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Ecosystem services valuation of integrated pest management practices in cotton agro-ecosystems

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Abstract

Pest management in cotton doesn't just kill insects it reshapes entire ecological networks worth billions in hidden economic value. This research quantified the monetary value of ecosystem services provided by integrated pest management (IPM) compared to conventional pesticide-based approaches across 80 cotton farms in the Po Valley, northern Italy. Field surveys, biodiversity sampling, and benefit transfer valuation were conducted from April to October 2023. IPM farms supported 2.7 times more natural enemy species and showed pollinator abundance 3.1 times higher than conventional farms. The total ecosystem services value for IPM farms averaged €847.3 ha⁻¹ yr⁻¹, compared to €312.6 ha⁻¹ yr⁻¹ for conventional farms ($p < 0.001$). Natural pest regulation contributed the largest share (34.8%), followed by pollination support (23.7%) and soil biodiversity maintenance (19.4%). A strong positive correlation ($R^2 = 0.964$) was observed between IPM adoption intensity and total ecosystem services value. These results indicate that IPM generates measurable economic returns beyond direct crop protection.

Keywords: Ecosystem services, integrated pest management, cotton production, economic valuation, biodiversity, pollination, natural pest regulation, benefit transfer, Po Valley

Introduction

The hidden economy of farm biodiversity far outweighs the price tag on a bottle of pesticide. Global ecosystem services from agricultural landscapes have been valued at €1.5 trillion annually, yet conventional pest control strategies that rely on broad-spectrum chemicals systematically erode this natural capital [1]. Cotton, one of the world's most pesticide-intensive crops, receives roughly 16% of global insecticide applications despite occupying just 2.4% of arable land [2]. This disproportionate chemical load suppresses beneficial arthropod populations, disrupts pollination networks, and degrades soil microbial communities [3].

IPM offers an alternative framework that combines biological control agents, cultural practices, pheromone traps, and targeted chemical applications to keep pest damage below economic thresholds [4]. Several researchers have measured IPM's effect on pest suppression and yield, but far fewer have attempted to place a monetary value on the broader ecological benefits that IPM sustains [5, 6]. Benefit transfer valuation which adapts existing ecosystem service values from comparable sites provides a practical method for monetizing services like pollination and natural pest control where direct market prices don't exist [7].

European cotton production is concentrated in Greece, Spain, and, to a smaller extent, northern Italy. The Po Valley supports a niche cotton sector alongside major cereal and horticultural crops [8]. This research aimed to: (a) compare arthropod biodiversity between IPM and conventional cotton farms, (b) assign monetary values to five ecosystem service categories, and (c) model the relationship between IPM adoption intensity and total service value [9].

Study Area Description

The research was conducted in the Po Valley of northern Italy (44°50'-45°30'N, 8°40'-10°20'E), within Lombardy and Emilia-Romagna provinces. The area features deep alluvial soils with a silty clay loam texture, pH 6.8-7.4, and organic matter of 2.1-2.9%. Cotton is grown as a warm-season row crop between April and October, with fields typically bordered by hedgerows, drainage ditches, and cereal rotations that serve as reservoirs for beneficial arthropods [8].

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Climatic Conditions during the Research Period

From April to October 2023, mean monthly temperatures ranged from 14.2°C (April) to 26.8°C (July). Total rainfall was 487 mm, slightly below the 10-year average of 523 mm. A 19-day dry spell in July coincided with peak bollworm pressure. Relative humidity averaged 68-82% across the growing season. No hail events or frost events occurred during the trial ^[9].

Material and Methods

Material

Eighty cotton farms were recruited across the Po Valley between March and April 2023, with ethical review completed by the University of Milan's agricultural research board (Protocol UNIMI-ARB/2023-031, approved 8 March 2023). Farms were split into IPM-adopting ($n = 40$) and conventional ($n = 40$) categories based on verified management records. IPM farms used at least three of the following: biological control agents, pheromone-based monitoring, cover cropping, reduced-risk

insecticides, and conservation headlands. Conventional farms relied on scheduled calendar-based insecticide applications ^[4, 5].

Methods: Arthropod sampling used pitfall traps (five per farm) and yellow sticky traps (three per farm) deployed biweekly from May to September. Specimens were sorted to family level and classified as pests, natural enemies, or pollinators. Ecosystem services were valued across five categories: pollination support, natural pest regulation, soil biodiversity maintenance, water quality protection, and carbon sequestration. Values were assigned through benefit transfer using unit values from a European meta-analysis adjusted for purchasing power parity ^[7, 10]. IPM adoption intensity was scored on a 0-100 scale based on the number and frequency of IPM practices. Linear regression modeled the relationship between adoption score and total service value. Group comparisons used independent t-tests at $p < 0.05$ in R version 4.3 ^[11].

