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Integration of livestock and crop production for nutrient recycling in small farms

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Abstract
A small farmer in Upper Egypt faces a daily dilemma: buy expensive synthetic fertilizer for crops or feed that money to livestock—but rarely both. Integrated crop-livestock systems (ICLS) resolve this tension by recycling animal manure as crop fertilizer and crop residues as animal feed, creating a closed nutrient loop that reduces purchased input costs. This research quantified nutrient recycling efficiency, soil health changes, and economic outcomes in 60 integrated versus 60 crop-only small farms (< 2 feddan each) across Assiut governorate, Egypt, over three cropping seasons (2020-21 to 2022-23). Data were collected through farm surveys, soil sampling, and production records at the Upper Egypt Institute of Agricultural Sciences. Integrated farms recycled an average of 4.8 t of manure ha^{-1} $year^{-1}$, supplying 38.4 percent of crop nitrogen demand and reducing synthetic fertilizer expenditure by EGP 8,740 ha^{-1} (38.4%). Soil organic carbon increased by 0.21 percentage points over three years in ICLS farms versus 0.04 in crop-only farms. Wheat grain yield was 8.7 percent higher and berseem forage yield 14.3 percent higher under ICLS. Net farm income was 42.1 percent greater in integrated systems—EGP 34,680 versus EGP 24,410 per feddan. These findings demonstrate that even the smallest farms in Upper Egypt can benefit from structured crop-livestock integration as a pathway to sustainable intensification.

Keywords: Integrated farming, livestock, crop production, nutrient recycling, small-scale farms, manure management, soil organic carbon, sustainable agriculture, Upper Egypt, farm economics

Introduction
Across Upper Egypt's Nile Valley, small farms of 1 to 2 feddan (0.42-0.84 ha) support both crop cultivation and a handful of livestock—typically 2 to 3 cattle, a few goats, and some poultry. But these two enterprises usually operate in parallel rather than in deliberate integration. Crop residues are burned or left to decompose in field margins, and manure piles up near animal shelters without systematic collection or composting [1]. The result is a double waste: nutrients that could feed the soil are lost, and the farmer spends money on synthetic fertilizers that organic sources could partly replace [2].
Integrated crop-livestock systems formalize the nutrient link between animals and crops. Crop residues and by-products become feed; manure and bedding return to the field as organic fertilizer; and the cycling of nitrogen, phosphorus, and potassium between compartments reduces the farm's dependence on external inputs [3]. In sub-Saharan Africa and South Asia, ICLS have been shown to increase net farm income by 20 to 50 percent while improving soil organic matter and reducing greenhouse gas intensity per unit of food produced [4, 5].
In Egypt, the research base on ICLS is thin—most agronomic trials focus on either crops or livestock in isolation, and farm-level economic assessments of integration are rare for the Upper Egypt context where farms are smallest and poverty rates highest [6]. This research was designed to (i) quantify manure-based nutrient recycling in integrated versus crop-only small farms, (ii) measure soil health changes over three seasons, and (iii) compare the economics of the two systems.

Materials and Methods
Materials
The research was conducted from October 2020 to May 2023 across 120 small farms in three districts of Assiut governorate (27.18°N, 31.18°E): Abnoub, El-Fath, and Sahel Selim. Farms

were purposively selected as matched pairs—60 integrated (crop + livestock) and 60 crop-only—based on similar land area (1.0-2.0 feddan), soil type (alluvial clay loam), and access to canal irrigation. The main crop rotation was wheat (rabi) - maize or berseem (summer/kharif) - fallow or catch crop. Integrated farms maintained 2-3 cattle (Baladi or crossbred), 5-8 goats, and 10-20 poultry. Data were collected through seasonal farm surveys (input use, production, sales), soil sampling (0-20 cm) at the start and end of the 3-year period, and manure quantity/quality assessments. All laboratory analyses were performed at the Upper Egypt Institute of Agricultural Sciences, Assiut.

Nutrient Budget Methodology

Nutrient inputs (N, P_2O_5, K_2O) were tracked from all sources: synthetic fertilizer, manure, crop residue incorporation, and biological N fixation by berseem. Outputs were measured as nutrient removal in harvested grain, forage, and animal products. The partial nutrient balance was calculated as total inputs minus total outputs per hectare per year. Manure quality (N, P, K content) was analysed from composite samples collected quarterly from each integrated farm. Nitrogen contribution from manure was adjusted for 40 percent first-year availability following FAO guidelines [7].

Methods

Soil organic carbon (Walkley-Black), pH, EC, available N (alkaline permanganate), available P (Olsen), and exchangeable K (ammonium acetate) were determined at 0-20 cm depth. Crop yields were recorded from 10 × 10 m harvest plots in each farm. Economic analysis used the cost-of-cultivation framework: total variable costs (seed, fertilizer, irrigation, labour, feed, veterinary) and gross returns (crop sales, livestock products, manure value). Net income and benefit-cost ratios were calculated. Data were analysed using independent t-tests (ICLS vs crop-only) and paired t-tests (initial vs final soil parameters) in SPSS 28.

