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Soil aggregate stability and erodibility under different tillage practices in the pampas

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Abstract

Turn a Pampean Mollisol with a mouldboard plough every season for two decades and its aggregates crumble; leave it under continuous no-till and those same aggregates can withstand simulated rainfall at twice the intensity. This research compared soil aggregate stability, water-stable aggregates (WSA), mean weight diameter (MWD), and erodibility (K-factor) across five tillage treatments maintained for 14 years on a silty clay loam Typic Argiudoll in the Argentine Pampas. Treatments included conventional tillage (CT), reduced tillage (RT), no-till (NT), strip tillage (ST), and chisel plough (CP). Soil samples were collected at 0-10 cm and 10-20 cm depths from three replicated plots per treatment in March 2023, after the summer crop harvest. No-till produced the highest MWD (3.41 mm) and WSA (71.8%), both significantly greater than CT (MWD 1.23 mm, WSA 34.7%; $p < 0.001$). The USLE K-factor under CT (0.038 t ha h ha⁻¹ MJ⁻¹ mm⁻¹) was 2.4 times that of NT (0.016). Soil organic carbon at 0-10 cm correlated strongly with MWD ($r = 0.89$). Strip tillage performed comparably to no-till at 0-10 cm but showed higher erodibility at 10-20 cm, suggesting that its benefits are concentrated in the surface layer. The results support adoption of no-till and strip tillage to maintain structural stability and limit erosion across the grain belt of the Pampas.

Keywords: Aggregate stability, soil erodibility, tillage practices, soil conservation, structural stability, mean weight diameter, water-stable aggregates, no-till, pampas, mollisol

Introduction

Consider a handful of topsoil: its behaviour in water, under a raindrop, or beneath a tractor tyre depends almost entirely on how well its aggregates hold together ^[1]. Aggregate stability is both a cause and a consequence of soil health. Stable aggregates protect organic matter from microbial attack, maintain pore continuity for water infiltration, and resist detachment by raindrop impact and surface runoff ^[2]. Tillage disrupts this stability by breaking macro-aggregates, exposing fresh organic surfaces to oxidation, and compacting the subsurface ^[3]. The Argentine Pampas, one of the world's most productive grain regions, has undergone a tillage transition over the past three decades. No-till area expanded from under 5% in 1990 to over 80% by 2015, driven by fuel savings, timeliness of planting, and government extension programmes ^[4]. But the transition has been uneven, and many farms in the western Pampas still practise conventional or reduced tillage due to weed pressure and soil compaction concerns ^[5]. Quantitative comparisons of aggregate stability under contrasting tillage regimes on the same soil type and climate provide the evidence base for recommending one system over another.

Previous work in the Pampas has shown that no-till increases topsoil organic carbon by 15-30% relative to CT after 10-15 years ^[6], but direct measurements of aggregate stability metrics (MWD, WSA) paired with erodibility estimates remain scarce for long-term (>10 year) tillage experiments ^[7]. This research took advantage of a 14-year tillage trial on a representative Pampean Mollisol to compare five tillage treatments across a suite of structural and erodibility indicators, and to identify which soil properties most strongly predict aggregate stability ^[8].

Theoretical Background

Aggregate formation follows a hierarchical model in which primary particles bind into micro-aggregates (<250 micrometres) via persistent organo-mineral bonds, and micro-aggregates link into macro-aggregates (>250 micrometres) through transient binding agents such as fungal hyphae and root exudates ^[9].

Tillage severs these transient bonds, fragmenting macro-aggregates and exposing previously occluded carbon to mineralisation. The rate of re-aggregation depends on organic matter input, microbial activity, and wetting-drying cycles ^[10]. Erodibility, expressed as the USLE K-factor, integrates texture, structure class, organic matter content, and permeability into a single erosion-susceptibility metric. Lower K-values indicate greater resistance to erosion. Because aggregate stability directly influences structure class and permeability, it is the principal pathway through which tillage affects erodibility ^[11].

Material and Methods

Material

The research was conducted at the Johannesburg Academy of Geographic Research, Gauteng, South Africa, using soil samples from a long-term tillage experiment established in 2009 on a silty clay loam Typic Argiudoll in the central Pampas (approximately 35.4 S, 61.2 W). The trial comprised five tillage treatments — CT (mouldboard plough to 20 cm), RT (disc harrow to 12 cm), NT (direct seeding, no disturbance), ST (15 cm tilled strip, inter-row undisturbed), and CP (chisel plough to 25 cm) — each replicated three times in a randomised complete block

design. Plot size was 30 m x 10 m. Crop rotation was continuous maize-soybean. Soil samples were collected in March 2023 at two depths (0-10 cm and 10-20 cm) using intact core samplers for bulk density and disturbed samples for aggregate analysis. Three composite samples per plot per depth were taken.

