Residual Dry Matter, Weeds and Soil Aggregates After Winter Cover Crop

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ABSTRACT

Soil quality maintenance in a no-tillage system (NTS) depends on cover crops. They are essential for crop rotation, affect several soil attributes, and contribute to phytosanitary control. However, cover crop efficacy is influenced by their root function and the presence of plant straw on soil surfaces. The objective of this study was to compare various winter cover crops in terms of their effects on dry mass yield, straw persistence after 40 d, weed incidence, and soil aggregate stability. The soil tested was an Oxisol Ustox Hapludox in Western Paraná State, southern Brazil. A randomized block design was used with four replicates and six treatments (fallow, black oat, fodder turnip, field pea, common vetch, and fodder turnip + black oat). Cover crops were managed 88 d after sowing. Dry mass (DM) and residual dry mass (RDM) were measured at 20 d and 40 d after harvest. Aggregate stability and weed type and density were evaluated after 40 d of management (DAM). The results showed that black oat obtained the lowest decomposition; therefore, a potential species to be used in the system of crop rotation in the no-tillage.The consorted of fodder turnip and black oat provided relatively higher dry mass yields and improved soil aggregation. Cover crops reduced the incidence of weeds, being important for no-till sustainability

Keywords: Green manure, no-tillage, soil management, soil quality, aggregation, weeds

1. INTRODUCTION

Cover crops are essential for the maintenance of no-tillage systems (NTS) because they improve both soil coverage and biodiversity. They also facilitate crop rotation, diversify production, and participate in integrated pest management. Cover crops are an integral part of conservation agriculture [1]. They affect physicochemical and biological soil properties, improve cultivation, lower production costs, and reduce chemical fertilizers, phytosanitary products, and mechanical soil preparation [2]. In this way, they promote the production of healthier food and mitigate the human and ecological impact of agriculture [3]

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Cover crops add organic matter to the soil and change the local soil ecosystem. They increase soil macroporosity, thereby improving soil water infiltration and retention. Consequently, oxygen flow increase, and mechanical resistance to root penetration decreases [4,1].

The organic matter derived from plant material decomposition links with soil clay minerals and forms hydrostable aggregates. Even when cover crops do not alter local organic matter (OM) content, their presence and the straw they leave on the soil surface reduce the impact of rainwater and prevent the formation of compacted surface layers (crust). Soil surface compaction is a major cause of soil particle disaggregation, which, in turn, leads to soil erosion.

The benefits of cover crops are correlated with straw quantity and quality and its permanence on the soil surface. Therefore, it is essential to choose cover crop species that are suited to the soil and climate conditions of each region [5]. Plants indicated for cultivation in the State of Paraná in the wintertime are black oat, oat, fodder turnip, lupine, common vetch, and field pea [6].

Of these, fodder turnips and oats produce copious dry matter and have aggressive root systems. Legumes like lupines, common vetch, and field peas fix atmospheric nitrogen and increase OM [7]. Plants like black oat and fodder turnip with aggressive root systems rupture compacted soil layer when used in rotation. They also improve soil aggregation [8,9,10]. However, prompt sowing after cover crop management is not always practical or even possible. Climatic factors (drought, excessive rainfall, low temperatures) and ecological and legal reasons (agricultural zoning; fallowing) may delay planting. Consequently, the straw produced during the winter season may degrade, thereby reducing nutrient (especially nitrogen) availability and cycling and permitting the proliferation of weeds and/or diseased plants in the area.

Cover crop decomposition rates vary with plant species. They depend on the C/N ratio, soil fertility, edaphoclimatic conditions, soil microbial activity, plant age at the time of management, and management type. Moreover, the amount of dry mass remaining over time is regulated mainly by the carbon/nitrogen (C/N) ratio and the management of the plant material. Cover crops either decompose rapidly and have C/N <25 (*Fabaceae, Brassicaceae*) or they decompose slowly and have C/N >25 (*Poaceae*) [11,12].