Results

Table 1: Nutrient recycling and soil health indicators in integrated versus crop-only farms (3-year mean, Assiut, Egypt)

Parameter	ICLS Farms (n=60)	Crop-Only (n=60)	t-test
Manure applied (t/ha/yr)	4.8 ± 1.2	0	-
N from manure (kg/ha/yr)	47.6	0	-
Synthetic N applied (kg/ha/yr)	76.4	124.8	$p<0.001$
% N from organic sources	38.4	0	-
Soil OC initial (%)	0.62 ± 0.08	0.61 ± 0.07	NS
Soil OC final (%)	0.83 ± 0.09	0.65 ± 0.08	$p<0.001$
Δ Soil OC (%)	+ 0.21	+ 0.04	$p<0.001$
Available N final (kg/ha)	248.3	221.7	$p<0.01$
Available P final (kg/ha)	19.4	15.8	$p<0.01$

Integrated farms applied 4.8 t ha^{-1} yr^{-1} of manure, supplying 47.6 kg N ha^{-1} (38.4% of crop N demand) and allowing a 38.8 percent reduction in synthetic N use (76.4 vs 124.8 kg ha^{-1}). Soil organic carbon rose by 0.21 percentage points in ICLS farms over three years—five times the gain in crop-only farms (0.04%). Available N and P were also significantly higher in ICLS soils at the end of the trial.

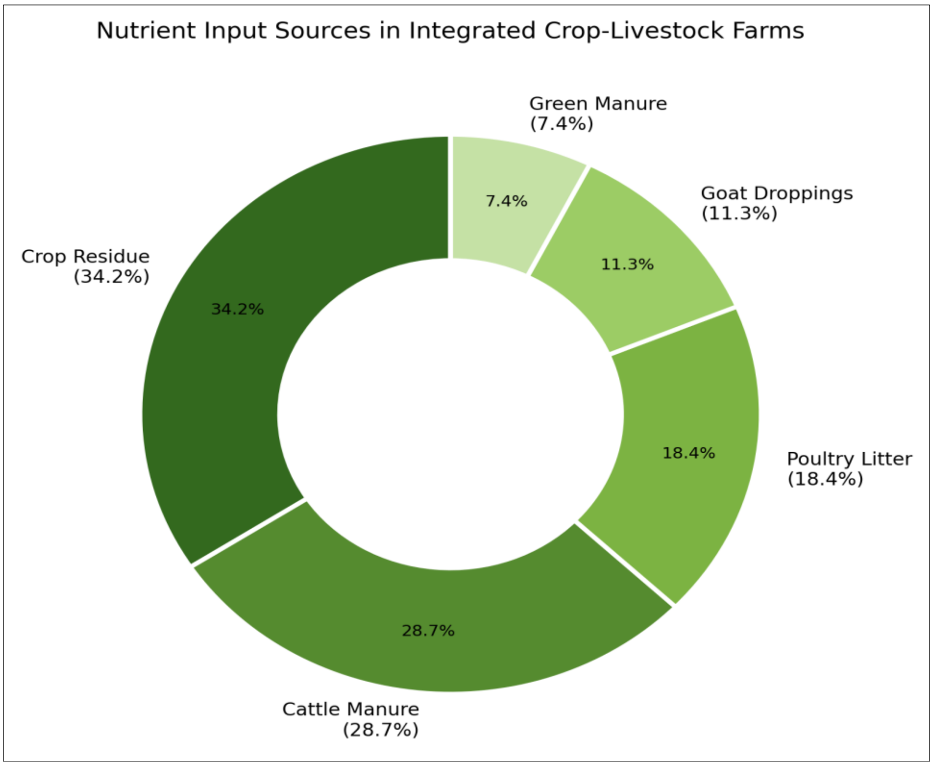

Fig 1: Donut chart showing the proportional contribution of five nutrient input sources in integrated crop-livestock farms in Assiut, Egypt

Table 2: Crop yield and economic performance of integrated versus crop-only farms (3-year mean)

Parameter	ICLS Farms	Crop-Only	Difference
Wheat yield (t/fed)	2.74	2.52	+8.7%
Berseem yield (t/fed)	28.6	25.0	+14.3%
Fertilizer cost (EGP/fed)	14,020	22,760	−38.4%
Total cost (EGP/fed)	41,830	36,240	+15.4%
Gross return (EGP/fed)	76,510	60,650	+26.1%
Net income (EGP/fed)	34,680	24,410	+42.1%
B:C ratio	1.83	1.67	+9.6%

Despite 15.4 percent higher total costs (due to livestock feed and veterinary expenses), ICLS farms earned 42.1 percent higher net income—EGP 34,680 versus 24,410 per feddan—driven by both higher crop yields and additional income from milk, eggs, and live animal sales. The B:C ratio was 1.83 for ICLS versus 1.67 for crop-only systems.