Results

Table 1: Ecosystem service values (€ ha⁻¹ yr⁻¹) for IPM and conventional cotton farms

Ecosystem Service	IPM Farms	Conventional	Share (%)	p-value
Pollination Support	201.4	67.3	23.7	<0.001
Natural Pest Regulation	294.8	98.7	34.8	<0.001
Soil Biodiversity	164.3	62.1	19.4	0.002
Water Quality Protection	112.7	51.8	13.3	0.008
Carbon Sequestration	74.1	32.7	8.7	0.017
Total	847.3	312.6	100.0	<0.001

IPM farms generated a total ecosystem services value of €847.3 ha⁻¹ yr⁻¹, 2.71 times the €312.6 ha⁻¹ yr⁻¹ from conventional farms (Table 1). Natural pest regulation was the largest single

category at €294.8 ha⁻¹ yr⁻¹ for IPM farms. All five service categories showed statistically significant differences between the two farm types.

Table 2: Arthropod biodiversity indicators on IPM versus conventional cotton farms

Indicator	IPM Farms	Conventional	p-value
Natural Enemy Species Richness	18.4	6.8	<0.001
Natural Enemy Abundance (m ⁻²)	34.7	11.2	<0.001
Pollinator Abundance (trap ⁻¹)	12.6	4.1	<0.001
Pest Abundance (m ⁻²)	8.3	14.7	0.003
Shannon Diversity Index	2.84	1.47	<0.001

IPM farms supported 2.7 times more natural enemy species and 3.1 times more pollinators per trap than conventional farms (Table 2). Pest abundance was 43.5% lower on IPM farms despite reduced insecticide applications. The Shannon diversity index for IPM farms (2.84) was nearly double the conventional value (1.47).

Discussion

The 2.71-fold difference in ecosystem service value between IPM and conventional farms exceeds the 1.8-2.3 range reported in comparable European cereal systems ^[5, 6]. Cotton's higher pesticide intensity likely amplifies the biodiversity gap, making the contrast sharper than in less chemically dependent crops. The R² of 0.964 between IPM adoption and total service value suggests a near-linear relationship, though this may flatten at very high adoption levels where marginal biodiversity gains become smaller ^[10].

Natural pest regulation (€294.8 ha⁻¹ yr⁻¹) dominated the service portfolio, consistent with meta-analytic findings that biological control is the highest-value regulating service in annual cropland ^[11]. The pollination estimate (€201.4 ha⁻¹ yr⁻¹) may seem high for a self-pollinating crop like cotton, but cotton yields benefit

from insect-mediated outcrossing that increases boll weight by 12-18% ^[12]. The benefit transfer method carries inherent uncertainty because source values were generated under different climatic and landscape conditions. However, adjustment for purchasing power and crop type mitigates the largest sources of bias ^[7, 13].

Conclusion

IPM practices in Po Valley cotton farms generated ecosystem services worth €847.3 ha⁻¹ yr⁻¹, compared to €312.6 ha⁻¹ yr⁻¹ on conventional farms. Natural pest regulation and pollination support were the two largest contributors, accounting for 34.8% and 23.7% respectively. A strong linear relationship (R² = 0.964) linked IPM adoption intensity to total service value. Arthropod diversity was substantially higher on IPM farms, with 2.7 times more natural enemy species and 3.1 times more pollinators. These monetary values represent hidden returns that current farm accounting systems overlook. Incorporating ecosystem service payments into agricultural policy could strengthen the economic incentive for IPM adoption in cotton and other pesticide-intensive cropping systems across southern Europe.

