soil biology and seed quality. Therefore, in order to avoid negative effects on the environment and human health, sustainable and eco- friendly disease-management techniques are urgently required (Saini *et al.,* 2024).

Natural Farming is one such approach that has drawn a lot of interest; it stresses using as few external inputs as possible, eco-friendly methods and maximising the use of natural processes. Natural Farming is an ecological farming practice that works in harmony with nature and is based on the principle that nature answers all of the issues that humans have caused in the fields of agriculture and the food sector (Thakur *et al.,* 2024; Sharma *et al.,* 2024; Kumar *et al.,* 2023). The four core principles of natural farming are as follows (Sidhu *et al.,* 2026), *Jeevamrit* a microbial formulation that enhances soil microorganisms; Mixed cropping/intercropping, growing two or more crops together, Achhadan (mulching), the continuous coverage of soil using various crop residues and mulches; and Waaphasa, which refers to maintaining a soil microclimate that retains moisture (Dorin, 2022). *Jeevamrit* is prepared using native cow excreta, along with ingredients like water, jaggery, soil, pulse flour, or lime (Neelam and Kadian, 2016). *Jeevamrit* encourages the growth and population of beneficial soil microflora, cyanobacteria, and plant growth promoting rhizobacteria (PGPRs) in addition to some pathogen-harming antagonistic microorganisms. Adding this microbial mix increases humus levels, supporting a range of soil organisms (Singh *et al.,* 2022). This soil food web enhances crop productivity, biodiversity, carbon sequestration, and water retention (RySS, 2019).

Pest and disease control involves natural formulations such as *Neemaster, Agniaster, Brahmaster* and *Sounthaster,* obtained from neem, ginger, garlic and chili, which have insecticidal and fungicidal properties (Joshi *et al.,* 2020). Additionally, buttermilk (*Khatti lassi*) is used occasionally for disease management (Aulakh *et al.,* 2022). Buttermilk from cow milk shows strong antibacterial activity against pathogens like *Salmonella, E. coli* and *Staphylococcus aureus* (Jean *et al.,* 2016). Its composition includes casein, fats, lactose, lactic acid, and beneficial microbes combined with its acidic pH helps reduce phylloplane pH when applied foliarly (Libudzisz and Stepaniak 2003). It protect plants by forming physical barriers, inducing systemic resistance or promoting biocide production (Ferrandino and Smith, 2006). The foliar spray of *P. fluorescens* and buttermilk (0.5%) reduces the incidence of false smut and sheath rot in rice (Jeyalakshmi *et al.,* 2021). Limited reports are available on the use of these literature which integrated all the components and principles of natural farming for seed production in onion. Therefore, this study was carried out to investigate how natural farming components influence onion seed production and its quality parameters.

Materials and Methods

Experimental site: The study was carried out in the *Rabi* season (October- May) of 2022–2024 at Dr. Yashwant Singh Parmar University of Horticulture and Forestry in Nauni, Solan, and Himachal Pradesh, India. Laboratory research was done in the Department of Soil Science and Water Management and Seed Science and Technology, field experiments were carried out at the Natural Farming Model Farm. The study area falls in the mid-hill sub-temperate zone, where the experimental site is situated 1276 m above sea level and has chilly winters and warm summers.

Soil analyses: Prior to the experiment, composite soil samples (0–15 cm depth) were examined for microbiological and physio-chemical characteristics. Organic carbon was measured by Rapid titration method (Walkley and Black, 1934), available nitrogen, phosphorus by alkaline potassium permanganate method (Subbiah and Asija, 1956), alkaline sodium bicarbonate method (Olsen *et al.,* 1954), normal neutral ammonium acetate method (Merwin and Peech, 1951) and microbial count (Bacteria, Fungi, actinomycetes) by Serial dilution standard spread plate technique (Subha Rao, 1999). Initial value of soil parameters were recorded as organic carbon -1.12 (%), Nitrogen – 383 (kg ha^{-1}), Phosphorus - 26.9 (kg ha^{-1}), Potassium- 269 (kg ha^{-1}), Bacteria (112.25 × 10^5 cfu g^{-1} soil), Fungi (5.28 × 102 cfu g^{-1} soil), Actinomycetes (18.54× 10^3 cfu g^{-1} soil).

