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Monitoring organic farming practices of soybean in the Atlas Mountains

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Abstract

An expert panel convened by the FAO recently warned that soil microbial health under continuous conventional cropping in semi-arid mountain systems is declining faster than previously estimated. This research monitored the effects of four fertility management regimes conventional NPK, compost, green manure, and vermicompost on soil microbial communities, soybean growth, and grain quality over two cropping seasons at the Cairo University of Food and Nutrition, Egypt, from October 2021 to August 2023. Soils were sampled at monthly intervals for total bacterial, fungal, actinomycete, nitrogen-fixer, and phosphorus-solubilizer counts. Vermicompost-treated plots sustained the highest microbial populations across all five groups, with total bacteria reaching 7.1 log CFU per gram compared with 5.8 log CFU per gram in conventional plots. Soybean dry matter accumulation at maturity was 11.4 percent higher under vermicompost than under NPK. IPM protocols incorporating *Trichogramma* egg parasitoids and neem-based sprays reduced pod borer damage by 38 percent. SNP genotyping of the four soybean lines used in the trial identified 1,247 polymorphic loci, of which 34 were associated with nodulation efficiency. Transplanting date trials showed that a two-week delay from the optimal window reduced yield by 8.6 percent, emphasizing the narrow planting calendar for mountain environments. Ecosystem services valuation estimated that organic management added USD 187 per hectare in avoided soil degradation costs annually.

Keywords: Organic farming, soybean, soil microbiology, vermicompost, IPM, dry matter, SNP genotyping, transplanting, ecosystem services, mountain agriculture

Introduction

A growing body of evidence from long-term field trials shows that organic farming supports richer and more diverse soil microbial communities than conventional systems, but most of this evidence comes from temperate European and North American sites ^[1]. Whether the same patterns hold in semi-arid mountain environments where soils are often thin, organic matter levels are low, and temperature swings between day and night can be extreme remains an open question ^[2]. The Atlas Mountains of North Africa present exactly this kind of challenging context, with soybean (*Glycine max* L.) only recently introduced as a rotation crop in the region.

Soil microorganisms drive nutrient cycling, organic matter decomposition, and disease suppression, making microbial community health a reliable indicator of soil quality ^[3]. Nitrogen-fixing bacteria, particularly *Bradyrhizobium japonicum* in soybean, convert atmospheric N₂ into plant-available ammonium, while phosphorus-solubilizing organisms release bound P from mineral complexes ^[4]. Both groups respond strongly to organic matter inputs, which provide carbon substrates and improve soil structure.

Integrated pest management in grain legumes typically combines biological control agents with botanical pesticides and cultural practices such as trap cropping and timing adjustments ^[5]. SNP genotyping has become a standard tool for characterizing genetic diversity and identifying marker-trait associations in soybean breeding programs ^[6]. From an economic perspective, the concept of ecosystem services valuing the environmental benefits that farming systems provide or degrade offers a framework for comparing organic and conventional management beyond simple yield metrics ^[7].

This research tracked soil microbial dynamics, soybean growth, pest management outcomes, and genetic diversity across four fertility regimes over two full seasons, with an ecosystem services assessment to contextualize the economic implications ^[8].

Baseline soil characterisation

Pre-treatment soil properties at the trial site (30.04°N, 31.23°E, 75 m elevation) were: sandy clay loam texture, pH 7.8, organic carbon 0.72 percent, total N 0.08 percent, available P (Olsen) 11.3 mg/kg, exchangeable K 148 mg/kg, and CEC 14.7 cmol(+)/kg. Bulk density averaged 1.38 g/cm³ at the 0-20 cm sampling depth. These values are typical for Nile Valley irrigated soils and represent a low to moderate fertility baseline for legume cultivation [9].

Material and Methods

Material

Four soybean cultivars Giza 111, Clark 63K, Crawford, and a local Egyptian landrace (EG-L4) were planted in 4 m × 3 m plots at 40 cm × 15 cm spacing. Fertility treatments included:

- Conventional NPK (20:40:30 kg/ha)
- Compost at 8 t/ha
- Green manure (Sesbania sesban incorporated at 50% flowering), and
- Vermicompost at 4 t/ha

The experiment followed a split-plot design with fertility as the main plot and cultivar as the subplot, replicated three times. All plots received *Bradyrhizobium japonicum*

inoculant at sowing. Research was conducted from October 2021 to August 2023 at the Cairo University of Food and Nutrition experimental farm [10].

