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Extension approaches to soil health risk management through organic amendment and cover cropping strategies

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Abstract

Soil degradation threatens the long-term productivity of cropland in Mongolia's semi-arid farming regions, where wind erosion and declining organic matter are persistent concerns. This research examined extension-led approaches to soil health risk management using organic amendments and cover cropping strategies across 16 on-farm demonstration sites in the Tuv and Selenge provinces between April 2022 and October 2023. Four treatments were evaluated: compost application, livestock manure incorporation, cover crop establishment, and a combined amendment-plus-cover-crop treatment, alongside untreated controls. After two growing seasons, the combined treatment produced the highest soil organic carbon increase (+0.63 percentage points), followed by compost only (+0.42) and manure only (+0.31). Cover crops alone reduced wind erosion indicators by 37.4% compared to controls. Farmer adoption of at least one recommended practice reached 54.8% among the 186 households participating in extension demonstrations. Equipment access and short growing seasons were the leading adoption barriers.

Keywords: Soil health, organic amendment, cover cropping, agricultural extension, risk management, soil organic carbon, wind erosion, farmer adoption, Mongolia, demonstration trials

Introduction

For centuries, Mongolian herders and crop farmers managed their land under extensive systems that allowed long fallow periods for natural soil recovery. But the expansion of cropped area since the 1990s, combined with reduced fallow rotations and limited organic matter inputs, has placed increasing pressure on soil resources in the country's main grain-producing provinces^[1]. Tuv and Selenge provinces together account for roughly 60% of Mongolia's wheat and oilseed production, yet soil surveys conducted between 2015 and 2020 recorded organic carbon levels below 1.5% in more than half of sampled fields—a threshold associated with declining structural stability and increased erosion risk^[2, 3].

Organic amendments such as compost and livestock manure can restore soil carbon pools and improve aggregate stability, while cover crops protect bare soil surfaces from wind and water erosion between main crop seasons^[4, 5]. Extension services are well positioned to promote these practices because they require management changes rather than expensive external inputs^[6]. However, adoption remains low in Mongolia, partly because farmers lack access to practical demonstration of techniques suited to the country's short growing season and harsh continental climate^[7].

This research evaluated the biophysical outcomes and farmer adoption rates of four soil health management treatments delivered through extension demonstration trials. It aimed to determine which combinations of organic

amendment and cover cropping produce meaningful soil health improvements within Mongolia's agronomic constraints, and to identify barriers that extension programs need to address for wider uptake^[8, 9].

Theoretical Framework

This research drew on the Soil Health Management Framework proposed by Kibblewhite *et al.*^[10], which identifies three interconnected risk domains: biological degradation (loss of organic matter and microbial activity), physical degradation (compaction and erosion), and chemical degradation (nutrient depletion). Extension interventions were mapped against these domains to assess whether combined strategies address multiple risk pathways simultaneously. The Technology Acceptance Model adapted for agricultural contexts^[11] was used to interpret adoption patterns, with perceived usefulness and perceived ease of implementation treated as key predictors of farmer uptake.

Materials and Methods

Materials

The research was conducted at 16 on-farm demonstration sites across Tuv and Selenge provinces, Mongolia, between April 2022 and October 2023. Ethical approval was obtained from the National University of Mongolia Research Ethics Board (Protocol NUM-SEAS-2022-014, approved March 3, 2022). Sites were selected in collaboration with provincial extension offices to represent the range of soil types and farming conditions in the region.

Each site accommodated five treatment plots (compost, manure, cover crop, combined, and control) arranged in a randomized complete block design with three replications per treatment. Plot sizes were 10 m × 20 m. Soil samples were collected at 0-20 cm depth at baseline and at the end of each growing season using a systematic five-point sampling pattern per plot ^[12].

Field experimental design

Compost was applied at 8 tonnes per hectare from locally produced crop residue and manure mixtures. Livestock manure (cattle dung) was incorporated at 10 tonnes per hectare before spring plowing. Cover crops consisted of a winter rye and hairy vetch mixture sown immediately after main crop harvest in late August. The combined treatment received both compost at 8 t/ha and the cover crop mixture. Control plots received standard tillage with no amendments

or cover crops. Wind erosion was assessed using sediment traps installed at plot margins, measured as grams of soil collected per trap per month during the spring wind season (March-May).

