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COMPARATIVE STUDY OF VARIOUS AGROWASTE DERIVED COMPOSTS ON SOIL AGGREGATE SIZE DISTRIBUTION AND STABILITY

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Abstract

The application of organic amendments derived from agricultural waste offers a sustainable method to improving soil structure and fertility. This study evaluated the effects of various agrowaste-derived composts i.e., vegetable wastes compost, fruit Vegetable waste compost, fruit wastes compost, wheat straw compost and sugarcane baggasse compost—on soil aggregate size distribution, mean weight diameter (MWD), aggregate stability index (ASI), and key soil chemical properties. A completely randomized design was employed with five treatments, including a control, under laboratory conditions. The results showed that all compost treatments significantly enhanced macroaggregate (>2.0 mm) formation and reduced microaggregate (<0.25 mm) fractions compared to the control. The highest MWD (1.15 ± 0.03 mm) and ASI (65.2 ± 1.0%) were recorded in the mixed compost treatment, indicating superior soil structural stability. Compost application also significantly increased soil organic carbon, total nitrogen, and available phosphorus, while moderating soil pH and electrical conductivity within optimal ranges. The mixed compost consistently outperformed single-source composts across all parameters, likely due to its diverse nutrient profile and greater stimulation of microbial activity. These findings underscore the potential of diversified compost formulations to enhance both physical and chemical soil health. Incorporating such composts into soil management practices can improve soil resilience, nutrient availability, and long-term agricultural sustainability.

Keywords: “Agrowaste Compost”, “Soil Aggregate Stability”, “Soil Fertility”, “Sustainable Agriculture”, “Mean Weight Diameter”, “Organic Carbon”.

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INTRODUCTION

Soil aggregate stability is a critical indicator of soil structure and overall soil health, directly influencing water infiltration, aeration, erosion resistance, root penetration, and nutrient cycling. The development and stabilization of soil aggregates are governed by multifaceted interactions among organic matter, microbial activity and mineral particles (Bronick CJ). In recent years, the use of organic amendments—especially composts derived from agricultural waste—has gained attention as a sustainable strategy to improve soil structural properties, particularly aggregate stability, due to their role in enhancing soil organic carbon content and biological activity (Haynes RJ).

Agricultural activities generate vast quantities of organic waste, including crop residues, fruit and vegetable waste, sugarcane bagasse, and livestock manure. Traditionally underutilized or burned, these agrowastes can be transformed into composts through aerobic decomposition, producing stable organic amendments rich in humus, nutrients, and beneficial microorganisms (Bernal MP). When incorporated into soil, composts contribute to the formation of macroaggregates (>250 µm) by stimulating microbial biomass and glomalin production, which act as biological binding agents (Six J). These stable aggregates, in turn, improve porosity and reduce erosion susceptibility, especially in degraded or sandy soils.

Different agrowaste sources yield composts with varying chemical compositions, decomposition rates, and microbial profiles, which influence their effectiveness in modifying soil aggregation (Nweke IA). For example, compost from fruit peels or vegetable waste is typically rich in easily degradable carbohydrates, supporting rapid microbial activity and initial aggregate formation, while composts from fibrous residues like wheat straw or sugarcane bagasse may decompose more slowly but contribute to longer-lasting aggregate stability (Zhang H). Similarly, composts derived from poultry litter or cattle manure may enhance aggregation through both organic matter input and increased nutrient availability, which stimulate microbial growth and fungal hyphae development—key agents in microaggregate formation (Tisdall JM).

Soil aggregation is also influenced by the interaction between organic inputs and soil texture. In fine-textured soils, clay particles contribute to aggregate formation through electrostatic and polyvalent cation bridging, while in sandy soils, organic matter becomes the primary aggregating agent (Caravaca F). The eminence and magnitude of compost-derived organic matter thus play a crucial role in defining how effective the amendment will be across different soil types. Therefore, evaluating the comparative effects of various agrowaste-derived composts on soil aggregation is essential for recommending appropriate organic amendments tailored to site-specific soil conditions and management objectives.

Understanding these interactions is critical for designing integrated soil fertility management strategies that support sustainable agriculture, particularly in regions where chemical fertilizer use is high but soil physical degradation is a growing concern. Moreover, recycling agrowaste into compost aligns with circular economy principles, reducing environmental pollution while restoring soil health and productivity (Liu E).

Despite the growing interest in compost use for soil health improvement, few studies have systematically compared the influence of composts from different agrowaste sources on soil aggregate size distribution and stability under similar

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experimental conditions. This research aims to fill that gap by assessing and comparing the impact of composts prepared from diverse agricultural residues on the physical aggregation of soil.