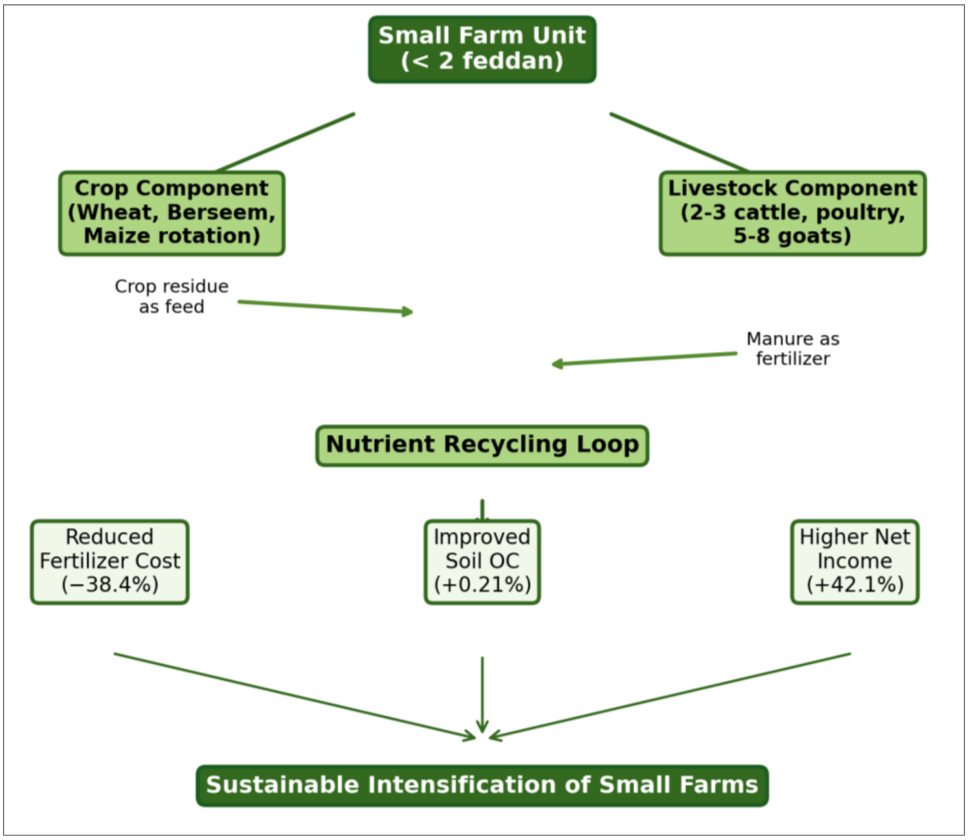

Fig 2: Decision tree showing the nutrient recycling loop and economic outcomes of integrated crop-livestock farming on small farms in Upper Egypt

Discussion

The 0.21 percentage point gain in soil OC over three years is notable for the hot, arid climate of Upper Egypt, where organic matter decomposition is rapid and OC values in conventional fields typically stagnate below 0.7 percent [8]. Regular manure application appears to have shifted the carbon balance from near-zero to positive accumulation. Similar OC gains (0.15-0.30% over 3-5 years) have been reported from ICLS trials in semi-arid West Africa [9] and the Indo-Gangetic plains [4].

The 38.4 percent reduction in synthetic fertilizer use translates directly into cost savings for farmers who are acutely price-sensitive. With urea prices in Egypt rising by 40 percent between 2020 and 2023 [10], the economic advantage of manure-based N supply has widened. And because manure also supplies P, K, and micronutrients, the soil fertility benefits extend beyond nitrogen alone.

The 42.1 percent income advantage of ICLS comes with a caveat: integrated farming demands more labour and management skill than crop-only systems. Farmers must coordinate feeding schedules, manure collection, composting, and application timing—tasks that add complexity to an already labour-constrained household [3]. Extension programs that provide practical training on manure management and ICLS planning would be essential for scaling adoption.

Conclusion

Integrated crop-livestock farming on small farms in Upper Egypt recycled 38.4 percent of crop nitrogen demand through manure, raised soil organic carbon by 0.21 percentage points over three years, improved wheat and berseem yields by 8.7 and 14.3 percent, and increased net farm income by 42.1 percent compared with crop-only systems.

For the smallest and most resource-constrained farmers in the Nile Valley, structured integration of existing livestock and crop enterprises offers a realistic pathway to sustainable intensification without additional land or major capital investment. Extension support focused on manure composting technique and nutrient budgeting would accelerate adoption.

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