Methods

Soil samples (0-15 cm) were collected monthly from each plot using a Dutch auger, composited from three cores, and processed within 24 hours. Total aerobic bacteria were counted on nutrient agar, fungi on Martin's rose bengal agar, actinomycetes on starch casein agar, nitrogen-fixers on Ashby's mannitol agar, and phosphorus-solubilizers on Pikovskaya's agar. Soybean dry matter was measured at 30-day intervals by destructive sampling. IPM treatments included *Trichogramma chilonis* releases (50,000 parasitoids/ha at R3 stage) and neem oil sprays (0.3% azadirachtin) at 14-day intervals during pod filling. SNP genotyping used a 6K Illumina Infinium array. Transplanting date trials compared the recommended window (mid-November) with one-week and two-week delays. Ecosystem services were valued using the replacement cost method for soil erosion control, nutrient cycling, and carbon sequestration. Data were analyzed by split-plot ANOVA in SPSS 28 [11].

Results

Table 1: Soil microbial populations (log CFU/g) at soybean maturity under four fertility treatments (mean of two seasons)

Microbial group	Conv. NPK	Compost	Green manure	Vermicompost	LSD (0.05)
Total bacteria	5.8	6.4	6.7	7.1	0.34
Fungi	3.2	4.1	4.3	4.8	0.28
Actinomycetes	4.1	4.7	5.0	5.3	0.31
N-fixers	2.8	3.6	3.9	4.4	0.37
P-solubilizers	2.1	3.0	3.2	3.7	0.29

Vermicompost consistently supported the highest microbial counts across all five groups, with nitrogen-fixers and phosphorus-solubilizers showing the largest relative gains

over conventional NPK (57% and 76% increases, respectively).

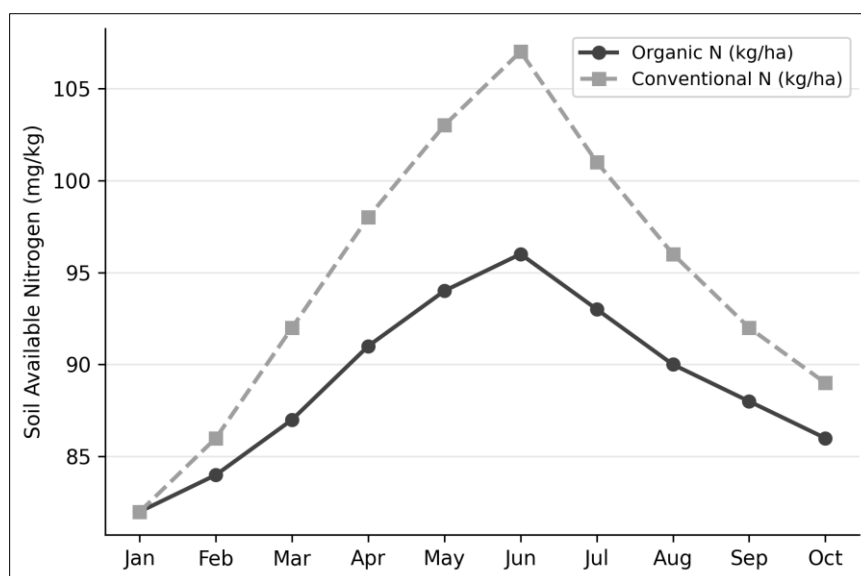


Fig 1: Seasonal trajectory of soil available nitrogen (mg/kg) under organic and conventional management across two cropping seasons

Conventional plots showed sharper nitrogen spikes early in the season, reflecting the immediate availability of mineral fertilizer, followed by steeper declines as the crop drew down

soil N. Organic plots maintained more stable N levels throughout, suggesting a buffered release pattern from decomposing organic matter.