Experiment detail: Thirteen treatments viz. T_1: Onion+Pea with 4 sprays of Butter milk; T_2: Onion+Pea with 4 sprays of *Sounthaster;* T_3Onion+Pea with 2 sprays of Butter milk and 2 sprays of *Sounthaster;* T_4: Onion+Fenugreek with 4 sprays of Butter milk; T_5: Onion+Fenugreek with 4 sprays of *Sounthaster;* T_6: Onion+ Fenugreek with 2 sprays of Butter milk and 2 sprays of *Sounthaster;* T_7: Onion+Pea+Fenugreek with 4 sprays of Butter milk; T_8: Onion+ Pea+Fenugreek with 4 sprays of *Sounthaster;* T_9: Onion+Pea+Fenugreek with 2 sprays of Butter milk and 2 sprays of *Sounthaster;* T_{10}: Onion sole crop with 4 sprays of Butter milk; T_{11}: Onion sole crop with 4 sprays of *Sounthaster;* T_{12}: Onion sole crop with 2 sprays of Butter milk and 2 sprays of *Sounthaster;* T_{13}: Control–Conventional in a Randomized Block Design (RBD) with three replications and a Completely Randomized Design (CRD) with four replications were applied in the field and laboratory experiment on onion (cv. Palam Lohit) seed production, respectively. Pea and fenugreek were used as intercrops, with 39 plots sown on 17[th] October 2022 and 2023. The field was prepared by ploughing, harrowing and levelling. Onion bulbs (cv. Palam Lohit) were planted at 45 × 30 cm spacing. Natural farming inputs like *Jeevamrit, beejamrit* and *GhanJeevamrit* were prepared and applied. All natural farming formulations were made on the farm as per the method Devvrat (2017). Grass mulching (*Achhadan*) and limited irrigation through waaphasa maintained soil moisture (Kumar *et al.,* 2023). Harvesting was done when 25–30% of seeds were visible, followed by sun-drying. Threshing was done by hand-rubbing, and seeds were dried until moisture content was below 8%.

Preparation of Butter milk: Three litres of milk were used to make curd. After removing the creamy layer, it was left for three to five days to allow a grey layer to form. It was combined with water and sprayed @ 3% on onion crop to prevent fungal diseases (Devvrat, 2017).

Preparation of *Sounthaster*: It was made by combining 200 g of ginger powder with 2 l of water. The mixture was then boiled until it was half by volume and allowed to cool, followed by adding 2 l of desi (native) cow milk to a bowl, boiling it, and then removing the cream. After two hours of mixing and stirring with a wooden stick, the solutions were ready for use. *Sounthaster* was sprayed at 3% to prevent fungal disease (Devvrat, 2017).

Natural farming practices: *Jeevamrit* drenching at a 10% concentration was uniformly applied across all treatments, excluding control, at 15-day intervals to enhance soil microbial activity and nutrient availability. *Achhadan* (grass mulching) was practiced in all treatments, except control to conserve soil moisture, regulate temperature, and suppress weed growth. Additionally, a *waaphasa* line measuring 1 × 1 × 1 feet was established in the field to facilitate proper aeration and efficient irrigation management. To further support plant health and protection, foliar sprays of buttermilk and *Sounthaster* were applied at weekly intervals at a 3% concentration.

Data collection: From the ground to the longest umbel, the height of the plant was measured. Ten randomly selected plants were counted for leaves, bolters and umbels. Vernier caliper was used to measure umbel diameter and the number of days till seed harvesting was recorded from the date of bulb planting until the umbellets dried and began to open, revealing the black seeds. Five randomly selected mature umbels per plot were counted to determine the average number of seeds per umbel. Seed yield per plot was calculated by weighing the collected seeds from a plot. Seed yield per hectare was calculated using the formula:

$$\text{Seed yield per ha (kg)} = \frac{\text{Seed Yield per plot} \times 8000}{\text{Size of plot (m}^2\text{)} \times 1000}$$

Disease incidence (DI) and diseases severity (DS) were determined using established formulae. Purple blotch and Stemphylium blight severity were assessed on a 0–5 scale (Tarr 1981):

$$\text{DI (\%)} = \frac{\text{Number of plants infected}}{\text{Total number of plants observed}} \times 100$$

$$\text{DS (\%)} = \frac{\text{Sum total of all ratings}}{\text{Maximum diseases grade} \times \text{number of leaves observed}}$$

Crop equivalent yield (CEY) was computed based on intercrop yields and market prices and calculated by the formula:

$$CEY = \sum(Yi.ei)$$

Where, Yi is yield of ith component and e_i is equivalent factor of ith component or price of ith crop. Harvested onion seed was examined for seed quality characteristics such as germination (%), seedling length (cm), seedling dry weight (mg), seedling vigor index-I and II, electrical conductivity (dSm^{-1}) and accelerated aging test as per procedure given by ISTA (1985).

Economics: The input and output involved were used to calculate the benefit-to-cost ratio. The following formula was used to determine the gross returns and net returns.

Gross returns = Seed yield × Seed price
Net returns = Gross returns – Production cost
Benefit cost ratio = Net returns/ Total expenses

Statistical analyses: Using computer software OPSTAT, the statistical analysis for Randomized Block Design (RBD) and Completely Randomized Design (CRD) was conducted in accordance with the experiment's design as recommended by Panse and Sukhatme (2000).