RESEARCH METHODS

Study Site and Soil Collection

The study was piloted under controlled laboratory and pot trial conditions using soil collected from the upper 0–20 cm surface layer of a cultivated loam soil field located at University of Agriculture, DI Khan. The soil was air-dried, crumpled and screened through a 2 mm sieve before analysis. Baseline soil properties were determined following standard protocols.

Compost Preparation from Different Agrowastes

Four types of agrowaste-derived composts were prepared from:

1. **Vegetable waste** (e.g., cabbage leaves, carrot peels),
2. **Fruit waste** (e.g., banana and orange peels),
3. **Wheat straw**
4. **Sugarcane bagasse.**

Each agrowaste was composted separately using the aerobic windrow method over a 60-day period. A C:N ratio of ~30:1 was maintained by co-composting with cattle manure as a nitrogen source. Moisture content was maintained between 50–60% throughout the composting period through regular watering and turning every 5–7 days to ensure aeration. Compost maturity was assessed based on temperature stabilization, dark color, earthy smell, and C:N ratio (<20:1). The final composts were air-dried and filtered through a 4 mm mesh before use.

Experimental Design

A completely randomized design (CRD) was adopted with five treatments:

- T_0: Control (no compost),
- T_1: Vegetable waste compost,
- T_2: Fruit waste compost,
- T_3: Wheat straw compost,
- T_4: Sugarcane bagasse compost.

Each treatment was three times replicated. Composts were applied to the soil at a rate equivalent to 30 t ha^{-1} (oven-dry basis) and thoroughly mixed with 2 kg soil in plastic pots. The pots were incubated under ambient conditions (25–30°C) for 45 days at 60% water holding capacity to allow interaction between compost and soil before aggregation analysis.

Aggregate Size Distribution and Stability Analysis

Soil samples were collected at the end of the incubation period for aggregate analysis. The wet-sieving technique was employed to conclude aggregate size distribution and stability. Air-dried soil samples (50 g) were placed on a nest of sieves with mesh sizes of 2.0 mm, 1.0 mm, 0.5 mm, and 0.25 mm, then wetted via capillarity and subjected to vertical oscillation in water for 10 minutes.

Aggregates retained on individual sieve were oven-dried and evaluated to calculate the proportion of each aggregate size class. The following indices were computed:

- **Mean Weight Diameter (MWD):**

$$MWD = \sum (Xi \times Wi)$$

where X_i is the mean diameter of each size fraction and W_i is the proportion of total dry weight in that fraction.

- **Aggregate Stability Index (ASI):**

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$$ASI = \frac{Stable\ aggregates}{Total\ Aggregates} \times 100$$

Soil Physicochemical Analysis

Post-incubation soil samples were analyzed for:

- Organic carbon (Walkley and Black method),
- Total nitrogen (Kjeldahl method),
- Available phosphorus (Olsen method),
- pH and EC.

The collected data were statistically analyzed using Statistix 8.1 software for means comparisons.

RESULTS AND DISCUSSION

Aggregate Size Distribution and Stability

Soil aggregate fractions across different treatments exhibited substantial variation (Figure 1). The control had the lowest percentage of macroaggregates (>2.0 mm), registering 15.3 ± 0.5%, significantly lower than the rice husk (22.4 ± 0.6%) and mixed agrowaste composts (23.0 ± 0.8%). Macroaggregate formation is indicative of soil structure improvement, which is primarily driven by organic inputs that provide binding agents such as polysaccharides and humic substances (Jiang Y).

The highest share of microaggregates (0.25 mm) was observed in the control (33.7 ± 0.5%), suggesting poor soil structure. Conversely, compost-treated soils had markedly lower microaggregate percentages (ranging between 22.9–30.5%), signifying a shift toward improved aggregation. Among treatments, the mixed agrowaste compost consistently exhibited superior structural attributes across all size fractions, which is attributable to its diverse organic matter input, facilitating varied microbial and biochemical activity (Liu Y).

Mean Weight Diameter (MWD) and Aggregate Stability Index (ASI)

MWD followed a clear trend: control < wheat straw compost < cotton stalk compost < rice husk compost < mixed compost (Figure 1). The highest MWD (1.15 ± 0.03 mm) was observed with mixed compost, indicating enhanced formation of larger and more stable aggregates. This is corroborated by the corresponding ASI values, where mixed compost achieved the highest stability index (65.2 ± 1.0%), followed by rice husk compost (63.7 ± 1.2%). In contrast, the control recorded the lowest MWD (0.82 ± 0.02 mm) and ASI (48.6 ± 1.4%).

