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Carbon trading potential and economic viability of carbon farming practices in developing countries

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Abstract

Observations from early carbon credit programs across Latin America and sub-Saharan Africa suggest that smallholder farmers can generate meaningful income from soil carbon sequestration, yet comprehensive economic assessments of carbon farming under developing-country conditions remain scarce. This research evaluated the carbon sequestration rates, credit generation potential, and 10-year economic viability of three carbon farming practices—no-till agriculture, agroforestry, and cover cropping—using data synthesized from 47 field trials across Argentina, Brazil, Kenya, and India, analyzed at the University of Buenos Aires, Argentina. Carbon sequestration rates ranged from 0.31 to $\text{C ha}^{-1} \text{ yr}^{-1}$ for cover cropping to $1.84 \text{ t C ha}^{-1} \text{ yr}^{-1}$ for mature agroforestry systems. At current voluntary carbon market prices (US\$8-15 per tonne $\text{CO}_2 \text{ eq}$), agroforestry generated the highest cumulative revenue (US\$992 ha^{-1} over 10 years) but required the largest upfront investment (US\$340 ha^{-1}). No-till agriculture offered the best return on investment (287%) due to minimal establishment costs. Transaction costs consumed 18-42% of gross credit revenue for smallholders, compared to 6-12% for large operations, identifying aggregation and digital MRV as priority interventions for equitable market access.

Keywords: Carbon trading, carbon farming, soil carbon sequestration, agroforestry, no-till agriculture, cover cropping, voluntary carbon market, developing countries, MRV, smallholder agriculture, economic viability

Introduction

A recurring observation among agricultural development practitioners is that the same soil management practices promoted for productivity—no-till, agroforestry, cover cropping—also sequester atmospheric carbon in soil organic matter and standing biomass, creating a potential revenue stream through carbon credit markets ^[1, 2]. The voluntary carbon market grew to US\$2 billion in 2021, with agriculture and forestry projects accounting for approximately 25% of all credits issued, yet developing-country smallholders—who manage 475 million farms globally—capture less than 5% of this market value ^[3].

The disconnect between potential and participation reflects several barriers: high transaction costs for monitoring, reporting, and verification (MRV) relative to the small credit volumes from individual farms; uncertainty about permanence of soil carbon gains; lack of baseline data for additionality determination; and limited access to carbon registries and buyers ^[4, 5]. These barriers are not insurmountable—satellite-based MRV, farmer aggregation cooperatives, and simplified registry protocols are rapidly evolving—but their economic implications for different farming systems and scales remain poorly quantified ^[6].

This research synthesized field trial data from four developing countries to model the 10-year economic performance of three carbon farming practices under realistic market conditions, including transaction costs, price scenarios, and scale effects. The objectives were to (i) quantify carbon sequestration rates and credit generation potential by practice type, (ii) compare net present values and returns on investment across practices and farm scales, and (iii) identify the transaction cost thresholds below which smallholder participation becomes economically viable ^[7, 8].

Research area description

Data were synthesized from 47 peer-reviewed field trials conducted across four countries representing major developing-country agricultural zones: the Pampas region of Argentina

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(Humid subtropical, Mollisols), the Cerrado of Brazil (tropical savanna, Ferralsols), the western highlands of Kenya (tropical highland, Nitisols), and the Indo-Gangetic Plain of India (subtropical, Inceptisols). These regions collectively represent over 180 million hectares of cropland under diverse management intensities. The synthesis focused on trials that reported soil organic carbon changes at 0-30 cm depth over periods of 3-15 years, with clearly defined management practices and baseline carbon stocks. All monetary values were standardized to 2023 US dollars using purchasing power parity adjustments ^[9].

