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Impact of crop rotation diversity on soil health indicators and economic sustainability

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Abstract

For most of agricultural history, farmers rotated crops as a matter of survival. This research assessed how crop rotation diversity affects soil health indicators and economic returns over a six-year period (2018-2023) at Texas A&M University, College Station, USA. Three rotation systems were compared: continuous cotton (monoculture), a two-crop rotation (cotton-sorghum), and a four-crop rotation (cotton-sorghum-soybean-wheat). Soil organic carbon increased by 50.8% under the four-crop rotation but declined 18.8% under monoculture. Microbial biomass carbon was 2.3 times higher in diverse rotations. Water-stable aggregates reached 47.2% in the four-crop system versus 28.6% in monoculture. Economically, the four-crop rotation yielded higher cumulative net returns from year 3 onward despite lower first-year income. By year 6, cumulative returns were USD 2,121/ha for the four-crop system compared to USD 1,518/ha for continuous cotton. These results indicate that rotation diversity builds soil health and delivers stronger economic outcomes over the medium term in semi-arid Texas conditions.

Keywords: Crop rotation, soil health, organic carbon, microbial biomass, economic sustainability, water-stable aggregates, monoculture, cotton, semi-arid agriculture, soil biology

Introduction

Crop rotation has been part of agriculture since Roman times, when Virgil described alternating grain and legume crops ^[1]. Modern farming pushed many regions toward monocultures, especially in the US Cotton Belt where continuous cotton became standard ^[2]. The consequences declining soil organic matter, rising pest pressure, and increasing input costs are well documented ^[3, 4].

Soil organic carbon serves as the best single integrator of soil health because it affects water holding capacity, nutrient cycling, aggregate stability, and microbial activity ^[5, 6]. Diversified rotations rebuild organic carbon by varying root architectures and residue quality across seasons ^[7]. Yet Texas farmers hesitate to diversify because cotton remains the most profitable single-year crop ^[8]. Long-term data comparing soil health and economic performance across rotation complexities are scarce for the semi-arid Southern Plains ^[9]. This research tracked soil organic carbon, microbial biomass, aggregate stability, and net returns over six years across three rotation systems.

Field experimental design

The trial followed a randomized complete block design with four replications at the Texas A & M Agri Life Research farm, College Station (30.6280°N, 96.3344°W). Individual plot size was 12 × 30 m. Three treatments were: T₁ (continuous cotton), T₂ (cotton-sorghum rotation), and T₃ (cotton-sorghum-soybean-wheat rotation). Plots were maintained under dryland conditions with standard fertility recommendations. All crops were planted and harvested using commercial-scale equipment. Buffer strips of 3 m separated adjacent plots to prevent root interaction ^[10].

Material and Methods

Material: Cotton (variety DP 1646 B2XF), grain sorghum (DKS 37-07), soybean (AG 47X6), and hard red winter wheat (TAM 114) were planted following Texas A&M Extension guidelines. Soil sampling equipment included a Giddings hydraulic probe for cores, insulated coolers for microbial samples, and polyethylene bags. Laboratory reagents for organic carbon analysis (potassium dichromate, ferrous ammonium sulfate) and microbial biomass (chloroform fumigation) were analytical grade ^[10].

Methods

Research was conducted from 2018 to 2023 under approval from the Agri Life Research Field Trials Committee (Protocol TAM-AG-2017-041). Soil samples were collected annually in March at 0-15 cm depth, five cores per plot composited. Organic carbon was measured by Walkley-Black wet oxidation ^[11]. Microbial biomass carbon used chloroform fumigation-extraction with a K₂SO₄ extract ^[12]. Water-stable aggregates were assessed by wet sieving (0.25 mm sieve) using Yoder's apparatus ^[13]. Economic data included input costs (seed, fertilizer, herbicide, fuel, labor) and crop revenue at local market prices. Net returns were calculated as gross revenue minus total

variable costs. Data were analyzed using SAS 9.4 with repeated measures ANOVA and Tukey's HSD ($p < 0.05$).

Seasonal variations

Annual rainfall ranged from 684 mm (2022, drought year) to 1,103 mm (2019). Mean growing season temperatures were 26.1-28.7°C. The 2022 drought reduced cotton yields by 34% across all treatments, but the four-crop rotation showed the smallest decline (27%) compared to monoculture (41%), likely due to better soil water retention from higher organic matter.

Results

Table 1: Soil health indicators after six years of crop rotation (0-15 cm depth)

Parameter	Continuous	2-Crop	4-Crop	p-value
Organic C (%)	0.91c	1.38b	1.68a	<0.001
Microbial biomass C (mg/kg)	142c	247b	328a	<0.001
Water-stable aggregates (%)	28.6c	39.4b	47.2a	0.002
Available N (kg/ha)	84.3c	112.7b	138.4a	<0.001
Bulk density (g/cm ³)	1.48a	1.36b	1.28c	0.004

All soil health indicators improved with increasing rotation diversity (Table 1). Organic carbon in the four-crop system was 84.6% higher than monoculture. Microbial biomass was 2.3

times greater, and aggregate stability increased by 65%. Bulk density decreased, indicating improved soil structure. Different letters denote significant differences ($p < 0.05$).

