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# Evaluation of soil health under conventional and integrated organic farming systems models for upper Gangetic plain zone

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ABSTRACT

The study was carried out during 2021–2024 at ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh to evaluate the impact of Integrated Organic Farming System (IOFS) and Integrated Farming System (IFS) on soil biological properties namely microbial population, enzyme activities, and glomalin levels across cereal, vegetable, fruit and fodder crop systems. IOFS consistently demonstrated superior performance with respect to soil health indicators as compared to IFS. Higher microbial populations (bacteria, fungi, and actinomycetes) were observed under IOFS, particularly in vegetable crops. Soil under cereal crops (food system) showed around 41% increase in bacterial population in IOFS model compared to IFS model. Similarly soils under vegetable system showed 32% increase in fungal population in IOFS model. Enzyme activities, including dehydrogenase, β-glucosidase, urease, and alkaline phosphatase, were significantly higher in IOFS, with notable improvements in fruit and vegetable crops. Fodder system showed greater improvement in dehydrogenase (36.8%) and β-glucosidase (34.7%) under IOFS as compared to IFS. IOFS also showed increased levels of Easily Extractable Glomalin (EEG) and Total Glomalin (TG). Vegetable system showed 32% and 14% improvement in EEG and TG respectively, indicating enhanced arbuscular mycorrhizal fungi activity and potential for carbon and nitrogen sequestration. These findings highlight the benefits of organic nutrient and pest management practices in promoting soil fertility and sustainability.

**Keywords**: β-glucosidase, Dehydrogenase, Glomalin, Integrated farming system, Integrated organic farming system, Residue recycling

Intensive agricultural practices such as cropping system based approach, non-judicious use of agrochemicals, mono-cropping etc. has led to the continuous deterioration of soil health which is a serious concern affecting the sustainability of agriculture production in long run. Soil health is declining in many cropping systems in developed as well as developing countries (FAO 2011). Sahrawat *et al.* 2008 have reported widespread deficiency of nitrogen, phosphorus, sulphur, boron and zinc in the farmer's field from different states of India. Soil microbiological activities play a crucial role in soil fertility and plant growth by accelerating the cycling of nutrients, enzymes, and hormones essential for proper plant development. Various agricultural management practices can impact microbial biomass and enzyme activities by modifying the soil microclimate, microorganism habitats, and nutrient cycling processes (Wang *et al.* 2021). Sustainable agricultural development requires the adoption of Integrated Farming Systems (IFS), which incorporate efficient and eco-friendly management of soil, water, crops, and pests in a cost-effective, resource saving manner. In IFS, waste generated by one component serves as a valuable input for another, thus integration of components with each other helps in optimizing resource utilization. For instance, in an integrated crop-livestock farming system, crop residues can be used as animal feed, while livestock manure enhances soil fertility and agricultural productivity.

IFS significantly contribute to improving soil health by increasing levels of nitrogen, phosphorus, organic carbon, and microbial activity, thereby reducing the dependence on chemical fertilizers. It ensures nutritional security, conservation of natural resources, and enhances the climatic and economic resilience of agricultural production systems (Paramesh *et al.* 2019). Livestock manure improves soil

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structure, enriches nitrogen (N), phosphorus (P), and potassium (K) and enhances water infiltration, retention, and cation exchange capacity. It also raises soil *p*H and accelerates organic matter decomposition, boosting fertility (Brouwer and Powell 1998, Walia and Kaur 2013). Therefore, this study was conducted to assess the role of management practices on soil biological properties under different prototype models namely IFS and IOFS Model.

## MATERIALS AND METHODS

*Experiment site and details*: The study was carried out during 2021 to 2024 at ICAR-Indian Institute of Farming Systems Research, Modipuram (29°4'37.36"N, 77°42'15.70"E; 230 msl), Uttar Pradesh. The area located in the northern part of the Indian sub-continent has a semi-arid tropical continental monsoon climate with average maximum and minimum temperatures of 40 °C and 7.8 °C, respectively, and annual precipitation averaging 823 mm. Approximately 90% of the region's annual precipitation occurs between July and October, with usual drought conditions during winter and spring seasons. The soil is classified as sandy loam (*Typic Ustochrept* in the USDA system).

*Prototype models*: Organic and conventional nutrient and pest management practices are followed in two different prototype models namely Integrated Farming System (IFS) and Integrated Organic Farming System Model (IOFS). The IFS model (0.72 ha) is developed with the inclusion of different modules such as cropping systems, agri-horti, multi-layer farming, dairy, boundary plantation and residue recycling (Table 1). The crop residues and farm waste were recycled in the form of compost and vermicompost and applied to the different crops. Paddy straw was also used as mulch in garlic (vegetable module). The remaining amount of nutrients is supplied through chemical fertilizers. Pest and diseases are controlled using chemical controls only. This IFS model with the given components is running from 2020.