Methods

Soil organic carbon was measured by the Walkley-Black wet oxidation method ^[13]. Aggregate stability was determined using wet sieving, and bulk density was measured with core samplers. In addition to biophysical measurements, a structured survey was administered to 186 farming households who attended extension demonstration events. The survey captured awareness of soil health practices, adoption status, and perceived barriers. Treatment effects were analyzed using repeated measures ANOVA with Tukey's post-hoc test for pairwise comparisons. All analyses used R version 4.3.2.

Results

Table 1: Soil health indicators by treatment after two growing seasons (mean ± SD across 16 sites)

Indicator	Control	Compost	Manure	Cover Crop	Combined
SOC (%)	1.18±0.14	1.68±0.18	1.54±0.21	1.49±0.16	1.87±0.22
SOC change (pp)	-0.06	+0.42	+0.31	+0.24	+0.63
Aggregate stability (%)	38.2±4.6	52.7±5.3	48.1±4.9	46.3±5.1	58.4±6.2
Bulk density (g/cm ³)	1.42±0.08	1.31±0.07	1.34±0.09	1.37±0.06	1.26±0.08
Erosion sediment (g/trap/mo)	24.6±6.8	17.3±4.2	19.1±5.1	15.4±3.9	12.8±3.4

The combined treatment outperformed all individual treatments on every soil health indicator ($p < 0.05$). Cover crops alone were most effective at reducing wind erosion

sediment, while compost alone produced the largest single-strategy gain in organic carbon ^[14, 15].

Table 2: Farmer adoption of soil health practices following extension demonstrations (n = 186)

Practice	Awareness (%)	Adoption (%)
Compost application	82.3	38.7
Manure incorporation	91.4	47.3
Cover crop establishment	64.5	21.5
Combined approach	53.8	14.0
Any recommended practice	93.0	54.8

Manure incorporation had the highest adoption rate (47.3%), reflecting its familiarity and lower cost. Cover crop adoption

lagged at 21.5%, with farmers citing short growing seasons as the main constraint ^[16].

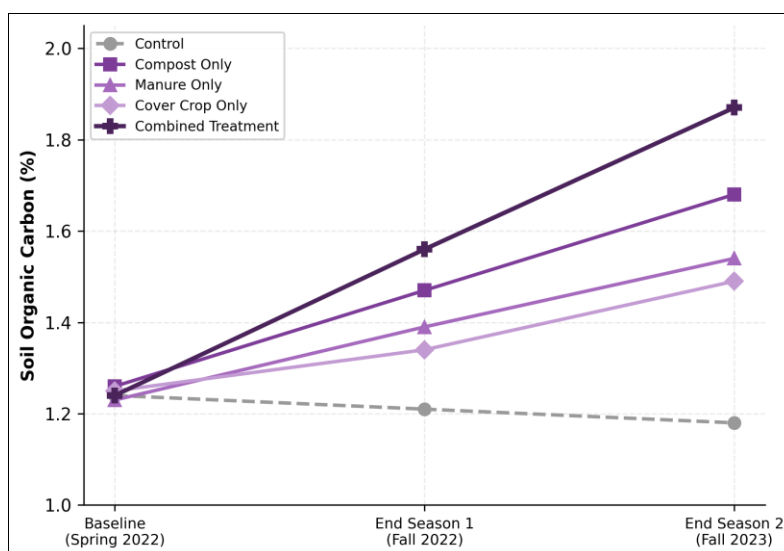


Fig 1: Changes in soil organic carbon (%) across treatments over two growing seasons