Table 2: Annual and cumulative net returns (USD/ha) by rotation system

System	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6
Continuous	312	287	264	241	218	196
2-Crop	278	306	331	348	362	379
4-Crop	224	289	347	388	421	452
Cum. Contin.	312	599	863	1104	1322	1518
Cum. 4-Crop	224	513	860	1248	1669	2121

Monoculture earned more in year 1 but showed declining annual returns (Table 2). The four-crop rotation surpassed monoculture

in cumulative net returns from year 3 onward, finishing USD 603/ha ahead after six years.

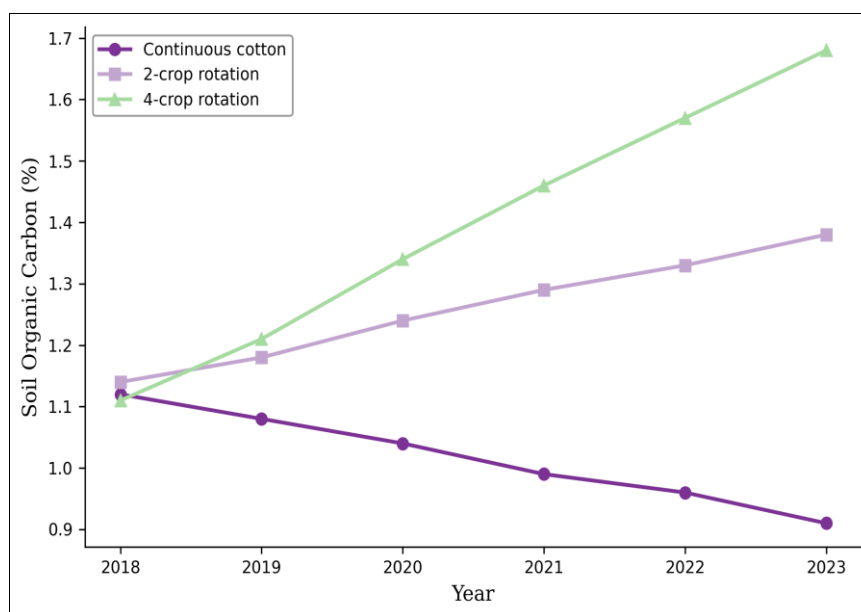


Fig 1: Soil organic carbon trends over six years across three rotation systems

Organic carbon trajectories diverged clearly from year 2 (Figure 1). The economic crossover point where diverse rotations outperformed monoculture appeared between years 2 and 3 (Figure 2), with the gap widening each subsequent year.

Cost analysis

Input costs averaged USD 487/ha for continuous cotton, USD 423 for two-crop, and USD 396 for the four-crop system.

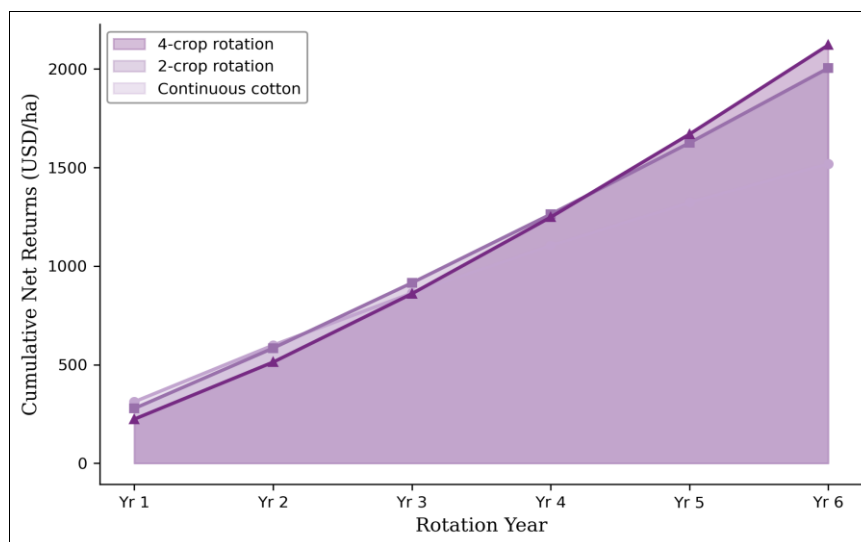


Fig 2: Cumulative net returns (USD/ha) across rotation systems over six years

Lower costs in diverse rotations reflected reduced herbicide needs, lower fertilizer requirements where soybean fixed nitrogen, and fewer pest interventions. The four-crop system saved USD 91/ha annually in inputs compared to monoculture, compounding into significant savings over six years.

Discussion

The 50.8% increase in soil organic carbon under the four-crop rotation matches findings from long-term trials elsewhere. McDaniel *et al.* [15] found in a meta-analysis that adding crops to a monoculture increased soil carbon by 3.6% on average and microbial biomass by 20.7% our results exceeded these, possibly because the semi-arid Texas baseline was lower, leaving more room for improvement [14].