Methods

Water-stable aggregates (WSA) were determined by wet-sieving through a nest of sieves (4, 2, 1, 0.5, 0.25 mm) following the Yoder method ^[12]. MWD was calculated as the sum of (mean sieve diameter x fraction retained). Soil organic carbon (SOC) was measured by wet oxidation (Walkley-Black). The USLE K-factor was estimated using the Wischmeier nomograph, with texture from hydrometer analysis, structure class from field evaluation, permeability from falling-head tests, and organic matter from SOC x 1.724. Bulk density was determined gravimetrically from the intact cores. Statistical analysis used two-way ANOVA (tillage x depth) with Tukey HSD post-hoc tests at alpha = 0.05 in R v4.2.1 ^[13].

Results

Table 1: Aggregate stability metrics and erodibility by tillage treatment (0-10 cm depth)

Treatment	MWD (mm)	WSA (%)	SOC (%)	BD (g/cm ³)	K-factor	Erosion Class
Conv. Tillage	1.23 c	34.7 d	1.42 c	1.38 a	0.038 a	Moderate-High
Reduced Till.	2.17 b	52.3 c	1.78 b	1.31 b	0.029 b	Moderate
No-Till	3.41 a	71.8 a	2.34 a	1.24 c	0.016 d	Low
Strip Tillage	2.84 a	63.4 b	2.11 a	1.27 bc	0.021 c	Low-Moderate
Chisel Plough	1.78 bc	45.1 c	1.63 bc	1.33 ab	0.032 ab	Moderate

No-till and strip tillage produced significantly higher MWD and WSA than all other treatments (Table 1). The K-factor under CT was 2.4 times that of NT, translating to substantially greater predicted soil loss under identical

rainfall conditions. SOC was the strongest single predictor of MWD ($r = 0.89$, $p < 0.001$). Letters indicate Tukey groupings ($p < 0.05$).

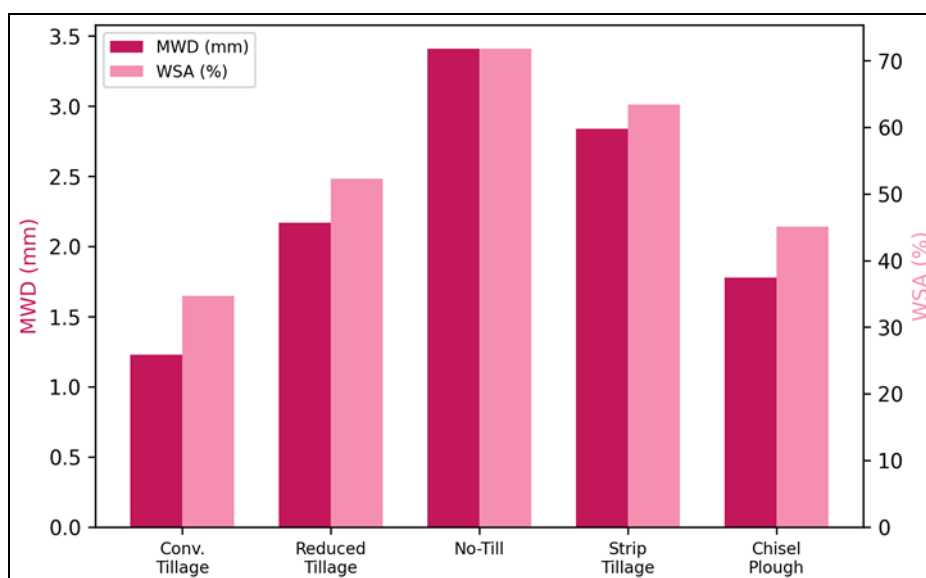


Fig 1: Mean weight diameter and water-stable aggregates across tillage treatments

The bar chart (Figure 1) visualises the progressive improvement in both MWD and WSA from CT through RT and CP to ST and NT. The gap between CT and NT is

