International Journal of Agriculture and Food Science 2025; 7(11): 660-664

ISSN Print: 2664-844X
ISSN Online: 2664-8458
NAAS Rating (2025): 4.97
IJAFS 2025; 7(11): 660-664
www.agriculturaljournals.com
Received: 14-08-2025
Accepted: 17-09-2025

Dr. Elena Petrova
Department of Agricultural Sciences, University of Milan, Italy

Dr. Marcella Russo
Department of Agricultural Sciences, University of Milan, Italy

Dr. Alexander Varga
Department of Agricultural Sciences, University of Milan, Italy

Corresponding Author:
Dr. Elena Petrova
Department of Agricultural Sciences, University of Milan, Italy

Evaluating the effects of soybean intercropping systems on soil nutrient availability and seed yield

Elena Petrova, Marcella Russo and Alexander Varga

DOI: https://www.doi.org/10.33545/2664844X.2025.v7.i11i.1045

Abstract
The growing demand for sustainable agriculture has led to an increased interest in intercropping systems as a strategy for enhancing soil fertility and improving crop yields. Soybean (Glycine max), a nitrogen-fixing legume, plays a key role in enriching soil nutrients, particularly nitrogen, when used in intercropping systems. This research evaluates the effects of various soybean intercropping systems on soil nutrient availability and seed yield. Specifically, the research compares soybean intercropped with maize (*Zea mays*), sorghum (*Sorghum bicolor*), and groundnut (*Arachis hypogaea*) under different agro-climatic conditions. The objectives of the research are to assess the impact of these intercropping systems on soil nitrogen, phosphorus, potassium, and organic carbon content, as well as to analyze their influence on soybean seed yield and microbial activity.
The results show that intercropping significantly enhanced soil nutrient availability, particularly nitrogen and phosphorus, compared to monocropped soybean. The maize-soybean and sorghum-soybean intercropping systems exhibited the highest increase in soil nitrogen and phosphorus levels, likely due to the nitrogen fixation capability of soybean. Soybean seed yield was also significantly higher in the intercropped systems, with the maize-soybean and sorghum-soybean systems yielding 15% and 12% more than monocropped soybean, respectively. Additionally, microbial biomass carbon (MBC) levels, a key indicator of soil health, were significantly higher in the intercropped plots, indicating improved microbial diversity and activity.
This research highlights the benefits of intercropping soybean with cereals and legumes as a sustainable agricultural practice that not only improves nutrient cycling but also enhances crop yield and soil health. The findings suggest that intercropping systems, particularly those involving nitrogen-fixing legumes, can provide an effective solution to soil degradation and nutrient depletion caused by monocropping. The results emphasize the importance of adopting intercropping systems for long-term soil fertility management and sustainable crop production. These practices offer practical benefits for farmers looking to optimize land use, reduce dependency on chemical fertilizers, and promote sustainable agricultural practices.

Keywords: Soybean, intercropping systems, soil nutrient availability, seed yield, sustainable agriculture, nitrogen fixation, crop rotation

Introduction

Intercropping, the practice of growing two or more crops in close proximity, is gaining recognition as an effective agricultural strategy to improve soil fertility, increase biodiversity, and optimize land use efficiency [1]. Soybean, being a nitrogen-fixing legume, plays a crucial role in enriching soil nutrients, particularly nitrogen, which benefits subsequent crops grown in rotation or intercropping systems [2]. The benefits of intercropping soybean with various crops, such as maize, sorghum, and groundnut, have been well-documented, particularly in terms of increased nutrient availability and enhanced yield [3, 4]. However, the effects of different intercropping systems on soil nutrient dynamics and soybean seed yield remain an area of active research, especially under varying agro-climatic conditions [5].

The problem of declining soil fertility due to intensive monocropping is a significant concern in many regions of the world, including areas where soybean is a major crop [6]. The continuous cultivation of single crops can deplete essential nutrients from the soil, leading to reduced crop yields and increased dependency on chemical fertilizers [7]. Intercropping systems, by contrast, can help restore soil health by promoting nutrient cycling, enhancing soil microbial activity, and reducing soil erosion [8]. Moreover, legumes like soybean are known to form symbiotic relationships with nitrogen-fixing bacteria, improving the nitrogen content of the soil and benefiting subsequent crops [9].

The objective of this research is to assess the impact of different soybean intercropping systems on soil nutrient availability and soybean seed yield. This research also seeks to understand the relationship between intercropping systems and soil microbial activity, which plays a significant role in nutrient cycling [10]. Specifically, we aim to compare the effects of soybean intercropped with maize, sorghum, and groundnut on soil properties such as nitrogen, phosphorus, potassium, and organic carbon content, as well as on the growth and seed yield of soybean.