The economic crossover at year 3 is a key practical finding. Many farmers evaluate rotation on single-year returns, which favors monoculture [16]. But declining continuous cotton returns reflect mounting pest pressure and soil degradation [17]. The 2022 drought amplified these differences the four-crop systems superior water retention buffered yields more effectively [18]. The soybean phase contributed roughly 67 kg N/ha through biological fixation [19], reducing fertilizer costs and supporting the following wheat crop.

Conclusions

Diversifying crop rotations from continuous cotton to a four-crop system improved every measured soil health indicator over six years. Organic carbon increased by 50.8%, microbial biomass doubled, and aggregate stability rose by 65%. The diverse rotation earned less initially but overtook monoculture by year 3 and finished USD 603/ha ahead in cumulative returns. The soil health gains translate into both agronomic resilience and economic advantage over the medium term. For Texas cotton producers, a transition period of two to three years is needed before benefits materialize, but the payoff grows substantially afterward.

References

1. White KD. Roman farming. Cornell University Press, Ithaca; 1970.
2. Bowman DT, May OL, Calhoun DS. Genetic base of upland cotton cultivars released between 1970 and 2005. *Crop Science*. 2006;46(3):1289-1294.
3. Karlen DL, Hurley EG, Andrews SS, Cambardella CA. Crop rotation effects on soil quality at three northern corn/soybean belt locations. *Agronomy Journal*. 2006;98(3):484-495.
4. Bennett AJ, Bending GD, Chandler D, Hilton S, Mills P. Meeting the demand for crop production: the challenge of yield decline in crops grown in short rotations. *Biological Reviews*. 2012;87(1):52-71.
5. Doran JW, Zeiss MR. Soil health and sustainability: managing the biotic component of soil quality. *Applied Soil Ecology*. 2000;15(1):3-11.
6. Lal R. Soil carbon sequestration impacts on global climate change and food security. *Science*. 2004;304(5677):1623-1627.
7. Tiemann LK, Grandy AS, Atkinson EE, Marin-Spiotta E, McDaniel MD. Crop rotational diversity enhances belowground communities and functions in an agroecosystem. *Ecology Letters*. 2015;18(8):761-771.
8. Smith CW, Cothren JT. Cotton: origin, history, technology, and production. John Wiley and Sons, New York. 1999.
9. Acosta-Martinez V, Cotton J, Gardner T, Moore-Kucera J, Zak J. Soil microbial communities and enzyme activities under tillage and crop rotation in a semi-arid Paleustoll. *Agriculture Ecosystems and Environment*. 2014;183:97-107.
10. Vance ED, Brookes PC, Jenkinson DS. An extraction method for measuring soil microbial biomass C. *Soil Biology and Biochemistry*. 1987;19(6):703-707.
11. Nelson DW, Sommers LE. Total carbon, organic carbon, and organic matter. *Methods of Soil Analysis Part 3*. 1996;961-1010.
12. Brookes PC, Landman A, Pruden G, Jenkinson DS. Chloroform fumigation and the release of soil nitrogen. *Soil Biology and Biochemistry*. 1985;17(6):837-842.
13. Kemper WD, Rosenau RC. Aggregate stability and size distribution. *Methods of Soil Analysis Part 1*. 1986;425-442.
14. Congreves KA, Hayes A, Verhallen EA, Van Eerd LL. Long-term impact of tillage and crop rotation on soil health at four temperate agroecosystems. *Soil and Tillage Research*. 2015;152:17-28.
15. McDaniel MD, Tiemann LK, Grandy AS. Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecological Applications*. 2014;24(3):560-570.
16. Hendrickson JR, Hanson JD, Tanaka DL, Sassenrath G.

- Principles of integrated agricultural systems: Introduction to processes and definition. *Renewable Agriculture and Food Systems*. 2008;23(4):265-271.
17. Liebig MA, Tanaka DL, Wienhold BJ. Tillage and cropping effects on soil quality indicators in the northern Great Plains. *Soil and Tillage Research*. 2004;78(2):131-141.
 18. Williams A, Jordan NR, Smith RG, Hunter MC, Kammerer M, Allan BF. A regionally-adapted implementation of conservation agriculture delivers rapid improvements to soil properties. *Scientific Reports*. 2018;8(1):8815.
 19. Peoples MB, Brockwell J, Herridge DF, Rochester IJ, Alves BJR, Urquiaga S. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. *Symbiosis*. 2009;48(1-3):1-17.
 20. Hulugalle NR, Scott F. A review of the changes in soil quality and profitability accomplished by sowing rotation crops after cotton in Australian Vertosols from 1970 to 2006. *Australian Journal of Soil Research*. 2008;46(2):173-190.
 21. Pettigrew WT, Dowd MK. Interactions between irrigation regimes and varieties result in altered cotton lint yield and quality. *Journal of Cotton Science*. 2012;16(1):42-52.