The IOFS model (1.0 ha) is developed in the year 2019 with the inclusion of different modules as food system, fodder system, horticulture, Livestock cum bio-input preparation unit (Table 1). The crop residues and farm waste are recycled to make compost and vermicompost which are used to supplement the crop nutrient demand. Weeds are controlled by hand weeding. For insect pest and disease control, traditional preparations like Dashparni, Neemastra, Brahmastra, Agniastra, chilli-garlic extract, Panchagavya, Fermented butter milk etc. were used.

*Soil sample collection and analysis*: Soil samples from IFS and IOFS prototype models were collected after the harvesting of *rabi* season crops (May 2024) at 0–15 cm soil depth. The total viable count of bacteria (Nutrient Agar), fungi (Rose Bengal Agar medium), actinomycetes (Kenknights and Munaier's Medium) were estimated by standard serial dilution and plating method. The soil samples were diluted up to $10^{-5}$ level with a series of 10-fold dilution tubes. A 5.0 g soil sample was mixed in sterilized 45 ml dilution blank ($10^{-1}$ dilution) and mixed properly. After this 1.0 ml aliquot from this mixture was transferred to a 9.0 ml water blank ($10^{-2}$ dilution). Subsequently the

Table 1 Area allocation under different modules of Integrated Farming System (IFS) Model and Integrated Organic Farming System (IOFS) Model

| Modules | Components | Area allocation (ha) | % Area | Modules | Components | Area allocation (ha) | % Area |
|---|---|---|---|---|---|---|---|
| IFS model | | | | IOFS model | | | |
| Cropping system | Rice - Wheat + Mustard - Greengram (0.125 ha) | 0.38 | 53 | Food system | Basmati Rice – Wheat -Sesbania<br>Basmati Rice – Mustard - Green Gram<br>Rice - Chick Pea - Sesbania<br>Maize - Wheat - Green Gram<br>Sugarcane - Ratoon - Wheat | 0.40 | 40 |
| | Maize + Soybean - Ryegrass - Fodder Sorghum (0.125 ha) | | | Fodder System | Bajra Napier hybrid<br>Sorghum + Cowpea - Oat<br>Maize + Cowpea - Berseem | 0.15 | 15 |
| | Sweet corn - Garlic - Vegetable cowpea (0.125 ha) | | | | | | |
| Agri-horti module | Banana + Turmeric, Papaya + Turmeric | 0.12 | 17 | Horticulture block (Vegetable and fruit) | Nutritional Kitchen Garden (0.06 ha)<br>Fruit Garden (0.26 ha) | 0.32 | 32 |
| Livestock | Dairy (1 buffalo and 1 cow) | 0.04 | 5 | Livestock cum bio-input preparation unit | Dairy (1 Buffalo, 1 Cow)<br>Pest Repellent plants<br>Compost, vermicompost and concoction preparation | 0.13 | 13 |
| Multilayer farming | Dragon fruit, cucurbits, leafy vegetables, turmeric | 0.18 | 25 | | | | |

dilutions were made up to $10^{-5}$ level. The dilutions used (0.1 ml aliquot) for spread plating for bacteria, fungi and actinomycetes were $10^{-5}$, $10^{-2}$ and $10^{-3}$, respectively. After plating, nutrient agar and Rose Bengal agar plates were kept in BOD incubator at 28 ± 2°C temperature and for actinomycetes (Kenknights and Munaier's medium) plates were kept at 35°C for 5 days. After incubation the number of colony forming units were counted and total number of viable bacteria, fungi and actinomycetes were calculated by the following formula.

Microbial Load (CFU/g soil) = Number of colonies on the plate/(dilution factor × volume plated)

The soil samples were also analysed for soil dehydrogenase by Casida *et al.* (1964), β-glucosidase (Eivazi and Tabatabai 1988) and urease activity with the method given by Tabatabai and Bremner (1972). Phosphatase activity was measured by the method given by Eivazi and Tabatabai (1977).

The easily extractable glomalin and total glomalin contents were measured with the method given by Wright and Upadhaya (1998). In brief, 2 g soil was mixed with 8.0 ml of sodium citrate buffer having 20 mM and 50 mM concentration, respectively for easily extractable glomalin and total glomalin. Then the soil suspension was autoclaved (121°C temperature and 15 psi Pressure) for 30 and 90 min, respectively for easily extractable glomalin and total glomalin. After this, the tubes were centrifuged at 10000 rpm for 5 min to collect the supernatant. The protein concentration in the supernatant was estimated by Bradford method (Bradford 1976). The concentration of glomalin in supernatant was measured with the standard curve equation of bovine serum albumin protein. The samples were collected and analysed in triplicates for all the parameters.

