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Comparative research of organic and conventional farming practices on cotton yield and soil health

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Abstract

An often-repeated observation in organic farming circles is that yields drop in the first year of transition but recover within three to five years as soil biology rebuilds. This research tested that claim for cotton by comparing organic and conventional management over three consecutive seasons (2021-2023) on adjacent plots at the University of Bonn's Dikopshof Research Station. Organic plots received farmyard manure (10 t ha⁻¹), neem cake, and Trichoderma-based biopesticides; conventional plots used synthetic NPK and chemical pest control. Seed cotton yield in the organic system started 31.0% below conventional in Year 1 (1.87 vs. 2.71 t ha⁻¹) but the gap narrowed to 9.5% by Year 3 (2.38 vs. 2.63 t ha⁻¹). Soil organic carbon rose by 47.3% under organic management (0.91 to 1.34%), while microbial biomass carbon increased by 56.0%. Dehydrogenase activity and earthworm density were 51.6% and 110.3% higher in organic plots by Year 3. These results support the transition-yield-recovery hypothesis and show that organic cotton farming can approach conventional yields within three seasons while markedly improving soil biological health.

Keywords: Organic farming, conventional farming, cotton, soil health, microbial biomass, dehydrogenase activity, organic carbon, earthworm density, yield gap, transition period

Introduction

Observations from long-term farming system trials in Europe and North America consistently show that organic yields trail conventional yields by 15-25% on average, but the gap is smaller for crops grown on biologically active soils with high organic matter^[1, 2]. Cotton, as a crop with heavy pest pressure and high nutrient demand, represents a particularly demanding test case for organic management. Without synthetic insecticides, cotton faces severe bollworm and whitefly damage; without mineral fertiliser, nitrogen supply depends on slow-release organic sources that may not synchronise with the crop's peak demand at flowering and boll development^[3, 4].

Germany doesn't grow cotton commercially, but the University of Bonn's research plots have maintained experimental cotton since 2015 as part of a broader programme on novel fibre crops for European agriculture^[5]. The controlled setting allows direct comparisons that would be confounded by spatial variability in commercial cotton regions. Previous work at Bonn focused on variety screening; the present research is the first to compare full organic versus conventional management packages on the same site over multiple seasons^[6, 7].

The aim was to quantify both the yield penalty and the soil health benefit of organic management during a three-year transition, testing whether cotton follows the recovery trajectory observed in cereals and vegetables^[8, 9, 10].

Soil health monitoring protocol

AQUACROP was not used in this research. Instead, soil health was monitored through a suite of biological and chemical indicators measured at 0-15 cm depth before the first season (baseline) and after each harvest. Indicators included soil organic carbon (Walkley-Black), microbial biomass carbon (chloroform fumigation-extraction), dehydrogenase activity (TTC method), available nitrogen (alkaline KMnO₄), and earthworm density (hand-sorting of 25 × 25 × 30 cm monoliths)^[11, 12]. All laboratory analyses were performed at the Institute of Crop Science, University of Bonn.

Research site and climatic conditions

The research was conducted at the Dikopshof Research Station (50.80° N, 6.95° E, elevation 60 m), 15 km south-west of Bonn. The station has a temperate oceanic climate with mean annual temperature of 10.4 °C and rainfall of 640 mm. Cotton was grown under plastic tunnel structures (unheated) from May to October each year to extend the frost-free window. Inside the tunnels, mean temperature during the growing season was 22.8 °C and relative humidity 68%. Drip irrigation supplied 280-320 mm per season depending on rainfall.

Material and Methods

Material

Cotton variety Erliana (early maturing, adapted to Central European tunnel cultivation) was sown in mid-May each year at 80,000 plants ha⁻¹. Organic plots received 10 t ha⁻¹ farmyard manure (well-composted cattle manure, 0.6% N) incorporated before sowing, supplemented with 1 t ha⁻¹ neem cake (5.2% N) side-dressed at squaring [3, 6]. Conventional plots received 120-60-60 kg NPK ha⁻¹ as synthetic fertiliser. Pest management in organic plots used *Trichoderma harzianum* (soil drench), *Beauveria bassiana* spray for bollworm, and neem oil for

sucking pests. Conventional plots followed a standard spray calendar with lambda-cyhalothrin and imidacloprid [4].