Results and Discussion

Pooled data from Table 1 indicate that natural farming significantly influenced onion plant growth. The maximum plant height (88.63 cm) was observed in T_{10}, followed by T_{13} (87.82 cm) and T_4 (86.38 cm), all statistically at par. Natural farming also significantly increased the number of leaves per plant at 90 days after planting. The maximum leaves per plant (30.54) were recorded in treatment T_{10} followed by T_4 (29.84), T_{13} (29.26) and T_{11} (28.57). These four treatments were statistically on par. The study confirms that parameters in natural farming treatments T_4 and T_{10} were comparable to conventional farming (T_{13}). Natural farming components like *Jeevamrit, GhanJeevamrit,* mulching (*Achhadan*) and *waaphasa* likely enhanced the microbial activity, improving nutrient availability and uptake (Choudhary *et al.,* 2022; Panda *et al.,* 2020). Chadha *et al.* (2012) and Sharma *et al.* (2023) have observed similar increase in the plant growth parameters in different crops including onion and cowpea after natural farming treatments and correlated with higher concentrations of nitrogen, phosphorus and potassium upon application of *Jeevamrit* to the soil. Jamwal *et al.* (2024) reported similar finding in pea under natural farming system. Fenugreek

Table 1: Impact of natural farming components on vegetative and flowering parameters in onion seed production

Treatments	PH (cm)			NOL/P			NOU/P			UD (mm)		
	2022-23	2023-2024	Pooled	2022-23	2023-2024	Pooled	2022-23	2023-2024	Pooled	2022-23	2023-2024	Pooled
T_1	83.95	82.90	83.43	27.92	26.37	27.14	6.75	6.61	6.68	59.10	53.53	56.32
T_2	83.34	82.22	82.78	26.94	27.34	27.15	6.39	6.29	6.34	56.55	55.49	56.02
T_3	83.01	80.86	81.94	26.36	26.14	26.25	6.13	6.11	6.12	55.48	53.67	54.57
T_4	86.38	86.86	86.38	30.05	29.63	29.84	7.55	7.21	7.38	64.33	58.33	61.43
T_5	84.69	83.29	83.99	27.12	28.01	27.56	7.32	7.15	7.23	64.30	53.60	58.95
T_6	84.48	83.05	83.77	27.57	27.03	27.30	7.16	6.96	7.06	59.23	56.10	57.67
T_7	82.68	78.34	80.51	25.79	24.55	25.17	5.86	5.85	5.85	54.58	53.27	53.93
T_8	80.64	77.78	79.21	24.76	24.93	24.85	5.56	5.52	5.54	53.08	52.98	53.03
T_9	80.53	77.34	78.93	22.84	20.41	21.62	5.60	5.46	5.53	52.67	51.97	52.32
T_{10}	89.21	88.04	88.63	30.86	30.23	30.54	7.61	7.58	7.60	67.11	66.33	66.72
T_{11}	87.51	84.46	85.98	27.44	29.70	28.57	7.38	7.33	7.36	60.69	60.50	60.59
T_{12}	85.69	83.40	84.54	26.64	28.59	27.62	7.31	7.22	7.26	61.89	56.30	59.10
T_{13}	88.29	87.35	87.82	28.89	29.63	29.26	7.57	7.49	7.53	63.14	63.50	63.32
Mean	84.65	82.76		27.17	27.12		6.78	6.67		59.39	56.58	
C.D. (P=0.05)	3.07	3.53	1.42	3.33	3.68	2.51	0.51	0.31	0.17	4.97	7.54	6.13

PH – plant height, NOL/P – number of leaves per plant, NOU/P- number of umbels per plant, UD- Umbel diameter

intercropping in T_4 contributed to nitrogen fixation, boosting onion growth. Buttermilk sprays in T_4 and T_{10} also helped reduce disease incidence, further enhancing plant growth. Dhkal *et al.* (2022) have observed plant growth improvement and disease reduction upon buttermilk sprays in musk melon.

The highest number of umbels per plant (7.60) was recorded in T_{10} followed by T_{13} (7.53, Conventional farming) and T_4 (7.38) all statistically at par with each other. The largest umbel diameter (66.72 mm) was also observed in T_{10} which was statically at par with T_{13} (63.32 mm), T_4 (61.43 mm) and T_{11} (60.59 mm) (Table 1), while the maximum seeds per umbel (1012.67) were found in T_{10}, followed by T_{13} (992.83) and T_4 (987.00) (Fig. 1). Natural farming components like *Jeevamrit, GhanJeevamrit,* mulching (*Achhadan*) and waaphasa enhanced microbial activity, increasing nutrient availability. These include microbes from genus *Bacillus* sp., *Pseudomonas* sp., *Azatobacter* sp., *Beijerinckia* sp., *Serretia* sp. and *Xanthomons* sp (Surpura *et al.,* 2025). *Jeevamrit* likely boosted macronutrient uptake, supporting root growth and nitrogen fixation, which improved flowering. *Jeevamrit* also improved nutrient solubilization and uptake and improved the plant growth (Brar *et al.,* 2019). *Jeevamrit* increased macronutrient availability may have contributed to the increase in umbels, umbel diameters and seeds per umbel by promoting strong root development and enhancing N fixation, both of which benefited overall plant growth. Increased photosynthetic activity brought on by more leaves and the transit of carbohydrates from source to sink during the reproductive stage ultimately increased the number of umbels per plant and other flowering characteristics. Panda *et al.* (2020) in tomato found similar results and reported that enhanced activities of beneficial microorganisms due to application of bio-formulations of natural manures like Jeevamrit and Ghanjeevamrit might have helped the plants to grow taller by encouraging vegetative growth and development. These microorganisms cause nutrient solubilization thereby increase the availability of important nutrient elements phosphorus, potassium, and nitrogen which ultimately enhances and provides the necessary supply of nutrients throughout the growing season. Fenugreek intercropping in T_4 contributed to nitrogen fixation, positively impacting flowering. El-Mehy *et al.* (2022) found that intercropping fenugreek with faba beans increased the pod production. Buttermilk application in T_4 and T_{10} reduced disease incidence, further improving flowering traits.