## RESULTS AND DISCUSSION

Around 38% global land is being used for agricultural activities worldwide (FAO 2020). Conventional (synthetic input based) agriculture have huge negative impact on above and below ground diversity along with adversely affecting environment (de-Vries *et al*. 2023). Adoption of organic nutrient and pest management practices have shown their impact in improving the soil biological properties such as organic carbon, microbial population and activities of different soil enzymes involved in nutrient mineralization along with the improvement in soil physico-chemical parameters. Nutrient cycling is an essential ecological process that involves the movement and exchange of nutrients from the environment into living organisms, followed by their return to the atmosphere or environment in a reusable form (Prasad *et al.* 2021). IFS allows the optimum resource utilization as the waste from one component is utilized as an input for the other component. Therefore adoption of IFS with proper integration of every component helps in improving soil fertility status as on farm waste is recycled which ultimately reduces the dosage of chemical fertilizers. Adoption of organic management in IFS, named as IOFS model, will boost the soil health status. Plant growth promoting microbes play a crucial role in nutrient cycling under organic production systems (Narwal *et al.* 2023).

Across food system modules (cereal, vegetable, fruit and fodder), the IOFS model significantly improve microbial populations (bacteria, fungi, and actinomycetes) than the IFS model. Soil under cereal crops (food system) showed around 41% increase in bacterial population in IOFS model compared to IFS model. Similarly soils under vegetable system showed 32% increase in fungal population in IOFS model. This indicates that organic farming practices, such as the use of organic manures, compost, and reduced chemical inputs, promote a more diverse and abundant microbial community in the soil, which is beneficial for soil health and fertility. The improvement in microbial population under organic management might be due to sustained release of nutrients, improved soil physico-chemical properties and reduced burden of chemical fertilizers and pesticides whose application affects the microbes in a negative manner. Furtak and Gałazka (2019) have found the improved microbiological activity and diversity in the organically managed soil as compared to conventionally managed soil. Therefore, adoption of organic farming practices for the restoration of soil quality and ecosystem services is necessary. Panwar *et al.* (2022) have found increased organic carbon, available N, P, K and microbial population under organically managed soils as compared to inorganic and integrated plots.

The increase in microbial populations in IOFS is consistent for all crop types, but it is especially notable in vegetable crops, where the differences in bacterial and fungal populations between IFS and IOFS are more substantial (Table 2). This suggests that organic farming systems are particularly effective in enhancing microbial activity in vegetable cultivation, which may be attributed to factors like the richer organic matter inputs and greater soil biodiversity in organic systems. The greater microbial population in the vegetable system may be due to the higher organic matter input, frequent irrigation maintaining the higher moisture levels, diverse roots exudates as variety of vegetables were maintained, shorter growth cycles leading to the more frequent turnover of the crop residues into soil, intensive soil management practices as compared to other crops like cereals, fodder, fruit crops.

The increase in actinomycetes, which play an important role in the decomposition of organic matter and nutrient cycling was also observed across the various modules of IOFS, though the differences were less pronounced in this study compared to bacteria and fungi.

Soil enzymes play a crucial role in nutrient mineralization in soil. The activity of extracellular soil enzymes has been proposed as an indicative of soil quality which catalyses the transformation of complex organic manures and minerals to available form of plant nutrients (Serrano-Grijalva *et al.* 2024). The activity of different enzymes was higher under IOFS model except β-Glucosidase activity in vegetable component which was higher in IFS (Table 3).

Table 2 Microbial population in the soil of different modules of Integrated Farming System (IFS) and Integrated Organic Farming System (IOFS) model

| Farming system module | Microbial population (CFU/g dry soil) | | | | | |
|---|---|---|---|---|---|---|
| | Bacteria ($*10^6$ CFU/g dry soil) | | Fungi ($*10^3$ CFU/g dry soil) | | Actinomycetes ($*10^4$ CFU/g dry soil) | |
| | IFS | IOFS | IFS | IOFS | IFS | IOFS |
| Cereal crops | 37.32±3.17* | 52.60±5.09 | 33.73±4.12 | 39.24±3.54 | 26.54±2.32 | 29.34±1.97 |
| Vegetable crops | 57.17±4.63 | 66.4±3.27 | 54.12±4.16 | 57.69±4.42 | 28.09±2.08 | 32.02±3.48 |
| Fruit crops | 43.52±3.19 | 52.6±3.12 | 44.31±3.81 | 50.44±6.09 | 33.87±3.21 | 32.76±2.46 |
| Fodder system | 38.41±3.87 | 49.01±4.72 | 29.70±2.67 | 44.38±3.62 | 21.62±4.33 | 24.61±4.52 |

*mean ± standard deviation (number of replication=3).
CFU, Colony Forming Unit.

