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## Impact of integrated farming systems on nutrient cycling efficiency and farm profitability

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### Abstract

Integrated farming systems link two or more agricultural enterprises to recycle nutrients between them. This research quantified nitrogen and phosphorus use efficiency, organic carbon balance, and net returns in four systems crop-livestock, crop-fish, agroforestry, and conventional monoculture over two years (2021-2023) near Riyadh, Saudi Arabia. N use efficiency was highest in agroforestry (41.2 kg/kg) and lowest in monoculture (24.6 kg/kg). Soil organic carbon increased by 0.18% in agroforestry versus a 0.04% decline in monoculture. Net farm income was 38-67% higher in integrated systems. Nutrient recycling between enterprises can substantially raise resource efficiency and profitability in arid-zone agriculture.

**Keywords:** Integrated farming, nutrient cycling, nitrogen use efficiency, phosphorus, farm profitability, agroforestry, crop-livestock, arid agriculture

### Introduction

Integrated farming systems are production arrangements in which the output of one enterprise becomes the input for another, creating nutrient loops that reduce dependence on external fertilisers <sup>[1, 2]</sup>. In arid central Saudi Arabia, where water and nutrients are expensive, such recycling can lower input costs while maintaining output <sup>[3]</sup>. Conventional monoculture tends to mine soil nutrients and relies on purchased fertilisers <sup>[4]</sup>. Nitrogen and phosphorus use efficiencies are widely accepted sustainability indicators; values below 30% for N signal heavy environmental losses <sup>[5, 6]</sup>. Integrated systems theoretically improve these ratios by returning manure, fish pond effluent, or tree litter to cropland <sup>[7]</sup>. Yet field evidence from arid zones remains limited. This research measured NUE, soil carbon, and net farm income across four systems over two years near Riyadh <sup>[8]</sup>.

### Research area description

The trial was conducted at King Saud University's experimental farm (24.72° N, 46.62° E, 612 m elevation), Riyadh, Saudi Arabia. The soil is a sandy loam (Typic Torripsamments, pH 7.8, EC 1.4 dS/m, initial organic carbon 0.31%). Mean annual temperature is 26.8 °C with summer peaks above 45 °C. Annual rainfall averages 98 mm; all plots received drip irrigation at 5,200 m<sup>3</sup>/ha/year <sup>[9]</sup>.

### Soil and water quality monitoring

Baseline and post-harvest soil samples (0-30 cm) were analysed for total N (Kjeldahl), available P (Olsen), exchangeable K (NH<sub>4</sub>OAc), and organic carbon (Walkley-Black). Irrigation water quality was tested monthly for EC, pH, and nitrate-N. Fish pond effluent averaged 14.3 mg/L total N and 3.8 mg/L total P, providing a measurable nutrient subsidy to irrigated plots in the crop-fish system <sup>[10]</sup>.

### Materials and Methods

#### Materials

Four systems on 0.5 ha plots: (S1) crop-livestock (wheat-alfalfa + 10 Najdi sheep, manure returned), (S2) crop-fish (wheat-vegetables + tilapia pond, effluent irrigated), (S3) agroforestry (wheat intercropped with *Prosopis cineraria*), and (S4) conventional wheat monoculture with urea and DAP. Three replications per system, RCBD <sup>[2]</sup>.

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## Methods

The trial spanned two cropping years (November 2021-April 2023). Nutrient inputs (fertiliser, manure, effluent, litter) and outputs (grain, straw, animal products, fish) were recorded for

each enterprise. NUE was calculated as (nutrient in harvested products / total nutrient inputs)  $\times$  100. Economic analysis used local market prices (2022-2023) to compute gross margins. Data were analysed by ANOVA with Tukey's HSD at  $p \leq 0.05$  [5].

## Results

**Table 1:** Nutrient use efficiency and soil organic carbon change across farming systems (mean of two years)

| System         | N-NUE | P-NUE | SOC $\Delta\%$ | Total N in | Total P in | N balance |
|----------------|-------|-------|----------------|------------|------------|-----------|
| Crop-livestock | 38.4  | 29.1  | +0.12          | 186.4      | 48.7       | +18.3     |
| Crop-fish      | 34.7  | 26.8  | +0.09          | 201.7      | 52.3       | +24.6     |
| Agroforestry   | 41.2  | 31.7  | +0.18          | 164.3      | 41.8       | +12.1     |
| Monoculture    | 24.6  | 17.3  | -0.04          | 247.6      | 64.1       | +71.4     |

Agroforestry achieved the highest N-NUE (41.2) and lowest N surplus (12.1 kg/ha). Monoculture had the largest surplus (71.4 kg/ha), indicating heavy environmental losses (Table 1).