Natural farming significantly influenced seed yield. The highest seed yield per plot (136.33 g) and seed yield per hectare (403.94 kg ha^{-1}) was recorded in T_{10} (Onion sole crop with 4 sprays of Buttermilk), followed by T_{13} (133.17 g and 394.58 kg ha^{-1}) and T_4 (132.33 g and 392.09 kg ha^{-1}) (Table 2; Fig. 2). The higher seed yield in T_4 and T_{10} was due to higher umbels per plant, larger umbel diameter and more seeds per umbel supported by *Jeevamrit* and *GhanJeevamrit* improving soil fertility and plant vigour. Enhanced seed yield and its components may be linked to improved root growth and efficient water and nutrient uptake, promoted by organic inputs. *Jeevamrit* application likely improved the soil structure, increasing porosity and water retention (Sharma *et al.,* 2024; Mariappan *et al.,* 2025). In *Jeevamrit,* growth-promoting compounds such as Indole acetic acid, giberellic acid, cytokinin and beneficial microbes increase leaf area, photosynthesis and nutrient flow, increasing seed yield (Shafiq *et al.*, 2025). Mulching increased crop-weed competitiveness, reduced weed growth, and improved water availability, all of which increased the production. Intercropping fenugreek with onion in T_4 contributed

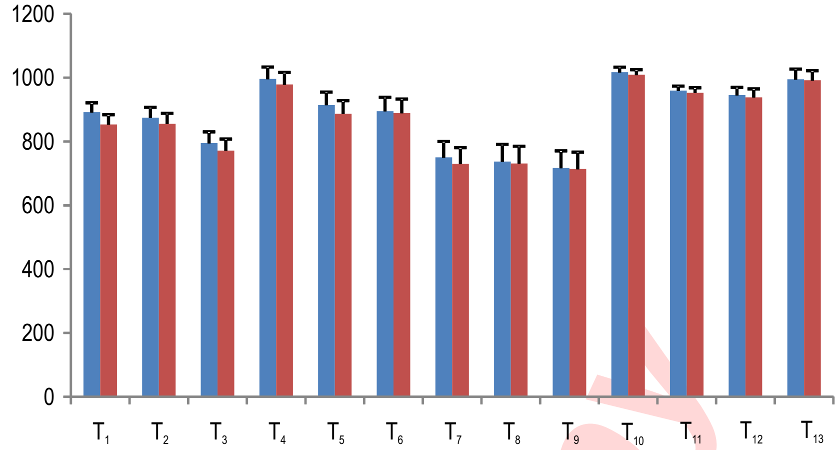

Fig 1: Effect of natural farming components on number of seeds per umbel (NOS/U) in onion.

Table 2: Effect of natural farming components on seed yield and yield contributing parameters in onion seed production

Treatments	DSH			1000SW (G)			SY/P (g)		
	2022-2023	2023-2024	Pooled	2022-2023	2023-2024	Pooled	2022-2023	2023-2024	Pooled
T_1	218.00	217.33	217.67	3.27	3.17	3.22	125.00	117.33	121.17
T_2	219.00	218.00	218.50	3.27	3.16	3.22	121.67	120.00	120.83
T_3	225.00	219.00	222.00	3.20	3.20	3.20	124.00	117.00	120.66
T_4	209.66	209.00	209.33	3.40	3.30	3.35	132.67	132.00	132.33
T_5	214.66	214.00	214.33	3.25	3.20	3.23	124.00	120.67	122.33
T_6	225.66	218.66	222.17	3.27	3.16	3.22	122.66	119.66	121.17
T_7	224.66	223.33	224.00	3.19	3.19	3.20	120.33	117.67	119.00
T_8	226.66	218.00	222.33	3.19	3.15	3.17	121.66	115.00	118.33
T_9	226.66	218.00	222.33	3.17	3.12	3.15	112.66	105.00	108.83
T_{10}	219.00	218.66	218.83	3.42	3.37	3.40	137.33	135.34	136.33
T_{11}	218.66	218.00	218.33	3.33	3.30	3.32	128.66	125.00	126.83
T_{12}	219.33	217.66	218.50	3.26	3.25	3.25	126.33	119.66	123.00
T_{13}	217.00	214.33	215.67	3.43	3.25	3.34	135.00	131.33	133.17
Mean	220.30	217.22		3.28	3.21		125.53	121.20	
C.D. (P=0.05)	5.80	3.70	5.54	0.17	0.10	0.09	12.05	7.50	13.83