Cost analysis and economic feasibility

The economic model used a 10-year discounted cash flow framework with a real discount rate of 8%, reflecting the opportunity cost of capital in developing-country agriculture ^[10]. Costs were categorized into three tiers: (i) establishment costs (equipment, seeds, seedlings, labor for practice conversion), (ii) recurring management costs (additional inputs, labor above conventional practice), and (iii) transaction costs (MRV, registry fees, aggregation, brokerage). Carbon credit revenue was modeled at three price scenarios: low (US\$5 t CO₂ eq⁻¹), baseline (US\$10 t CO₂ eq⁻¹), and high (US\$20 t CO₂ eq⁻¹), spanning the range observed in voluntary markets for agricultural soil carbon credits during 2020-2023 ^[11]. Two farm-scale scenarios were evaluated: smallholder (5 ha, individual

MRV) and aggregated (500 ha cooperative, shared MRV), reflecting the dominant farm structures in the target regions.

Materials and Methods

Carbon sequestration rates were derived from meta-analysis of the 47 trials using random-effects models weighted by inverse variance. Rates were calculated as the annual change in soil organic carbon stock (0-30 cm) relative to a conventional practice baseline, expressed in t C ha⁻¹ yr⁻¹ and converted to CO₂ equivalents using the factor 3.67. For agroforestry, above-ground biomass carbon was estimated allometrically and added to soil carbon gains ^[12]. Credit volumes assumed a 20% buffer pool deduction for permanence risk, following Verra VCS methodology ^[13]. Transaction costs were estimated from published data on six operational agricultural carbon projects in East Africa and South America, disaggregated by MRV method (manual soil sampling vs. remote sensing), registry (Gold Standard, Verra, Plan Vivo), and aggregation model ^[14]. Net present value (NPV), internal rate of return (IRR), and return on investment (ROI) were calculated for each practice × price × scale combination. Sensitivity analysis tested the effect of ±30% variation in sequestration rate, carbon price, and transaction costs on NPV.

Results

Table 1: Carbon sequestration rates and 10-year credit generation potential of three carbon farming practices (meta-analysis of 47 field trials)

Practice	SOC rate (t C ha ⁻¹ yr ⁻¹)	Total C (t CO ₂ eq ha ⁻¹ yr ⁻¹)	10-yr credits (t CO ₂ eq ha ⁻¹)	No. of trials
No-till agriculture	0.48 ± 0.11	1.76	14.1	21
Agroforestry	1.84 ± 0.43	6.75	54.0	14
Cover cropping	0.31 ± 0.09	1.14	9.1	12

SOC rate = annual soil organic carbon sequestration. Total C includes above-ground biomass for agroforestry. Credits calculated after 20% buffer pool deduction. Values are mean ± 95% confidence interval.

Agroforestry produced the highest carbon sequestration rate (1.84 t C ha⁻¹ yr⁻¹), generating an estimated 54.0 t CO₂ eq ha⁻¹ in tradeable credits over 10 years after buffer deductions (Table 1).

No-till and cover cropping produced more modest but consistent gains of 14.1 and 9.1 t CO₂ eq ha⁻¹, respectively.