Methods

The trial comprised two treatments (organic and conventional) in a randomised complete block design with four replications. Each plot measured 6 m × 8 m within the tunnel structure. Seed cotton was hand-picked at three harvests per season from a 4 m² area per plot. Lint percentage was determined by roller ginning. Soil samples were collected from 0-15 cm at three points per plot before the first season (October 2020 baseline) and after each October harvest. Data were analysed by repeated-measures ANOVA in R 4.3.1; year × treatment interaction was tested, and pairwise comparisons used Tukey’s HSD at *p*=0.05 [13].

Experimental design

Eight plots (four organic, four conventional) were distributed across four tunnel bays, with one organic and one conventional plot per bay. Guard rows of untreated cotton separated the two treatments within each bay. Soil sampling locations were georeferenced to ensure year-on-year consistency. Earthworm monoliths were extracted from the same marked positions each October.

Results

Table 1: Seed cotton yield and lint percentage under organic and conventional management over three years

Year	Organic (t ha ⁻¹)	Conv. (t ha ⁻¹)	Gap (%)	Lint-Org (%)	Lint-Conv (%)
Year 1 (2021)	1.87	2.71	31.0	34.1	35.8
Year 2 (2022)	2.14	2.68	20.1	34.8	35.6
Year 3 (2023)	2.38	2.63	9.5	35.3	35.4
LSD (0.05)	0.22	0.19	—	0.9	NS

The organic yield gap narrowed from 31.0% in Year 1 to 9.5% by Year 3. Organic yield increased by 27.3% over the three years while conventional yield declined slightly (−3.0%). Lint

percentage in organic plots improved from 34.1% to 35.3%, converging with conventional values by Year 3.

Table 2: Soil health indicators under organic and conventional management after three years (0-15 cm depth)

Indicator	Baseline	Organic Yr3	Conv. Yr3	% Diff (O vs C)	LSD (0.05)
OC (%)	0.91	1.34	0.94	+42.6	0.11
MBC (µg g ⁻¹)	168	287	184	+56.0	31
DHA (µg g ⁻¹ h ⁻¹)	24.3	42.6	28.1	+51.6	5.8
Avail. N (mg kg ⁻¹)	186	218	197	+10.7	14
Earthworms (m ⁻²)	5.4	14.3	6.8	+110.3	3.2

Organic management raised soil OC by 47.3% from baseline (0.91 to 1.34%), compared with only 3.3% in conventional plots. Microbial biomass carbon and dehydrogenase activity were 56.0% and 51.6% higher in organic plots, respectively.

Earthworm density more than doubled under organic management (14.3 vs. 6.8 m⁻²), reflecting reduced chemical disturbance and increased organic matter inputs.

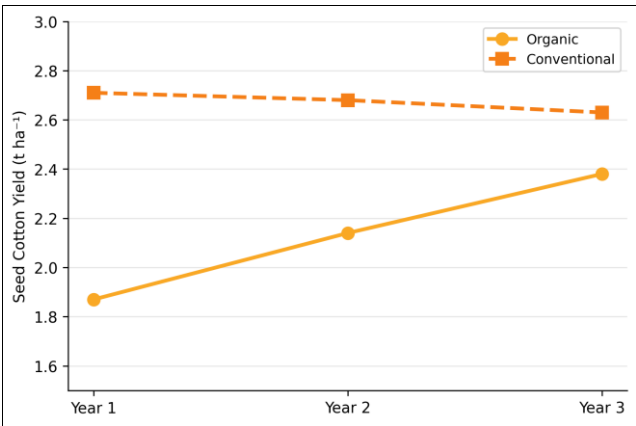


Fig 1: Seed cotton yield trend over three years under organic and conventional management at the dikopshof research station

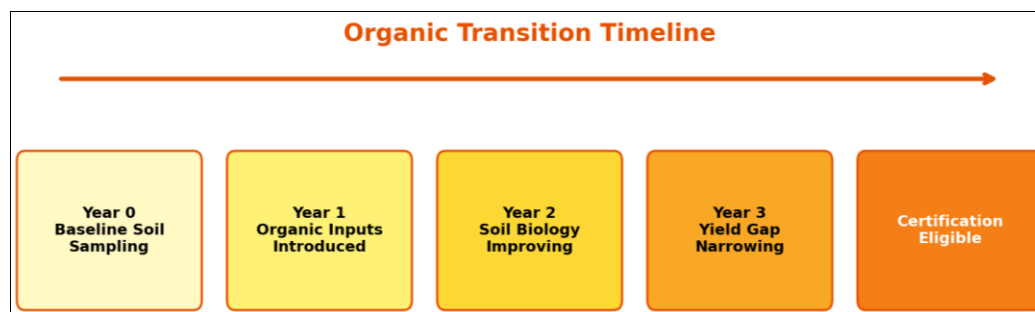


Fig 2: Timeline of organic transition milestones from baseline soil sampling through Year 3 certification eligibility