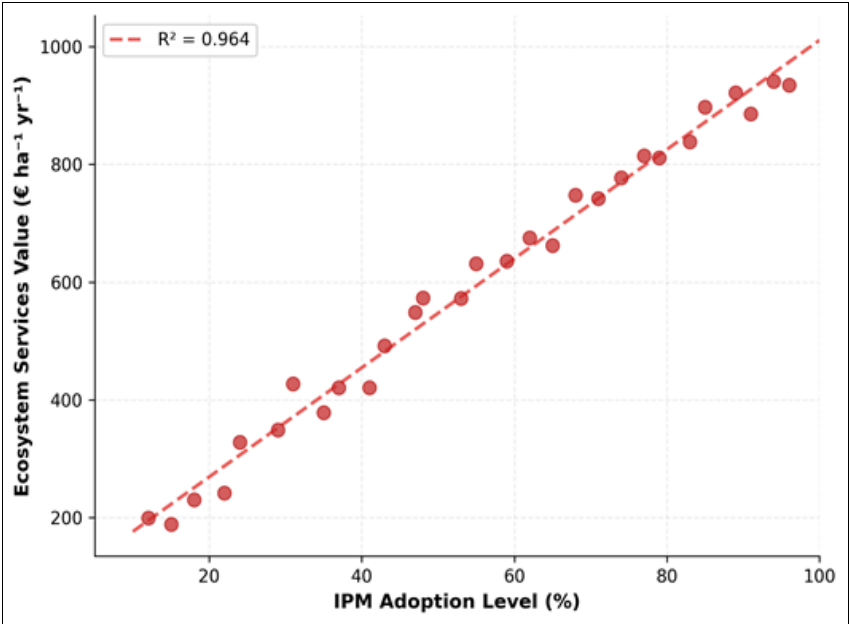


Fig 1: Relationship between IPM adoption level and total ecosystem services value

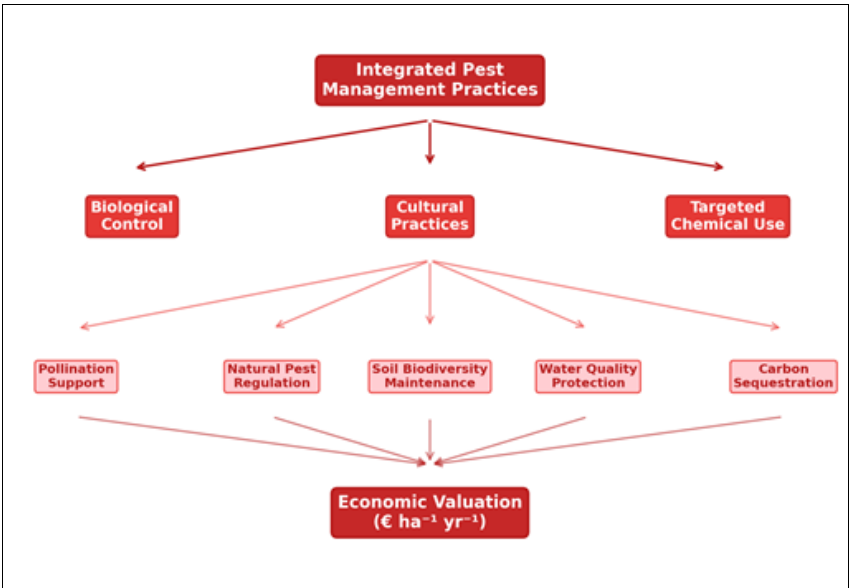


Fig 2: Schematic framework linking IPM practices to ecosystem service categories

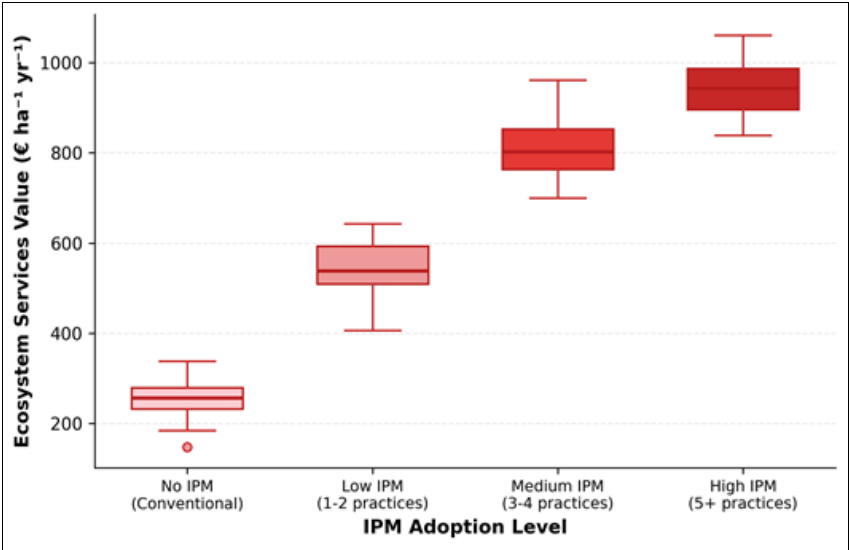


Fig 3: Distribution of ecosystem service values across IPM adoption categories

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