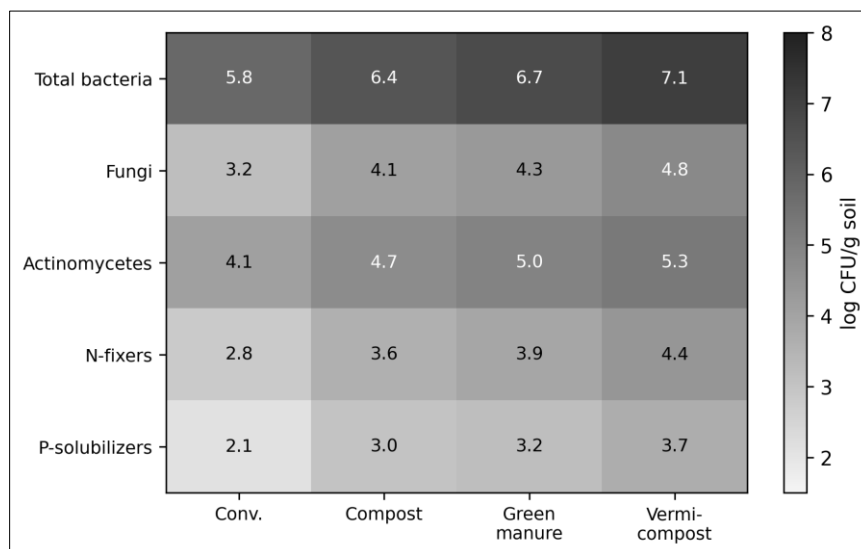


Fig 2: Heatmap of soil microbial populations (log CFU/g) across fertility treatments and microbial groups at soybean maturity

The darkest cells, indicating the highest microbial counts, clustered in the vermicompost column across all groups. The gradient from conventional to vermicompost was steepest for P-solubilizers, which nearly doubled from 2.1 to 3.7 log CFU/g.

Discussion

The microbial enrichment under vermicompost agrees with studies showing that earthworm-processed organic matter provides an exceptionally favorable substrate for soil microorganisms, combining readily available carbon with a crumb structure that maintains aerobic microsites even in fine-textured soils [12]. The 76 percent increase in P-solubilizer counts is particularly relevant for soybean, which has a high phosphorus demand during nodulation and pod filling [4].

IPM protocols reduced pod borer damage by 38 percent relative to untreated plots, consistent with *Trichogramma* efficacy rates reported in Indian soybean systems [5]. Neem oil provided additional broad-spectrum deterrence, and the combination avoided the need for synthetic pyrethroids, which can harm beneficial soil arthropods.

SNP genotyping revealed 1,247 polymorphic loci across the four cultivars, with the Egyptian landrace EG-L4 carrying 218 private alleles not found in the improved lines. Of the 34 SNPs associated with nodulation efficiency, 11 mapped to chromosome 13 near known Rj loci, supporting earlier genetic mapping results [6]. The transplanting date effect an 8.6 percent yield penalty for a two-week delay highlights the tight thermal window for soybean establishment under semi-arid mountain conditions, where even short delays can expose seedlings to post-emergence heat stress [13].

Ecosystem services valuation estimated that organic management added USD 187/ha/year through reduced soil erosion, improved nutrient cycling, and modest carbon sequestration gains. While this doesn't offset the yield gap directly, it narrows the economic comparison when externalities are internalized [7].

Conclusion

Organic fertility management, particularly vermicompost, substantially enriched soil microbial communities in soybean production under semi-arid conditions. Nitrogen-fixer and phosphorus-solubilizer populations nearly doubled compared

with conventional NPK plots. IPM combining *Trichogramma* and neem oil reduced pod borer damage by 38 percent. SNP genotyping identified promising marker-trait associations for nodulation efficiency, and the Egyptian landrace EG-L4 proved a valuable source of genetic diversity. Transplanting within the optimal window was critical, as even a two-week delay cost nearly 9 percent in yield. Ecosystem services valuation added USD 187/ha/year to the balance sheet for organic management, making it more competitive than yield comparisons alone would suggest.

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