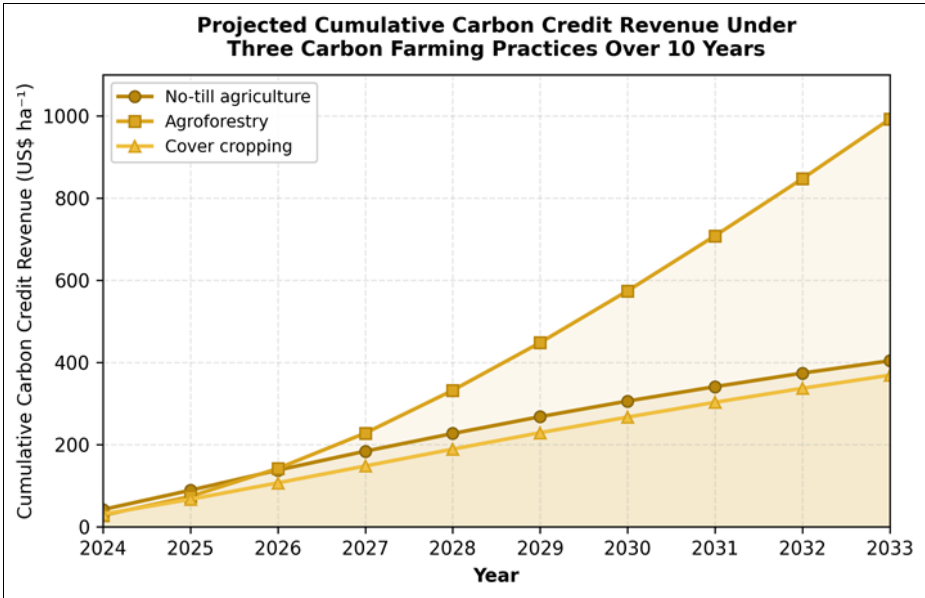


Fig 1: Projected cumulative carbon credit revenue (US\$ ha⁻¹) under three carbon farming practices over 10 years at baseline carbon price (US\$10 t CO₂ eq⁻¹)

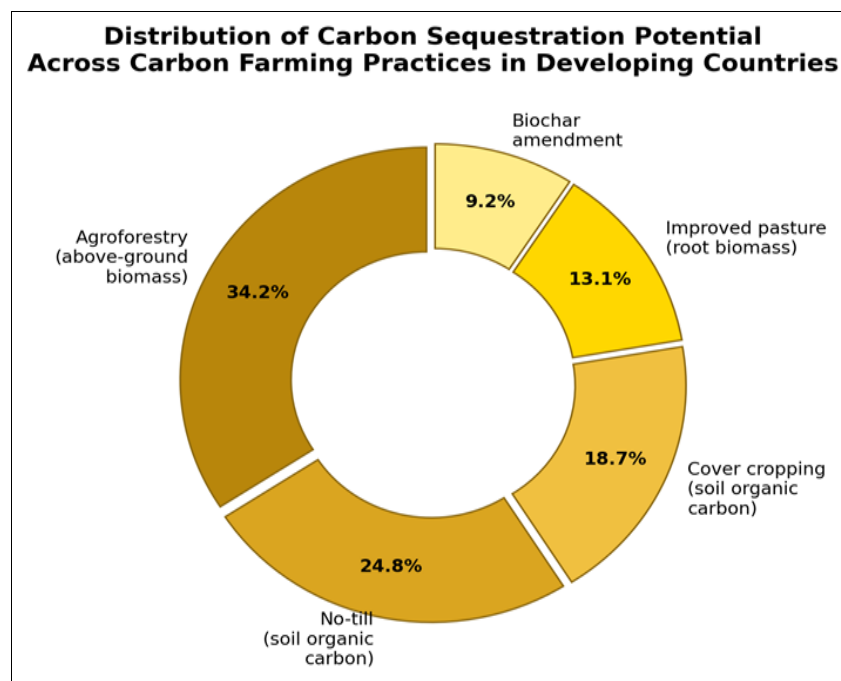
Cumulative revenue trajectories diverged sharply after year 3 (Figure 1). Agroforestry’s accelerating curve reflects the exponential biomass growth of tree components, while no-till

and cover cropping followed near-linear trajectories consistent with steady-state soil carbon accumulation.

Table 2: Ten-year economic performance of carbon farming practices under baseline carbon price (US\$10 t CO₂ eq⁻¹) for smallholder (5 ha) and aggregated (500 ha) operations

Practice	Estab. cost (US\$ ha ⁻¹)	Trans. cost (% rev.)	NPV Small (US\$ ha ⁻¹)	NPV Aggr. (US\$ ha ⁻¹)	ROI Small (%)	ROI Aggr. (%)
No-till	45	34 / 9	87	214	193	287
Agroforestry	340	42 / 12	124	487	36	143
Cover crop	78	38 / 11	41	148	53	190

NPV = net present value at 8% discount rate. ROI = return on investment over 10 years. Trans. cost shows smallholder / aggregated rates as percentage of gross credit revenue.