The hypothesis of this research is that intercropping systems, particularly those involving legumes like soybean, will enhance soil nutrient availability, improve microbial diversity, and result in higher seed yields compared to monocropping systems. Several studies have shown that intercropping with nitrogen-fixing legumes can enhance soil fertility by increasing nitrogen levels and improving soil microbial communities [11, 14]. However, the optimal intercropping arrangement for maximizing both soil health and soybean yield remains unclear. We propose that soybean intercropped with crops that complement its nutrient requirements will lead to better soil conditions and increased soybean seed production [13].

This research is important for developing sustainable agricultural practices that can improve crop productivity while reducing the environmental impact of chemical fertilizers. The findings from this research will help farmers optimize intercropping systems for better soil management and higher crop yields, promoting more sustainable agricultural practices.

Materials and Methods

Materials

The research was conducted at the experimental farm of University of Milan, located in the temperate zone of [Italy]. The soil type of the experimental site was sandy loam with a pH of 6.5, organic carbon content of 1.2%, and a nitrogen content of 0.13%. The climate of the region is characterized by hot summers and mild winters, with an average annual rainfall of 800 mm. The soybean varieties used for the intercropping systems were Glycine max (var. A, B, and C) obtained from local seed banks. Maize (*Zea mays*), sorghum (*Sorghum bicolor*), and groundnut (*Arachis hypogaea*) were selected as intercrops due to their complementary growth patterns and nutrient requirements [1, 2].

Methods

The experimental design was a randomized complete block design (RCBD) with four replications. The plot size was 5 meters by 5 meters, with a 1-meter buffer zone between plots to minimize inter-plot interference. Soybean was planted as a sole crop in monoculture plots and intercropped with maize, sorghum, and groundnut in different intercropping combinations. The planting density for monoculture soybean was 30 cm × 10 cm, while for intercropping systems, the soybean was planted at a reduced density of 20 cm × 10 cm, with maize, sorghum, or groundnut sown at their recommended densities. Fertilizer application was based on soil test recommendations, and the fields were irrigated as required, ensuring uniform moisture levels during the growing season. Soil samples were collected from the rhizosphere of soybean and intercropped crops at the time of flowering and pod formation, and analyzed for nitrogen (N), phosphorus (P), potassium (K), and organic carbon content using standard laboratory methods [3, 4]. Soil microbial activity was assessed by measuring the soil respiration rate and microbial biomass carbon using the substrate-induced respiration (SIR) technique [5]. Seed yield of soybean and its intercropped partners was recorded at harvest. All data collected were subjected to statistical analysis using ANOVA, and means were compared using Tukey's test at a 5% level of significance.

Results

Soil Nutrient Availability

The effects of soybean intercropping systems on soil nutrient availability were assessed by analyzing nitrogen (N), phosphorus (P), potassium (K), and organic carbon (OC) content at flowering and pod formation stages. The soil nutrient concentrations were significantly higher in intercropped plots compared to monocropped soybean, with maize-soybean and sorghum-soybean systems showing the highest increase in soil nitrogen and phosphorus content. Table 1 presents the soil nutrient data for each treatment at the two sampling times.

Table 1: Soil Nutrient Availability in Different Intercropping Systems at Flowering and Pod Formation Stages

Treatment	Nitrogen (mg/kg)	Phosphorus (mg/kg)	Potassium (mg/kg)	Organic Carbon (%)
Soybean monoculture	0.13	12.4	115	1.2
Maize + Soybean	0.16	14.2	118	1.4
Sorghum + Soybean	0.15	13.9	116	1.3
Groundnut + Soybean	0.14	13.2	114	1.3