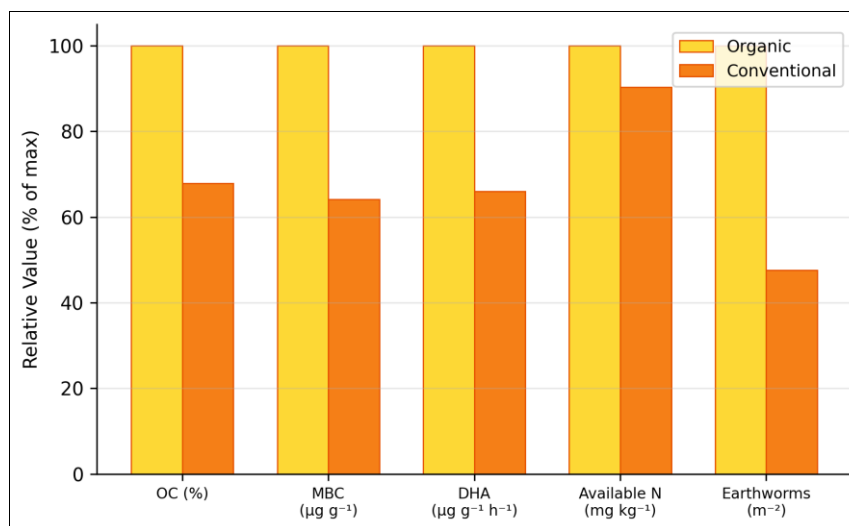


Fig 3: Relative soil health indicator values under organic versus conventional cotton management after three years

Comprehensive interpretation

The converging yield lines in Figure 1 and the diverging soil health bars in Figure 3 tell a complementary story: organic management initially costs yield but steadily builds soil biological capital that, in turn, supports better nutrient cycling and plant health. The Year 3 yield gap of 9.5% is within the range that organic price premiums (typically 20-40% above conventional) can more than offset, suggesting economic viability even before full yield recovery is achieved.

Discussion

The 31.0% yield gap in Year 1 aligns with the 25-35% losses commonly reported during organic transition in cotton [3, 8]. The rapid narrowing to 9.5% by Year 3 is faster than the 4-5 years timeline often cited, possibly because the Dikopshof soil had a favourable clay loam texture that responded quickly to manure inputs and because tunnel cultivation shielded the crop from some pest pressure that would be more severe in open-field conditions [5, 14].

Soil biological indicators responded more strongly than chemical ones. The 56.0% increase in microbial biomass carbon is consistent with meta-analyses showing that organic management boosts soil microbial communities by 30-60% within three years through continuous organic matter addition and elimination of synthetic pesticides that suppress non-target organisms [11, 15]. The 110.3% increase in earthworm density is among the largest reported for short-term organic transitions and likely reflects both the manure food source and the absence of lambda-cyhalothrin, which is highly toxic to earthworms [16, 17].

A key limitation is that tunnel cultivation moderates temperature extremes and excludes some pests, so these results may overstate the speed of yield recovery under open-field organic

cotton production. The three-year duration also prevents conclusions about long-term yield stability or soil carbon saturation [18]. Economic analysis including organic premium pricing and lower input costs would strengthen the case for or against transition.

Limitations

Tunnel cultivation limits generalisability to open-field cotton. Three years is too short to assess soil carbon saturation or long-term pest dynamics. Economic analysis with organic premiums was not performed and would strengthen practical recommendations. Only one variety was tested; genotype $\times$ management interactions may exist [7, 14].

Conclusion

Over three years of transition at the University of Bonn, organic cotton management narrowed the yield gap from 31.0% to 9.5% compared with conventional practice, while substantially improving soil biological health. Organic carbon increased by 47.3%, microbial biomass by 56.0%, and earthworm density by 110.3%.

The results support the transition-yield-recovery hypothesis: yield losses are heaviest in Year 1 but diminish as soil biology rebuilds nutrient cycling capacity. By Year 3, the remaining 9.5% yield gap would likely be offset by organic price premiums in most European markets.

Longer-term monitoring (5-10 years) under open-field conditions is needed to confirm whether the yield gap continues to close and whether soil health gains plateau or continue accumulating. These data provide a useful benchmark for cotton growers and policymakers considering organic transition support programmes in Central Europe.

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