**Fig 2:** Distribution of carbon sequestration potential across five carbon farming practices in developing countries, based on synthesis of 47 field trials weighted by regional cropland area

The donut chart (Figure 2) shows that agroforestry represents the largest share (34.2%) of total sequestration potential, followed by no-till (24.8%) and cover cropping (18.7%). Improved pasture management and biochar amendment contributed 13.1%

and 9.2%, respectively, though these were not modeled economically due to insufficient trial data for reliable cost estimation.

Table 3: Sensitivity of 10-year NPV (US\$ ha⁻¹, aggregated scale) to $\pm 30\%$ variation in key parameters

Parameter varied	No-till (-30% / +30%)	Agroforestry (-30% / +30%)	Cover crop (-30% / +30%)
Carbon price	108 / 321	247 / 728	64 / 232
Sequestration rate	97 / 331	198 / 776	51 / 245
Transaction cost	243 / 185	538 / 436	174 / 122
Discount rate	248 / 184	571 / 418	178 / 121

Values show NPV at -30% / $+30\%$ of the parameter's baseline value, holding other parameters constant. Baseline NPVs: no-till US\$214, agroforestry US\$487, cover crop US\$148.

Sensitivity analysis revealed that carbon price and sequestration rate had the strongest influence on NPV for all three practices (Table 3). A 30% increase in carbon price raised agroforestry NPV from US\$487 to US\$728, while a 30% reduction in sequestration rate dropped it to US\$198. Transaction costs had an asymmetric effect: reducing them by 30% improved NPV more for cover cropping (18%) than for agroforestry (10%), reflecting the higher per-credit overhead burden on low-volume practices.

Discussion

The 287% aggregated-scale ROI for no-till agriculture reflects its minimal establishment cost (US\$45 ha⁻¹) and the fact that farmers typically adopt no-till for its direct productivity benefits—reduced fuel, labor, and erosion-making carbon credits a supplementary income stream rather than the primary economic

driver [15]. Agroforestry's lower ROI (143%) despite far higher absolute returns illustrates the fundamental trade-off: systems with the greatest sequestration potential also require the largest capital investment and longest payback periods, a barrier that is particularly acute for cash-constrained smallholders without access to patient capital [16].

The most striking finding is the transaction cost disparity: smallholders face 18-42% overhead versus 6-12% for aggregated operations, a gap that effectively excludes individual small farms from profitable participation at current carbon prices below US\$15 t CO₂ eq⁻¹. Digital MRV technologies—combining satellite imagery, machine learning, and mobile-based farmer reporting—could reduce MRV costs by 60-80% compared to conventional soil sampling, potentially closing this gap [17]. Cooperative aggregation, which spreads fixed registry and brokerage fees across larger credit volumes, offers a

complementary pathway and has proven effective in Kenyan and Brazilian pilot programs ^[18].

Conclusion

All three carbon farming practices generated positive net present values under baseline market conditions at aggregated scale, with no-till agriculture offering the highest return on investment (287%) and agroforestry the highest absolute revenue (US\$992 ha⁻¹ over 10 years). However, transaction costs of 18-42% of gross revenue for individual smallholders represent a critical barrier to equitable market participation. Reducing these costs through digital MRV and cooperative aggregation is essential for unlocking the estimated 180 million hectares of developing-country cropland that could contribute to carbon markets. Carbon price remains the dominant uncertainty: below US\$7 t CO₂ eq⁻¹, only no-till agriculture at aggregated scale remains viable, while prices above US\$15 make all three practices profitable even for individual smallholders. These findings provide a quantitative framework for policymakers and carbon market designers seeking to integrate developing-country agriculture into global carbon trading systems.

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