DSH - Days to seed harvesting, 1000SW- 1000 Seed weight (g), SY/P - Seed Yield/plot (g)

to nitrogen fixation improving nutrient availability and efficiency. Intercropping fenugreek with onion likely played a significant role in enhancing seed yield by improving the soil fertility and resource utilization. As a leguminous crop, fenugreek has the ability to fix atmospheric nitrogen, thereby enriching the soil nitrogen pool and increasing its availability for the companion crop. This enhanced nitrogen availability may have promoted greater nitrogen accumulation in plants and improved nitrogen use efficiency. In addition, the intercrop system likely improved the water use efficiency through better resource sharing and reduced competition. The denser crop canopy and ground coverage provided by fenugreek may also have contributed to effective weed suppression (Duchene *et al.,* 2017). Collectively, these factors might have resulted in improved growth, yield attributes, and ultimately higher seed yield. Yogananda *et al.* (2018) in cowpea reported comparable results. There results indicate that the enhancement in seed yield and yield attributes which may be linked to improved root growth stimulated by organic nutrients and more efficient absorption of water and nutrients due to soil application of Jeevamrit, which loosens the soil and increases the water holding capacity.

The lowest incidence and severity of purple blotch (11.86% and 3.44%) and stemphylium blight (4.02% and 2.16%) were observed in T_4 comprising, Onion Fenugreek with 4 sprays of Butter milk . T_{13} treatment results were slightly higher, although they were statistically comparable. Additionally, T_{10} treatment showed the lowest disease incidence, demonstrating the benefits

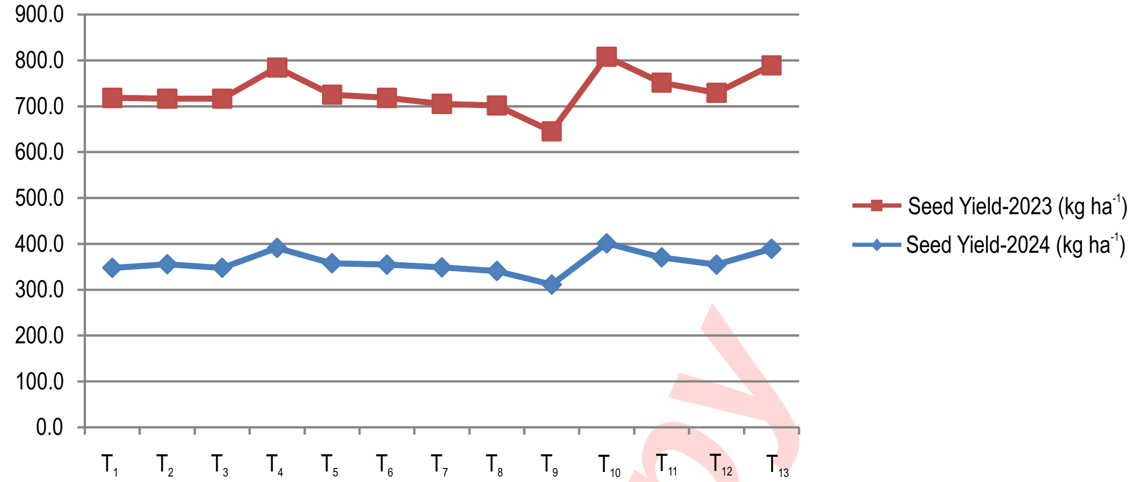

Fig. 2: Impact of natural farming components on seed yield per hectare in onion seed production.

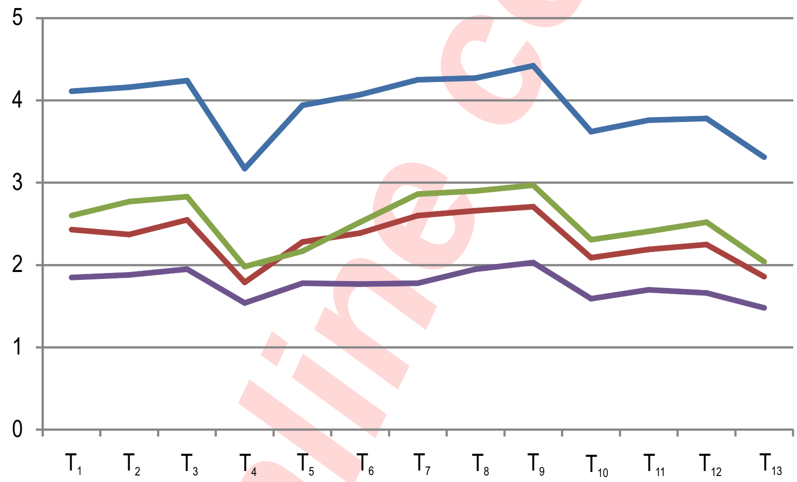

Fig. 3: Impact of natural farming components on purple blotch and stemphylium blight disease incidence and severity. DI- Diseases incidence, DS- Diseases severity, PB- Purple blotch, SB- Stemphylium blight. Pooled data from 2022-2024.

of natural farming methods (Fig 3). Natural farming components like *Jeevamrit, GhanJeevamrit,* mulching (*Achhadan*) and waaphasa enhanced the beneficial soil microbes, reducing disease incidence. These microorganisms increased the productivity and quality reinforced plant resistance, and enhanced nutrient availability (Vaish *et al.,* 2020; Maduka and Udensi, 2019). Actinobacteria found in Jeevamrit help in fixing nitrogen and breakdown organic materials, while acting as bio-control agents against plant diseases.