Straw type and permanence directly influence weed control. According to [5], important differences among cover crops include their relative influences on the health of subsequent cultures and weed control. Straw limits the passage of light and makes it difficult for positively photoblastic seeds to germinate. Soil coverage creates a physical barrier, which can also impede germinating plant development. These plants may become etiolated and susceptible to biological agents and mechanical injury [13]. In addition, cover crops can control weeds allelopathically by plant biomass decomposition and root exudations [14,15].

The objective of this paper was to evaluate the performance of cover crops in terms of dry mass and residual dry matter production, weed control, and aggregates stabilization. Our hypothesis was that cover crops help improve the physicochemical and biological soil environment, recover and/or maintain soil quality, and control weeds.

2. MATERIAL AND METHODS

The experiment was conducted between March and October 2015 at the experimental area of Unioeste, Marechal Cândido Rondon (PR) Campus, southern Brazil. The region has an Oxisol Ustox Hapludox (*Latossolo Vermelho Distroferrico (LVdf)* soil with clayey texture and good drainage (EMBRAPA, 2006). The average altitude is 420 m and its

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geographical coordinates are 24°33′26″S and 54°02′39″W. The climate is classified as subtropical with abundant rain evenly distributed throughout the year, hot summers, and rare wintertime frosts (K*öppen climate classification:* Cfa). The annual average temperature is 22 °C. Average temperatures in the coldest quarter range between 17 °C and 18 °C and between 28 °C and 29 °C in the hottest. The total annual average rainfall ranges between 1600 mm and 1800 mm. The wettest quarter (December-February) presents with an average rainfall between 400 mm and 500 mm [16]. The average temperature and precipitation data for the agricultural year 2015 are shown in Figure 1.

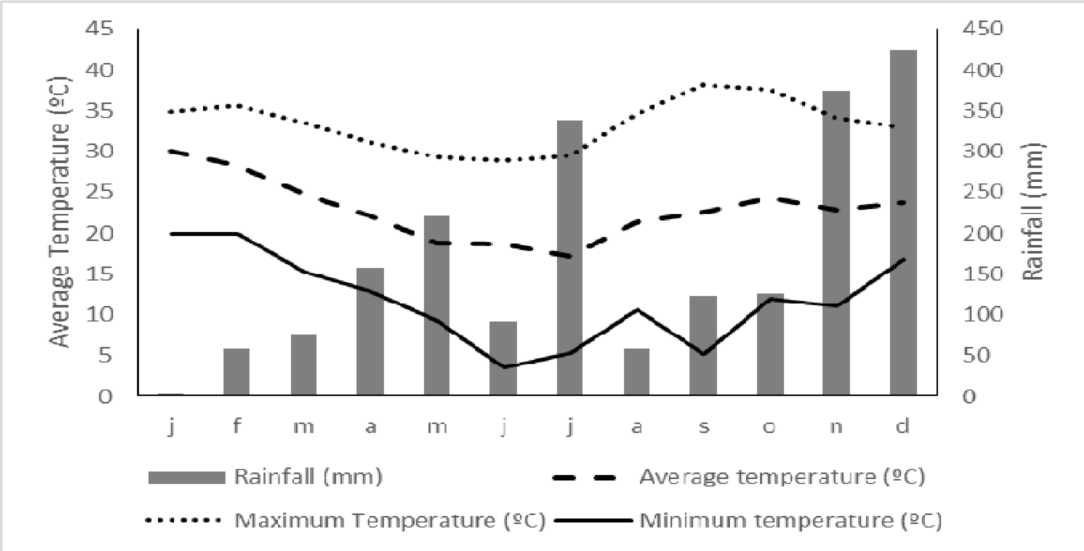

Fig. 1. Monthly average temperature (°C) and precipitation (mm) in Marechal Cândido Rondon – PR, 2015.

Chemical analysis of the soil in the experimental area was conducted in May 2015 on samples from the 0-20 cm layer. The samples were characterized according to [17]. The results are presented in Table 1.