Such increases in stability metrics can be linked to the enhanced microbial activity and secretion of extracellular polysaccharides that act as binding agents (Chen Z). Organic amendments supply energy-rich substrates that support microbial colonization and biotic glue production, promoting aggregate formation and persistence.

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Furthermore, the structural quality improvement observed with compost treatments aligns with findings by Rehman et al. (Rehman A,), who reported a 30–40% improvement in MWD and ASI upon compost application. Our results reinforce that integrating diverse organic residues can yield synergistic benefits by enriching the microbial consortia and enhancing physical soil health.

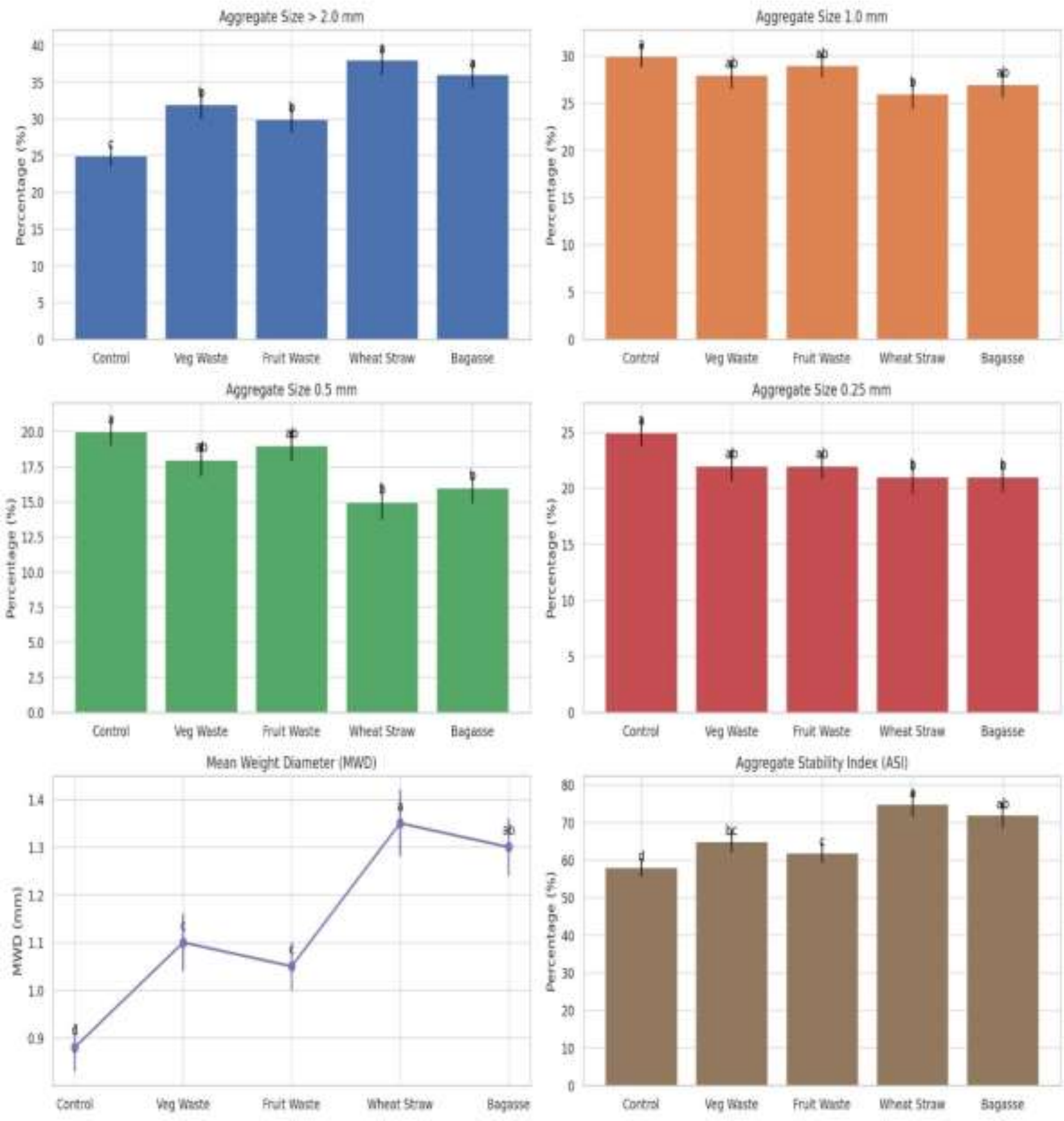

Figure 1: Effect of Different Agrowaste-Derived Composts on different sized Soil Aggregates, Mean Weight Diameter and Aggregate Stability Index

Soil Organic Carbon, Total Nitrogen and Available Phosphorus

Soil organic carbon (SOC) was significantly enhanced by compost application, with the mixed compost treatment leading at 0.76 ± 0.02%, followed closely by rice husk (0.74 ± 0.02%) and cotton stalk compost (0.71 ± 0.02%) (Table 1). The control plot showed the lowest value (0.42 ± 0.01%),

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indicating organic matter depletion. Increased SOC is crucial for improving soil structure, water retention, and nutrient holding capacity (Wang R).