Additionally, it contain metabolites that improve plant defense and growth, including as jasmonic acid indole-3-acetic acid and salicylic acid (Duraivadivel *et al.,* 2022). As salicylic acid and jasmonic acid are among the components of Jeevamrit, their application can aid in plant defense. Additionally, intercropping fenugreek and onion in natural farming treatment T_4 probably decreased the frequency of disease through induced resistance, in which plant components suppress pathogens or stimulate immune responses in nearby plants. Plant immunity may have been influenced by competition for resources (Boudreau, 2013). Furthermore, intercropping increased plant development and disease resistance by fostering beneficial soil microorganisms like *Bacillus* and *Pseudomonas* (Chang *et al.,* 2022). Buttermilk application in natural farming treatments T_4 and T_{10} reduced disease incidence and severity in onion due to its bioactive compounds, including lactic acid bacteria, fats, and proteins, which create protective barriers and promote systemic resistance (Libudzisz and Stepaniak, 2003). Its acidic nature lowers

Table 3: Impact of natural farming practices on seed quality parameters of harvested onion seeds

Treatments	G (%)*	SL (cm)	SDW (mg)	SVI	SVII	EC (dSm^{-1})	AAT (%)*
T_1	89.37 (9.50)	16.35	2.25	1361.45	207.29	0.166	78.38(8.85)
T_2	88.62 (9.46)	14.77	2.17	1311.89	201.85	0.167	77.75 (8.81)
T_3	88.37 (9.45)	14.67	2.05	1299.99	192.31	0.177	75.75 (8.70)
T_4	92.25 (9.65)	18.60	2.83	1719.08	261.31	0.133	83.63 (9.14)
T_5	90.50 (9.56)	17.39	2.47	1574.51	227.39	0.150	80.38(8.96)
T_6	89.75 (9.52)	17.96	2.30	1463.48	223.38	0.158	79.88(8.93)
T_7	87.12 (9.38)	13.39	2.01	1167.4	175.46	0.182	75.00(8.65)
T_8	86.00 (9.32)	12.12	2.00	1042.61	173.19	0.186	73.75 (8.58)
T_9	85.25 (9.28)	11.17	1.97	952.60	168.27	0.193	73.25 (8.55)
T_{10}	93.37 (9.71)	19.60	2.99	1832.66	280.22	0.127	87.50(9.35)
T_{11}	91.62 (9.62)	18.28	2.73	1676.00	250.44	0.140	83.38(9.12)
T_{12}	90.75 (9.57)	17.95	2.50	1628.15	227.40	0.146	81.50(9.02)
T_{13}	92.75 (9.68)	18.86	2.84	1751.55	263.29	0.133	87.13(9.33)
C.D.(0.05)	0.14	2.42	0.30	226.76	28.43	0.007	0.17

G- Germination, SL – seedling length, SDW – seedling dry weight, SV - seedling vigour index, EC- electrical conductivity, AAT – accelerated ageing. Pooled data of 2023 and 2024. * Square root transformation values are shown in parenthesis.

Table 4: Effect of natural farming practices on soil parameters in onion after harvest of crop

Treatments	Organic carbon (%)		Available ($kg\ ha^{-1}$) nitrogen		Available ($kg\ ha^{-1}$) phosphates		Available ($kg\ ha^{-1}$) potassium	
	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24	2022-23	2023-24
T_1	1.36	1.62	410.70	445.70	277.30	279.00	28.67	30.67
T_2	1.41	1.71	409.70	444.00	279.00	278.00	30.00	32.31
T_3	1.39	1.71	406.00	442.00	277.70	277.70	32.15	34.85
T_4	1.37	1.68	404.00	438.30	275.00	276.00	26.34	30.25
T_5	1.39	1.74	402.00	437.00	280.00	281.00	32.82	35.00
T_6	1.38	1.69	407.70	443.00	280.00	283.70	36.19	37.67
T_7	1.45	1.73	414.30	447.00	279.00	280.00	30.73	33.18
T_8	1.46	1.77	416.00	449.30	277.00	278.00	31.32	34.96
T_9	1.47	1.80	418.30	452.70	277.30	278.30	35.17	38.48
T_{10}	1.32	1.61	398.00	433.70	276.70	280.00	34.48	37.16
T_{11}	1.30	1.59	397.30	432.00	279.30	281.00	32.11	35.85
T_{12}	1.26	1.55	400.70	435.00	279.70	281.70	34.82	36.56
T_{13}	1.16	1.23	389.70	406.00	267.00	275.30	32.86	34.83
Mean	1.36	1.64	405.70	438.80	277.30	279.20	28.67	30.67
C.D. (P=0.05)	0.065	0.047	5.69	5.32	NS	NS	NS	NS

OC- Organic carbon, AN –available nitrogen, AP –available phosphorus, AK – available potassium, NS – non significant

phylloplane pH, inhibiting pathogen growth, while also serving as a base for bio-control agents that produce antimicrobial compounds (Benkerroum *et al.,* 2004). Additionally, buttermilk enhances chlorophyll content supporting the synthesis of salicylic and jasmonic acids which strengthen plant defence mechanisms (Dhkal *et al.,* 2022).