Table 1. Results of the chemical analysis of the soil at the 0-20 cm depth in Marechal Cândido Rondon-PR, 2015

Prof	P	OM	pH $CaCl_2$	H+Al	Al^{3+}	K^+	Ca^{2+}	Mg^{2+}	SB	CTC	V	Al
m	mg dm^3	g dm^3	0.01 mol L^{-1}	--------------------- $cmol_c$ dm^{-3} --------------------							----- % -----	
0-0.20	7.52	16.4	4.4	5.88	0.45	0.22	2.15	0.74	3.11	8.99	34.6	12.8

The experimental design was a randomized block (RBD) with four replicates and six treatments. The treatments consisted of a fallow plot and five others cultivated with the following covering plants: black oat (*Avena strigosa* Schreb.), fodder turnip (*Raphanus sativus* L.), common vetch (*Vicia sativa* L.), field pea (*Pisum sativum arvense*), and black oat + fodder turnip. Each plot had a functional area of 31.5 m² (4.5 m W ×7 m L). Weed control was carried out before cover crop seeding with 2 L ha^{-1} glyphosate (Roundup®) applied on June 5, 2015. Thereafter, certain plants were manually overseeded.

The cover crops were seeded on November 6, 2015 using a mechanical plot seeder adjusted to a sowing distance of 17 cm between lines. Seed densities were as follows: black oat, 60 kg ha^{-1}; fodder turnip, 12 kg ha^{-1}; common vetch, 60 kg ha^{-1}; field pea, 60 kg ha^{-1}; black oat + fodder turnip, 30 kg ha^{-1} and 6 kg ha^{-1}, respectively. A 10-15-15 NPK basal fertilizer was applied at 200 kg ha^{-1}.

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Dry mass yield (DM) was determined 88 d after seeding (DAS). Random plant material samples were collected from each plot within a 0.25-m² area. They were bagged, taken to the laboratory, and oven-dried at 65 ºC to a constant dry weight. This procedure was repeated 20 d and 40 d after cover crop mowing to determine the residual dry mass (RDM). The plants were then cut down with a weed wacker.

To determine aggregate stability, non-deformed monoliths were extracted at 0-10 cm and 10-20 cm depth 38 d after green manure management according to [18]. Subdivided plots were used in this evaluation. The main plot consisted of the winter cover crops and the subplots were the sampling depths (0-10 cm and 10-20 cm).

Weed mapping was carried out 40 d after cover crop management. The various weed species within a plot area of 0.25 m^2 were identified and counted. Data were subjected to ANOVA and compared by Tukey's test at a 5% probability with SISVAR [19].

3. RESULTS AND DISCUSSION

3.1. Cover Crop Dry Mass Productivity and Dry Mass Remaining After Management

The ANOVA indicated significant differences ($P < 0.05$) among winter cover crops in terms of dry mass (DM) and remaining dry mass (RDM) during the three evaluation periods. The initial dry mass production was highest for turnip fodder (5,017 kg ha^{-1}) and second highest for black oat + turnip fodder (4,754 kg ha^{-1}) (Figure 2). On average, these two treatments produced 123% more dry mass than the fallow, which consisted mainly of wild plants and weeds.

The dry mass yields of the field pea and the common vetch were 2,993 kg ha^{-1} and 2,382 kg ha^{-1}, respectively. They did not statistically differ significantly from the fallow field, for which the DM consisted largely of weeds and wild plants. They dry matter yields of 2,754 kg ha^{-1} for field pea and 2,527 kg ha^{-1} for common vetch. In the present study, the black oat yield was 3,178 kg ha^{-1}.