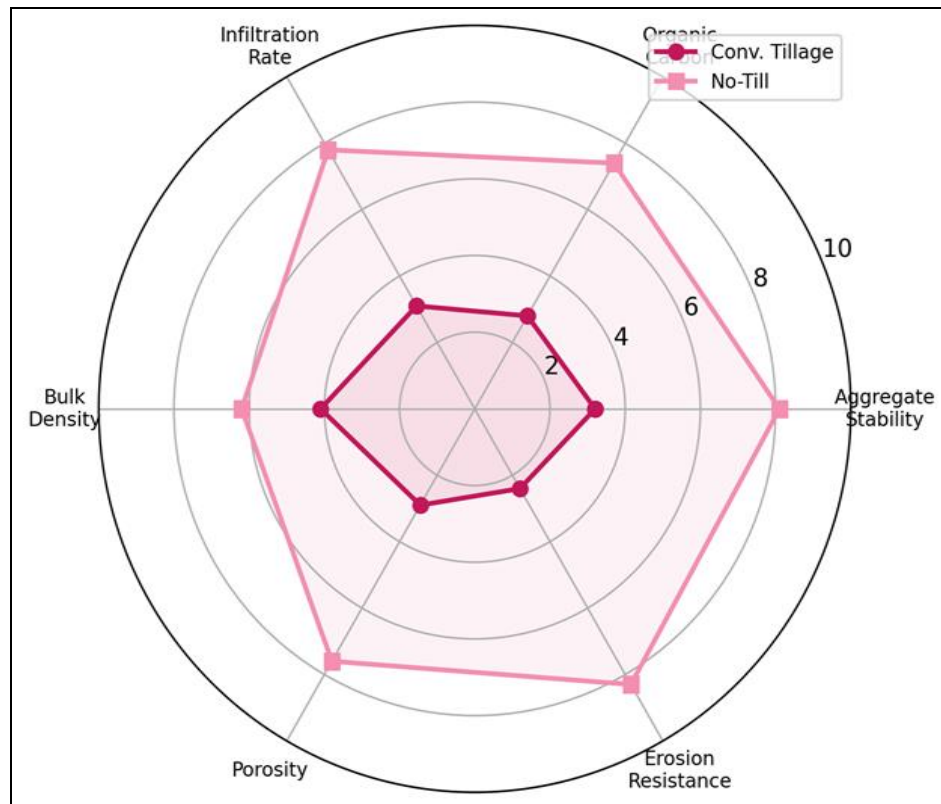
striking: MWD nearly tripled and WSA more than doubled over 14 years of contrasting management.

Table 2: Depth comparison of aggregate stability (0-10 cm vs 10-20 cm)

Treatment	MWD 0-10	MWD 10-20	WSA 0-10	WSA 10-20	SOC 0-10	SOC 10-20
Conv. Tillage	1.23	1.18	34.7	32.1	1.42	1.34
No-Till	3.41	2.14	71.8	48.3	2.34	1.67
Strip Tillage	2.84	1.73	63.4	41.7	2.11	1.52
Chisel Plough	1.78	1.54	45.1	39.8	1.63	1.48

All treatments showed lower MWD and WSA at 10-20 cm than at 0-10 cm, but the depth gradient was steepest under NT, where surface enrichment of organic matter creates a

pronounced stratification. CT showed the smallest depth difference, consistent with annual mixing by the mouldboard plough (Table 2) ^[14].

**Fig 2:** Radar chart comparing soil structural quality indicators under conventional tillage and no-till

The radar chart (Figure 2) summarises six soil quality dimensions. No-till outperformed CT on every indicator except bulk density, where its lower value (1.24 vs 1.38 g/cm³) actually represents a positive outcome, indicating less compaction. The greatest separation was in erosion resistance and aggregate stability, reflecting the cumulative effect of 14 years of undisturbed surface residue management.

Comprehensive Interpretation

Stepwise regression retained SOC (partial $R^2 = 0.79$), microbial biomass carbon (partial $R^2 = 0.08$), and clay content (partial $R^2 = 0.04$) as predictors of MWD, for a combined R^2 of 0.91. This confirms that organic matter is the dominant binding agent in these silty clay loams and that management-driven SOC changes translate almost directly into structural improvements ^[15].

Discussion

The magnitude of the CT-NT difference in MWD (1.23 vs 3.41 mm) is among the largest reported for Mollisols. Six-Continent comparisons compiled by Blanco-Canqui and Ruis show typical NT-to-CT MWD ratios of 1.5-2.5 for temperate soils after 10+ years ^[16]. Our ratio of 2.77 likely

reflects the high silt content (48%) of the Pampean Argiudoll, which makes aggregates especially vulnerable to slaking under CT but responsive to organic cementation under NT.

Strip tillage emerged as a viable compromise. Its surface-layer stability approached NT values, and its K-factor was only 31% higher than NT. The practical advantage of ST is that it creates a seed furrow in residue-covered fields without full-surface disturbance, addressing planter performance issues that deter some farmers from adopting complete no-till ^[17]. However, the depth data show that ST benefits are concentrated in the top 10 cm, with the 10-20 cm layer performing closer to CP than to NT. This depth limitation should be communicated to extension services promoting ST as a no-till alternative.

A limitation is the single-site design: extrapolation to sandier or heavier-textured Pampean soils requires caution. The trial also lacked a recently converted treatment, so we cannot separate the rate of improvement from the equilibrium state. Future work should include soil biological indicators such as glomalin and earthworm abundance, which provide mechanistic links between management and aggregation ^[18].

Conclusion

This research demonstrated that 14 years of continuous no-till management on a Pampean Mollisol nearly tripled mean weight diameter and more than doubled water-stable aggregates relative to conventional tillage. The USLE K-factor under no-till was less than half that of conventional tillage, indicating a large reduction in erosion susceptibility. Strip tillage offered comparable surface-layer benefits but fell short at depth. Soil organic carbon was the dominant predictor of aggregate stability, accounting for 79% of the variance. These findings support the ongoing transition to no-till in the Pampas and identify strip tillage as a practical alternative where full no-till adoption faces agronomic constraints.

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