Dehydrogenase enzyme is the indicator of total biological activity (oxidative activity) in soil. IOFS showed higher dehydrogenase activity than IFS across all food systems. Vegetable based systems harbour higher soil dehydrogenase activity (32.78 ± 3.12 µg TPF/g dry soil/h) in IOFS than fodder systems (16.62 ± 1.06 µg TPF/g dry soil/h) in IFS. Across all enzyme types and crop categories, IOFS generally supports higher soil enzyme activity compared to IFS. This could be attributed due to the organic farming practices that promote soil microbial diversity and activity. β-Glucosidase activity in soil is an indicative of carbon mineralization. This enzyme breaks the disaccharides into monosaccharides and makes them available for microbial growth and multiplication. IOFS also results in higher β-Glucosidase activity compared to IFS, except in vegetable crops where IFS has a higher value (IOFS: 52.84 ± 4.15 µg pNP/g dry soil/h. IFS: 44.57 ± 3.46 µg pNP/g dry soil/h). The higher β-glucosidase activity may be attributed to the application of rice straw as mulch in garlic crop. Wang *et al.* (2022) have observed significant improvement in β-Glucosidase and cellobiohydrolase activities with mulching (long term) as compared to clean tillage. Long-term mulching with *Vicia villosa* led to higher enzyme activity due to the accumulation of herbaceous residues, which increased soil organic matter. Mulching also support the microbial activity by maintaining the soil moisture and temperature in the favourable range. Bhagat *et al.* (2016) have observed greater microbial activity with rice straw mulching. The enhanced carbon input reduced microbial carbon limitation and increased the unstable components of soil organic carbon (SOC) (Kalinina *et al.* 2019). As a result, enzyme formation and release were accelerated, effectively boosting enzyme activities. Urease enzyme is involved in hydrolysis of urea. Better urease activity in soil is an indicative of better N mineralization in soil. Urease activity is consistently higher in IOFS compared to IFS across all crop types. The highest urease activity was observed in fruit crops under IOFS (14.44 ± 0.87 mg urea/kg dry soil), while the lowest is in cereal crops under IFS (9.80 ± 0.62 mg urea/kg dry soil). Alkaline phosphatase is an enzyme found in soil that plays a crucial role in the phosphorus cycle. It catalyzes the hydrolysis of organic phosphorus compounds into inorganic phosphate, which is readily available for plant uptake. This activity is essential for maintaining soil fertility, especially in phosphorus-limited environments. Similar trend was observed for alkaline phosphatase activity. The highest phosphatase activity is recorded in fruit crops under IOFS (76.23 ± 5.37 µg pNP/g dry soil/h), and the lowest in cereal crops under IFS (49.16 ± 3.14 µg pNP/g dry soil/h). The increased soil enzymes activity under IOFS model is due to secretion of greater amount of extracellular enzymes to mineralize the organic matter so that nutrients can be made available to the plants. Significant changes were observed in the activity of β-glucosidase as compare to the

Table 3 Activity of different soil enzymes under different modules of Integrated Farming System (IFS) and Integrated Organic Farming System (IOFS) model

| Farming system module | Activity of different soil enzymes | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Dehydrogenase (µg TPF/g dry soil/hour) | | B-Glucosidase (µg pNP/g dry soil/h) | | Urease (mg urea/kg dry soil) | | Alkaline phosphatase (µg pNP/g dry soil/h) | |
| | IFS | IOFS | IFS | IOFS | IFS | IOFS | IFS | IOFS |
| Cereal crops | 19.81±1.07 | 20.93±2.29 | 26.82±2.87 | 29.01±1.23 | 9.80±0.62 | 13.75±1.09 | 49.16±3.14 | 56.12±3.62 |
| Vegetable crops | 27.29±1.87 | 32.78±3.12 | 52.84±4.15 | 44.57±3.46 | 10.33±1.02 | 14.29±1.13 | 52.65±4.63 | 67.87±3.21 |
| Fruit crops | 22.52±2.09 | 24.08±2.64 | 26.55±1.16 | 54.61±3.67 | 11.14±0.8 | 14.44±0.87 | 69.09±4.97 | 76.23±5.37 |
| Fodder system | 16.62±1.06 | 22.74±2.23 | 24.32±3.14 | 32.76±3.43 | 10.19±0.97 | 13.15±0.95 | 46.37±4.21 | 52.79±5.31 |

*mean ± standard deviation (number of replication=3).