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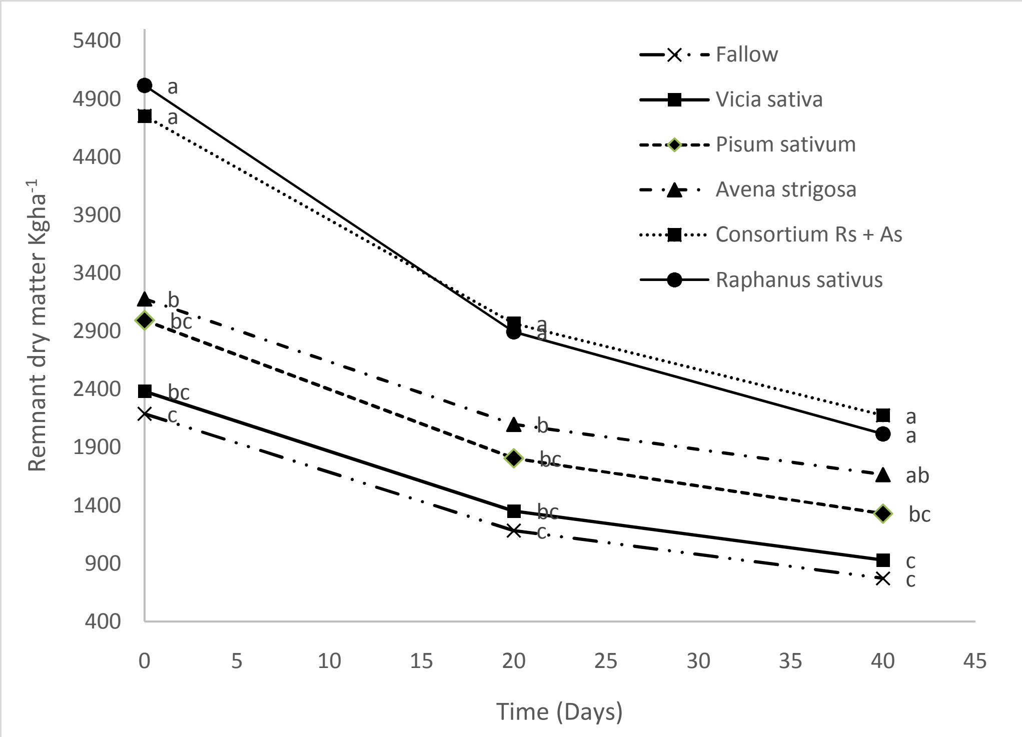

Fig. 2. Residual cover crop dry mass after forty days.

[20] achieved in their work find superior DM production with treatments combining Poaceae with Fabaceae or Brassicaceae. Moreover, these combinations had relatively higher N accumulations, longer straw half-lives, and greater RDM. The highest DM production was found for black oat + fodder turnip set and for fodder turnip alone. These can be explained by the rapid initial growth of the brassicas, which surpassed that of all other crops. On soils with high N availability, fodder turnip grew faster than black oat and competed relatively more effectively for nutrients, water, and light [21].

Straw decomposition was comparatively fast initially then slowed down thereafter. During the first 20-d period, DM decreased by 40% on average. Between days 20 and 40, the average DM reduction was 27%. The highest quantity of residual dry mass after the first 20 d was determined for black oat + fodder turnip and for fodder turnip alone (Fig. 1). The straw residue levels at days 20 and 40 were similar for both fodder turnip and black oat + fodder turnip probably because of the volume of DM produced. Intermediate decomposition rates would be expected for the black oat + fodder turnip treatment, according to [21]. Residue decomposition rates must be changed using a combination of plants that would also provide relatively more efficient coverage and better harmonization between the nutritional demand of subsequent crops and the nutrient supply afforded by cover crop straw decomposition.

The treatments providing the highest dry mass productivity at cutting (black oat + fodder turnip, and fodder turnip alone) were those presenting with higher RDM at 40 DAM. These differed significantly from those for field pea, common vetch, and fallow land. In general, all treatments had similar decomposition dynamics. However, black oat + fodder turnip and fodder turnip alone generated comparatively larger DM yields at 40 DAM.

ANOVA indicated a significant ($P < 0.05$) interaction between winter cover crop species and percentage dry matter decomposition over time. In the first 20-d period, the dry mass decomposition rates were 34.1% for black oat, 37.8% for black oat + fodder turnip, 39.8% for field pea, 42.6% for fodder turnip, 42.6% for common vetch, and 45.8% for fallow land. There were relatively greater losses of straw in the fodder turnip and black oat + fodder turnip treatments because fodder turnip has a low C/N ratio and a large)

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and the volume of material available for decomposition. The similarity of the decomposition rates for the other treatments is explained by the low straw production in the field pea, common vetch, and fallow treatments, and the high C/N ratio of the black oat treatment. Treatments with fodder turnip produced abundant biomass, which enabled high RDM at days 20 and 40 even with rapid decomposition. On the other hand, the RDM of black oat was similar that of fodder turnip ($P > 0,05$) because the former had a high C/N ratio.