Onion seed were tested for various seed quality parameters and maximum seed germination (93.37%), seedling length (19.60 cm), seedling dry weight (2.99 mg), seedling vigour index –I & II (1832.66 and 280.22), germination after accelerated ageing (87.50 %) and lowest electrical conductivity was reported in T_{10} (Table 3). Higher germination in natural farming treatments may be due to improved nutrient uptake, leading to better dry matter accumulation and bolder, high-quality seeds. Enhanced vegetative and reproductive growth under natural farming resulted in seeds with higher 1000 seed weight promoting better germination and other seed quality parameters.

The pooled data clearly demonstrate that natural farming treatments significantly improved the soil organic carbon after harvest compared to the initial value of 1.12%. T_9 intercropping combined with *Jeevamrit/GhanJeevamrit* treatments, mulching (*Achhadan*) and waaphasa, produced the highest organic carbon (1.64%), followed by T_8 (1.62%) (Table 4). These methods fared better than the conventional practices (T_{13}).

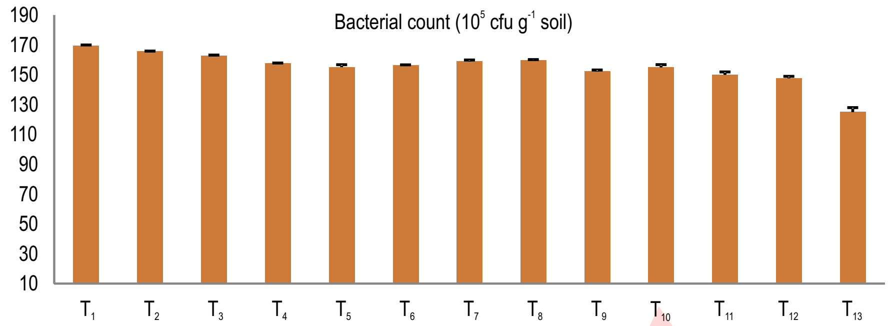

Fig. 4: Impact of natural farming practices on soil bacterial population after harvest of crop.

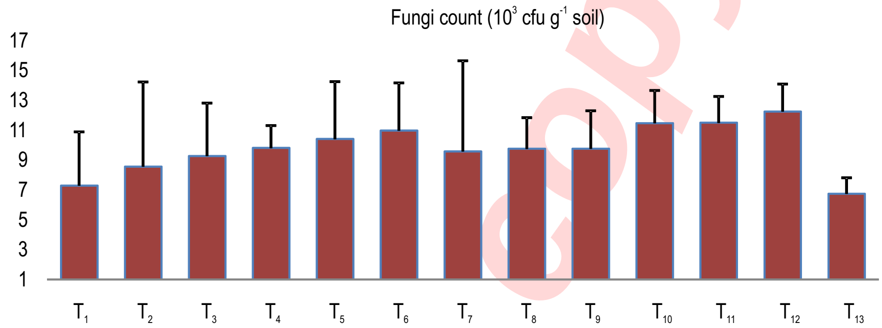

Fig. 5: Impact of natural farming practices on soil fungi count after harvest of crop.

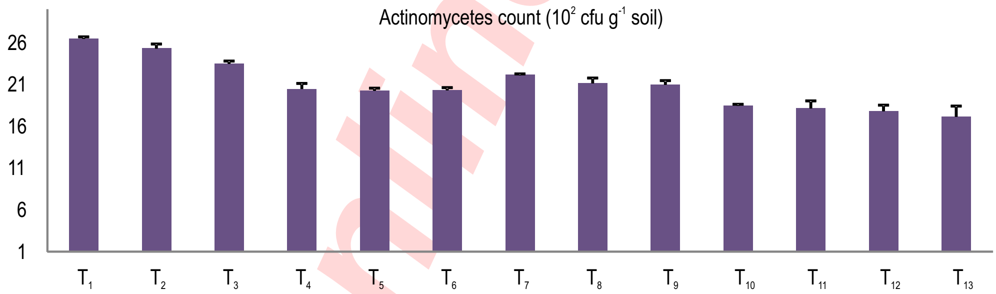

Fig. 6: Impact of natural farming practices on soil actinomycetes count after harvest of crop.

According to Sharma *et al.* (2008), the increase in organic carbon can be linked to the ongoing addition of organic matter through natural inputs based on cow dung, which enhance soil carbon. Further evidence of organic carbon enhancement under natural farming in grain and pulse systems from the study of Darjee *et al.* (2024). Intercropping improved soil carbon sequestration by adding more biomass, nitrogen-rich residues and root litter (Poddar *et al.,* 2017). Additionally, mulching was essential since it reduced the organic carbon losses and added decomposed plant material (Tang *et al.,* 2022; Bajoriene *et al.,* 2013). Mulching, intercropping and organic amendments all contributed to a notable rise in soil organic carbon in natural farming systems.