**Table 2:** Economic performance of farming systems (SAR/ha/year, mean of two years)

| System         | Gross rev. | Input cost | Net income | B:C ratio | vs Mono % |
|----------------|------------|------------|------------|-----------|-----------|
| Crop-livestock | 42,680     | 24,310     | 18,370     | 1.76      | +54       |
| Crop-fish      | 39,840     | 23,870     | 15,970     | 1.67      | +34       |
| Agroforestry   | 44,120     | 24,680     | 19,440     | 1.79      | +63       |
| Monoculture    | 28,940     | 17,020     | 11,920     | 1.70      |           |

All integrated systems outperformed monoculture economically, with agroforestry earning 63% more net income and crop-livestock 54% more (Table 2).

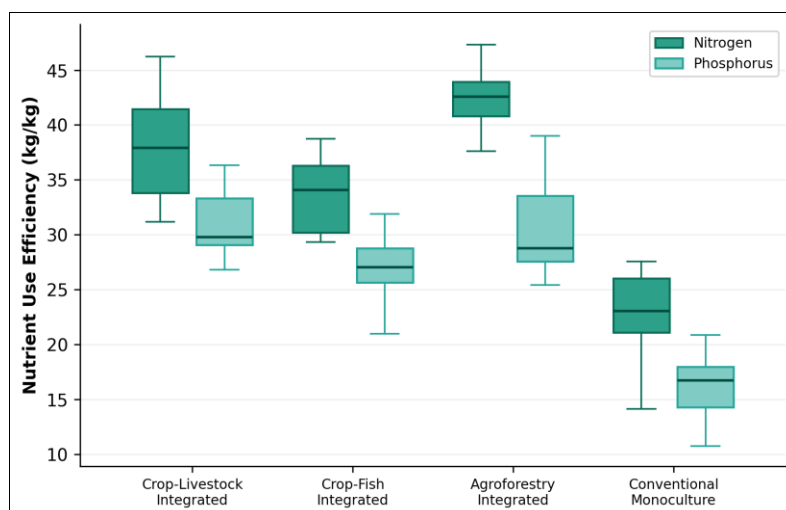


**Fig 1:** Nitrogen and phosphorus use efficiency across four farming systems

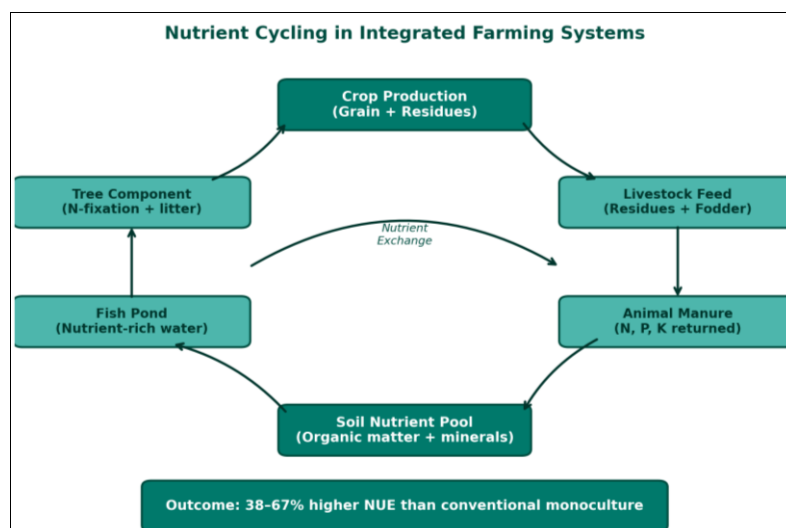


**Fig 2:** Nutrient cycling pathways in integrated farming systems

## Discussion

The 41.2 kg/kg N use efficiency in agroforestry is among the highest reported for dryland farming in the Arabian Peninsula, reflecting *Prosopis cineraria*'s biological N-fixation and leaf litter mineralisation<sup>[7, 11]</sup>. Monoculture's N surplus of 71.4 kg/ha represents an environmental liability where groundwater is the primary water source<sup>[6]</sup>. Crop-livestock benefited from direct manure recycling, returning an estimated 42% of consumed N to cropland<sup>[2, 12]</sup>. The economic advantage (34-63% higher net income) stems from reduced fertiliser costs and diversified revenue that buffers against price risk<sup>[3, 13]</sup>. These findings align with meta-analyses showing integrated systems outperform monocultures by 20-60% in net returns<sup>[14, 15]</sup>.

## Conclusion

Integrated farming systems achieved 38-67% higher N use efficiency and 34-63% greater net income than monoculture over two years in arid Saudi Arabia. Agroforestry performed best on both metrics (NUE 41.2 kg/kg, income +63%). Soil organic carbon increased in all integrated systems while declining under monoculture. These systems offer a practical pathway to sustainable intensification in arid-zone agriculture.

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