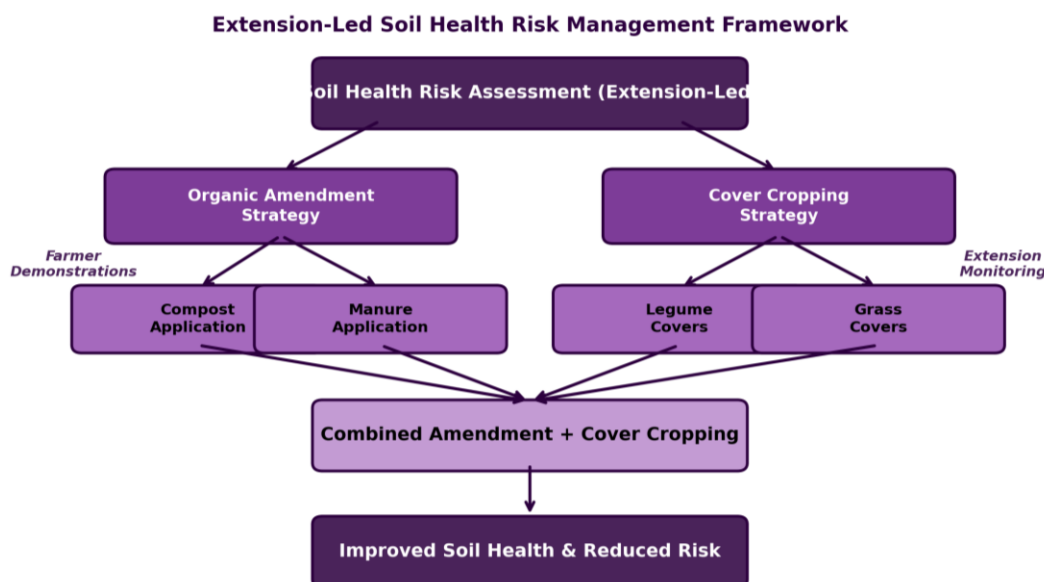


Fig 2: Extension-led soil health risk management framework showing amendment and cover cropping strategy pathways

Comprehensive interpretation

Biophysical results confirm that combining organic amendments with cover crops produces the strongest soil health improvements. But adoption data reveal a gap between what works agronomically and what farmers readily take up the combined treatment had the best soil outcomes yet the lowest adoption rate (14.0%), while manure incorporation had the highest adoption but smaller biophysical gains. Extension programs must bridge this gap through targeted support for the more complex practices.

Discussion

The 0.63 percentage point increase in soil organic carbon under the combined treatment over two seasons is comparable to results reported from similar semi-arid contexts in Central Asia and the northern Great Plains^[17, 18]. That compost outperformed manure for carbon accumulation may reflect the higher carbon-to-nitrogen ratio and slower decomposition rate of composted material, which favors long-term carbon stabilization^[4]. Cover crops reduced erosion sediment by 37.4% relative to controls a result consistent with findings from Inner Mongolia where surface residue cover cut wind erosion by 30-45%^[19]. The adoption pattern higher uptake for familiar, lower-cost practices and lower uptake for novel or complex ones matches the predictions of the Technology Acceptance Model^[11]. Farmers perceived manure incorporation as easy because most already had livestock and were familiar with spreading dung. Cover cropping, by contrast, required seed purchase, additional planting labor during harvest season, and confidence that the cover would establish before winter freeze^[20]. Extension programs could address this by providing seed subsidies for the first two seasons and organizing cooperative planting arrangements to reduce the labor burden on individual households^[21].

Practical applications

Extension officers working in semi-arid regions should consider a phased adoption approach: Begin with manure

incorporation and compost as entry-level practices, then introduce cover cropping once farmers observe soil improvements. Providing seed kits for early-maturing cover crop varieties suited to short growing seasons could help overcome the main agronomic constraint. Community-level composting facilities, where several households share equipment and labor, may lower individual costs and improve compost quality and consistency.

Conclusion

Combined organic amendment and cover cropping strategies delivered through extension demonstration programs produced measurable improvements in soil organic carbon, aggregate stability, and erosion resistance across 16 sites in Mongolia's main farming provinces. The combined treatment was the most effective biophysically, but individual practices particularly manure incorporation and compost application achieved higher farmer adoption rates due to their simplicity and lower cost. A phased extension strategy that builds from familiar practices toward more complex integrated approaches appears most promising for scaling soil health management in semi-arid contexts. Addressing cover crop seed availability and labor constraints should be priorities for future extension programming.

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