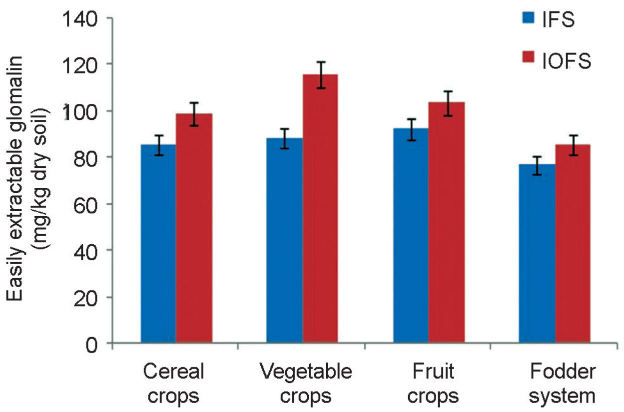


Fig. 1 Easily extractable glomalin levels under different modules of Integrated Farming System (IFS) and Integrated Organic Farming System (IOFS) Model.

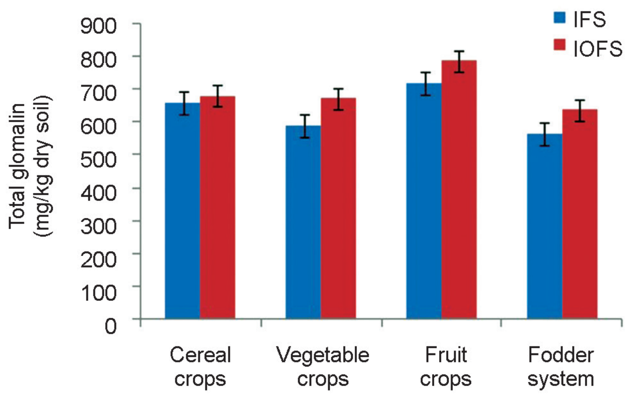


Fig. 2 Total glomalin content in the soil of different modules of Integrated Farming System (IFS) and Integrated Organic Farming System (IOFS) Model.

other enzymes. Serrano-Grijalva *et al.* (2024) summarizes that organic management practices generally enhance the activity of C related enzymes as compared to nitrogen and phosphate related enzymes.

Glomalin is a thermostable protein secreted by arbuscular mycorrhizal (AM) fungi therefore, considered as an indicator of greater mycorrhizal colonization in the soil. Due to its thermostable nature (stable at even 121°C) also considered as indicator for C and N sequestration in soil (Singh *et al.* 2017). IOFS consistently shows higher levels of Easily Extractable Glomalin (EEG) and total glomalin as compared to IFS across all crop types. The highest EEG was observed in vegetable crops under IOFS (115.56 ± 10.37 mg/kg), followed by fruit crops (103.36 ± 14.79 mg/kg) and cereal crops (98.57 ± 5.09 mg/kg). The lowest EEG was found in cereal crops under IFS (85.17 ± 6.32 mg/kg) (Fig. 1). Similarly total glomalin was also found higher under all modules of IOFS model (Fig. 2). This indicates that organic farming practices promote the production and accumulation of glomalin-related soil proteins, likely due to better support for AM fungi colonization and activity. AM fungi are extremely sensitive to the environmental changes therefore their activity can be taken as crucial parameter to compare the organic and conventional systems (de-Moura *et al.* 2024). de-Moura *et al.* (2024) have found significantly lower mycorrhizal colonization in sugarcane crop under conventional system as compared to organic system. The secretion and accumulation of glomalin protein can differ with plant species and edaphic factors as well (Singh *et al.* 2016, Staunton *et al.* 2020)

Therefore, it is concluded that adoption of IOFS significantly improves soil biological properties, as evidenced by higher population of bacteria, fungi, actinomycetes, soil enzyme activities, and glomalin levels across crop types. These improvements are attributed to organic practices such as the use of compost, vermicompost, organic fertilizers, traditional concoctions and reduced chemical inputs, which foster a thriving microbial community and enhance soil health. The study underscores the potential of IOFS in supporting sustainable agriculture, particularly for vegetable and fruit crops, where the benefits are most pronounced. Integrating organic practices into farming systems are essential for improving soil fertility, ensuring long-term productivity, and addressing environmental sustainability challenges.

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