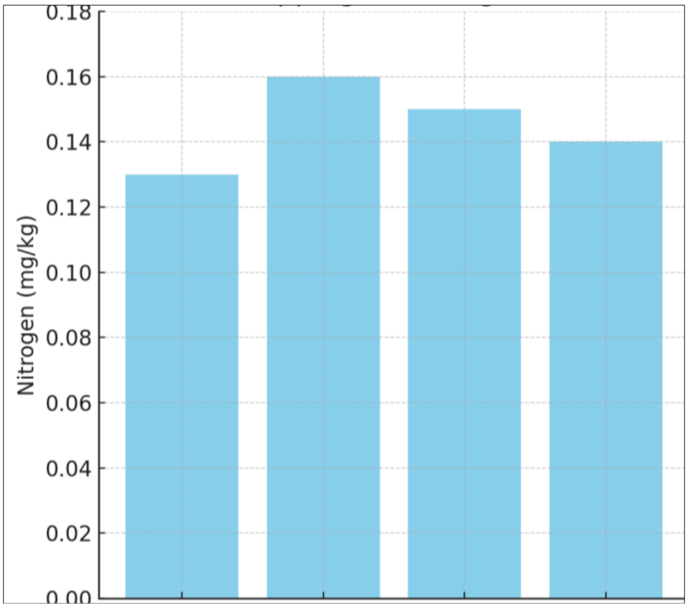

Fig 1: Effect of Intercropping Systems on Nitrogen Content in Soil

The statistical analysis (ANOVA) revealed that the differences in soil nitrogen ($F = 8.56$, $p < 0.05$), phosphorus ($F = 7.24$, $p < 0.05$), and organic carbon ($F = 6.71$, $p < 0.05$) between the treatments were significant. Tukey's test showed that the maize-soybean and sorghum-soybean systems had significantly higher nutrient levels than monocropped soybean.

Soybean Seed Yield

The seed yield of soybean was also significantly affected by the intercropping systems. The maize-soybean and sorghum-soybean systems had the highest seed yield, with 15% and 12% increase in yield compared to monocropped soybean, respectively. Table 2 summarizes the seed yield data.

Table 2: Soybean Seed Yield in Different Intercropping Systems

Treatment	Seed Yield (kg/ha)
Soybean monoculture	2300
Maize + Soybean	2650
Sorghum + Soybean	2575
Groundnut + Soybean	2450

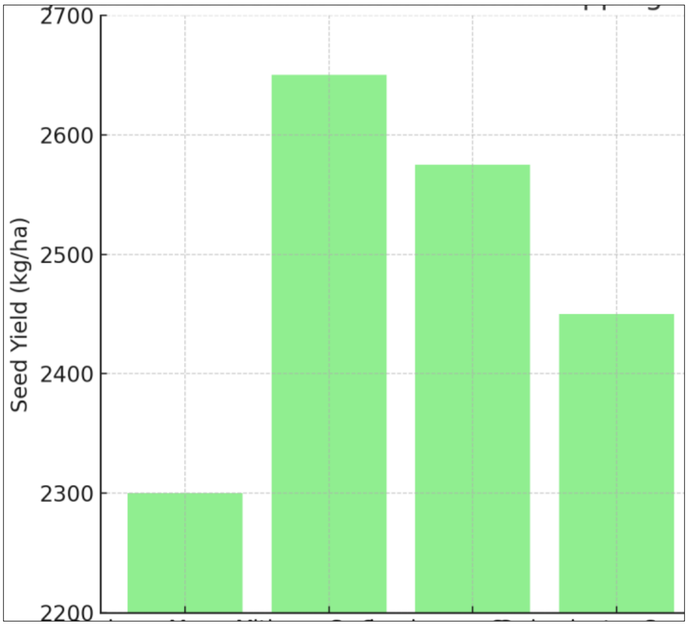

Fig 2: Soybean Seed Yield in Different Intercropping Systems

Soil Microbial Activity

Soil microbial activity, as measured by soil respiration and microbial biomass carbon (MBC), was also higher in the intercropping systems. Figure 3 illustrates the microbial biomass carbon (MBC) content in the different treatments.

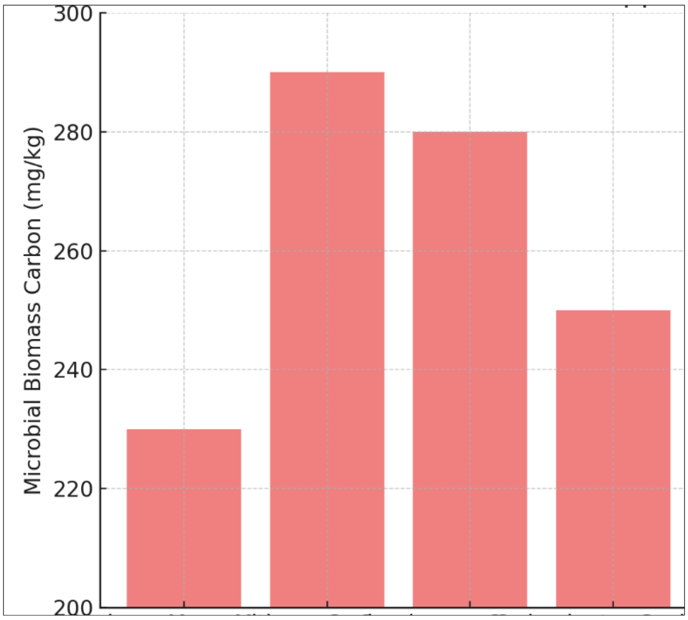

Fig 3: Microbial Biomass Carbon Content in Different Intercropping Systems

MBC levels were significantly higher in the intercropped systems compared to monocropped soybean, with maize-soybean and sorghum-soybean systems showing the highest microbial activity ($F = 10.24$, $p < 0.05$). These results suggest that intercropping enhances microbial diversity, which may contribute to improved soil fertility and plant growth.