The two year data results indicate that natural farming practices had a significant influence on available nitrogen in soil after harvest, compared to initial level of 383.00 kg ha^{-1}. The highest available nitrogen (435.50 kg ha^{-1}) was observed in treatment T_9, followed by 432.60 kg ha^{-1} in T_8, both of which outperformed the conventional farming treatment (T_{13}). The notable increase in nitrogen under natural farming is due to the use of organic inputs like *Jeevamrit, GhanJeevamrit,* mulching (*Achhadan*) and *waaphasa,* which increased microbial activity and promoted rapid mineralization of organic materials. Earlier it was found that adding natural and organic amendments enhanced the availability of nitrogen (Darjee *et al.,* 2024). Intercropping pea and fenugreek in treatments T_9 and T_8 increased the biomass, root

Table 5: Impact of natural farming practices on crop equivalent yield and economics in onion

Treatments	CEY (kg ha^{-1})	GR (₹ ha^{-1})	CC (₹ ha^{-1})	NR (₹ ha^{-1})	B:C ratio
T_1	361.86	430824	225202	205622	0.91
T_2	360.71	429618	205839	223778	1.08
T_3	360.14	429013	215518	213495	0.99
T_4	399.16	479001	199106	242018	1.21
T_5	367.60	441124	218466	260535	1.19
T_6	365.01	438012	209506	228506	1.09
T_7	355.41	426499	206098	220401	1.06
T_8	354.49	425387	196418	228969	1.16
T_9	326.62	391939	211906	180033	0.84
T_{10}	403.94	484740	200818	283922	1.41
T_{11}	375.79	450951	191138	259813	1.15
T_{12}	364.44	437333	206626	230707	1.11
T_{13}	394.58	473472	228550	244922	0.51

B:C – Benefit cost ratio, CEY – Crop equivalent yield, GR- Gross returns, NR- Net returns, CC- Cost of cultivation

exudates, and nitrogen fixation, enriching the microbial communities and elevating the nitrogen transformation processes (Nagar *et al.,* 2016). Mulching further supported nitrogen enhancement by increasing nitrogen mineralization potential and promoting nutrient release (Zheng *et al.,* 2018). Although the results for potassium and phosphorus were not statistically significant, there was a discernible increase above the starting values. Treatment T_6 had the highest levels of available potassium (283.73 kg ha^{-1}) and phosphorus (37.67 kg ha^{-1}), suggesting that natural farming methods also improved the overall availability of nutrients.

Compared to the initial soil status and the conventional farming treatment (T_{13}), pooled results revealed that natural farming practices significantly enhanced the populations of soil microorganisms, including bacteria, fungi, and actinomycetes. T_1 treatment produced the maximum number of bacteria (169.67 × 10^2 cfu g^{-1} soil) and actinomycetes (26.50 × 10^2 cfu g^{-1} soil), followed by T_2. T_{12} treatment showed the highest fungal count (12.26 × 10^3 cfu g^{-1} soil) (Fig. 4,5,6). The microbial load significantly improved over the original soil conditions in all natural farming methods.

Application of *Jeevamrit, GhanJeevamrit,* mulching (*Achhadan*) and waaphasa which provides organic matter, elevate soil carbon and produce a biologically active rhizosphere is required for increased microbial populations. By providing organic acids, proteins, and easily decomposable substrates *Jeevamrit* promotes microbial growth and contains beneficial bacteria (Gurjar *et al.,* 2024). Actinomycetes, which have a high link with soil organic content, are also supported by increased incorporation of organic matter (Sarkar *et al.,* 2024). In rice-wheat, maize-wheat, brinjal, cabbage and French bean systems, comparable increase in the microbial populations with natural agricultural inputs have been reported (Aulakh, 2013). Pea intercropping as used in T_1 and T_2, increased the microbial abundance because of *Rhizobium* nitrogen fixation, a variety of root exudates, and a higher contribution of organic matter. Intercropping systems based on legumes have been shown to enhance the soil biological health, diazotroph populations, and microbial activity (Maitra and Ray, 2019). Therefore, intercropping legumes with natural farming significantly enhances the microbial dynamics of the soil. Maximum crop equivalent yield (kg ha^{-1}) *i.e.* 403.94 kg ha^{-1} was recorded in treatment T_{10}, followed by 399.16 kg ha^{-1} in treatment T_4. Similarly the maximum benefit cost ratio (1.41:1) was recorded farming treatment T_{10}, followed by 1.21:1 in treatment T_4 (Table 5). Behera and Chandrashekara (2023) reported low cost of cultivation and highest benefit cost ratio with natural farming practices in wheat.

The current study concludes that using natural farming practices can successfully produce high-quality onion cv. Palam Lohit seeds. All the growth parameters, seed yield and quality parameters were better and incidence of diseases was lower when onion seed crop was planted under natural farming system using fenugreek as intercrop with four sprays of butter milk (T_4) or onion seed crop under natural farming system as sole crop with four sprays of butter milk (T_{10}) than that of conventional farming system (T_{13}). These two natural farming treatments also resulted in higher B: C ratio than that of conventional farming system, and thus can be recommended for quality seed production in onion.

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