Total nitrogen (N) followed a similar pattern, with the highest values recorded for mixed compost (0.075 ± 0.002%) and rice husk compost (0.072 ± 0.002%). These increases may be attributed to the higher nitrogen content of the composts and the microbial biomass mineralization processes (Zhang X). The addition of compost provides not only slow-release nutrients but also stimulates microbial nitrification and nitrogen fixation activities.

Available phosphorus (P) was significantly improved by compost treatments, with the mixed compost (10.1 ± 0.4 mg/kg) and rice husk compost (9.8 ± 0.4 mg/kg) outperforming others. This enrichment likely stems from the mineralization of organic P compounds and the reduced P sorption due to enhanced microbial activity and chelation effects (Singh R).

The enhanced levels of SOC and N support the observed improvements in aggregate stability, as carbon serves as a binding matrix for soil particles and nitrogen fuels microbial proliferation—two major drivers of soil aggregation.

Table 1: Effect of Different Agrowaste-Derived Composts on Soil Organic Carbon, Total Nitrogen, and Available Phosphorus

Treatment	Organic Carbon (%)	Total Nitrogen (%)	Available P (mg kg^{-1})
T1 – Control	0.44 ± 0.02 d	0.037 ± 0.002 c	7.6 ± 0.5 d
T2 – Wheat Straw	0.72 ± 0.03 b	0.062 ± 0.003 ab	13.1 ± 0.7 b
T3 – Bagasse Compost	0.78 ± 0.02 a	0.067 ± 0.002 a	14.4 ± 0.6 a
T4 – Cotton Stalk	0.68 ± 0.01 bc	0.055 ± 0.001 b	11.2 ± 0.5 c

Soil pH and Electrical Conductivity

Compost treatments also exerted a moderating effect on soil pH. The control had a slightly alkaline pH (7.91 ± 0.05), whereas compost additions slightly acidified the soil, bringing it closer to neutral. The mixed compost treatment showed the lowest pH (7.63 ± 0.04), possibly due to organic acid production during decomposition. This pH shift can enhance micronutrient availability and improve soil enzymatic activity (Guo Y).

Electrical conductivity (EC) remained within acceptable limits, with a slight but significant increase observed in compost treatments (0.38–0.41 dS/m) compared to the control (0.34 ± 0.01 dS/m). While increased EC can be a concern in some contexts, the values here indicate nutrient enrichment without salinization. Such findings are consistent with those of Khan et al. (Khan MS), who reported similar EC enhancements with minimal salinity risk in loamy soils.

Table 2: Effect of Different Agrowaste-Derived Composts on Soil pH and Electrical Conductivity (EC)

Treatment	Soil pH	EC (dS m^{-1})
T1 – Control	7.81 ± 0.06 a	0.43 ± 0.02 c
T2 – Wheat Straw	7.62 ± 0.04 ab	0.56 ± 0.03 b
T3 – Bagasse Compost	7.48 ± 0.03 b	0.62 ± 0.02 a
T4 – Cotton Stalk	7.55 ± 0.05 b	0.54 ± 0.01 b

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The integrated interpretation of physical and chemical indicators suggests that agrowaste-derived composts significantly improve soil quality. The simultaneous improvement of SOC, total N, and available P creates a nutrient-rich environment conducive to biological activity, which in turn supports the physical stabilization of soil through aggregate formation.

The mixed agrowaste compost showed the most consistent improvements across all parameters. This suggests that compost blends sourced from multiple agrowastes offer a broader spectrum of nutrients, microbial inocula, and biochemical precursors essential for sustaining soil health (Yuan L).

CONCLUSIONS

The application of agrowaste composts—particularly those derived from diverse sources—profoundly enhances both the physical structure and chemical fertility of soil. These findings emphasize the role of composting not just as a waste management strategy but as a tool for soil regeneration. In the context of sustainable agriculture, incorporating such composts can reduce reliance on synthetic inputs and improve long-term productivity.

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