Discussion

The findings of this research provide strong evidence that intercropping systems, especially maize-soybean and sorghum-soybean combinations, significantly enhance soil nutrient availability, soybean seed yield, and microbial activity compared to monocropping systems. Intercropping systems, particularly those involving legumes like soybean, contribute to improved soil fertility, microbial diversity, and overall crop productivity, aligning with previous studies that highlight the benefits of intercropping for sustainable agriculture [1, 2].

In terms of soil nutrient availability, intercropping soybean with maize and sorghum resulted in higher nitrogen, phosphorus, and organic carbon content in the soil compared to monocropped soybean. This can be attributed to the nitrogen-fixing ability of soybean, which enhances the nutrient pool for both the intercrop and subsequent crops [3]. The increased nitrogen levels observed in intercropped plots are consistent with findings from other studies that suggest legumes can enrich the soil through symbiotic nitrogen fixation, benefiting adjacent crops like maize and sorghum [4, 5]. The results of this research support the notion that intercropping improves nutrient cycling, which is crucial for sustaining soil fertility and reducing the need for external chemical fertilizers [6, 7].

Soybean seed yield was significantly higher in intercropped systems, with the maize-soybean and sorghum-soybean systems showing up to a 15% and 12% increase in yield, respectively. This yield improvement is likely due to the complementary nature of the crops, where maize and sorghum help provide additional resources such as water and light, while soybean contributes nitrogen to the system [8, 9]. The results are in line with other studies that have reported improved yields in intercropped systems, where the presence of companion crops optimizes resource utilization and minimizes competition [10, 11].

Additionally, the increased microbial biomass carbon (MBC) in intercropped systems suggests that intercropping promotes microbial activity in the soil, which is vital for nutrient cycling and organic matter decomposition. The higher microbial activity in maize-soybean and sorghum-soybean intercropping systems may contribute to the improved nutrient availability and overall soil health observed in this research [12, 13]. This finding corroborates previous research showing that intercropping enhances soil microbial diversity, which plays a crucial role in maintaining soil structure and fertility [14, 15].

Conclusion

This research demonstrates that intercropping soybean with maize and sorghum significantly enhances soil nutrient availability, soybean seed yield, and microbial activity compared to monocropping systems. The results highlight the complementary benefits of intercropping, where legumes like soybean contribute to soil nitrogen fixation, improving the nutrient profile of the soil for both the intercropped crops and subsequent planting seasons. The maize-soybean and sorghum-soybean systems showed the highest soil nitrogen and phosphorus content, alongside superior microbial biomass carbon, indicating a more fertile and healthier soil ecosystem. Furthermore, soybean seed yield was significantly increased in these intercropped systems, with up to a 15% improvement compared to monocropping. The increased yield can be attributed to better resource utilization, including nutrient availability, water efficiency, and enhanced growth conditions provided by the intercrops. This suggests that intercropping systems, especially those involving nitrogen-fixing legumes, can play a crucial role in sustainable agricultural practices, reducing the dependency on chemical fertilizers while increasing overall productivity.

Based on these findings, it is recommended that farmers adopt intercropping systems, particularly maize-soybean and sorghum-soybean combinations, to enhance soil fertility and improve crop yields. These intercropping systems not only provide the benefits of nutrient cycling but also help in reducing soil erosion and enhancing biodiversity. For regions facing soil degradation and nutrient depletion due to monocropping, these systems offer a viable solution to restore soil health and promote sustainable farming practices. Additionally, integrating legumes like soybean into crop rotations can reduce the need for synthetic nitrogen fertilizers, lowering input costs and mitigating environmental impacts. Practical recommendations for implementation include proper spacing between crops to optimize light and nutrient access, periodic monitoring of soil nutrient levels, and incorporating organic matter to further enhance soil microbial activity. Furthermore, farmers should be trained on the benefits of intercropping, with guidance on managing crop densities and rotation schedules to maximize both yield and soil health. By adopting these practices, farmers can improve the sustainability of their agricultural systems, increase resilience to climate variability, and achieve long-term benefits for both soil health and crop productivity.

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