Even at lower decomposition rates, black oat significantly differed from other crops according to [22]. They reported that at 20 DAM, only 12% of the black oat dry mass had decomposed. Its comparatively high C/N ratio at the time of harvest might account for the accelerated decomposition of its straw. It is related to the phenological stage of black oat at that time. The crop was cut at the onset of flowering and had not yet reached maximum nutrient accumulation and DM. Black oat has the highest C/N ratio at the milky grain stage. Nevertheless, straw decomposition rate may vary directly with C/N ratio.

Although it was not managed at the ideal time in this study (full bloom), black oat had the lowest percentage of decomposition based on its dry mass measured at 40 DAM. Fallow land had the highest decomposition rate even though it had the lowest DM volume at the start of the evaluation.

3.2. Weeds

Table 2 presents the weed species identified in each treatment 40 d after management (DAM). Four families of weeds were observed: Commelinaceae, Asteraceae, Brassicaceae, and Poaceae. ANOVA found a significant effect ($P < 0.05$) weed density. The largest number of weed families were observed in the fallow treatment.

The most highly represented weed families (in terms of the relative numbers of species found) were the Poaceae and the Asteraceae. Two species were identified for each of these. According to [12] these plant families include the most important weed species in Brazil. They infest several regions around the country and affect various crops like beans, corn, and soybeans.

The incidences of *Commelina benghalensis* and *Raphanus sativus* L. in all treatments is associated with the fact that they were already present at high density before cover crops cultivation and manual weeding. Therefore, there was a large weed seed bank in the cultivation area. According to [23], the lack of soil rotation in NTS areas changes weed population dynamics and community composition over time compared to conventional cultivation systems.

Straw cover influences light quantity and quality and decreases temperature oscillations and evapotranspirational water loss. Light, temperature, and humidity are the most important environmental factors overcoming seed dormancy. Straw covering, and soil permanence inhibit the embryonic growth in positively photoblastic seeds and those induced by temperature fluctuations, because lack of light impedes emergence and exposes seedlings to microbial pathogenesis and insect animal predation [24].

Table 2. Families and scientific names of the weeds found in each treatment 40 d after winter cover crop management

Treatment	Weeds	
	Family	Scientific name
Black oat *Avena strigosa*	Commelinaceae	*Commelina benghalensis* L.
	Asteraceae	*Bidens pilosa*
	Brassicaceae	*Raphanus sativus* L.

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	Poaceae	*Panicum maximum.* Jacq.
Field pea *Pisum sativum*	Commelinaceae	*Commelina benghalensis* L.
	Asteraceae	*Bidens pilosa*
	Brassicaceae	*Raphanus sativus* L.
	Poaceae	*Panicum maximum.* Jacq.
Consortium (Black oat + Fodder turnip)	Commelinaceae	*Commelina benghalensis* L.
	Asteraceae	*Bidens pilosa*
	Brassicaceae	*Raphanus sativus* L.
	Poaceae	*Panicum maximum.* Jacq.
Fallow	Commelinaceae	*Commelina benghalensis* L.
	Asteraceae	*Bidens pilosa*
	Asteraceae	*Conyza Bonariensis*
	Brassicaceae	*Raphanus sativus* L.
	Poaceae	*Panicum maximum.* Jacq.
	Poaceae	*Eleusine indica*
Fodder turnip *Raphanus sativus*	Commelinaceae	*Commelina benghalensis* L.
	Poaceae	*Panicum maximum.* Jacq.
	Brassicaceae	
Common vetch *Vicia sativa*	Commelinaceae	*Commelina benghalensis* L.
	Asteraceae	*Bidens pilosa*
	Asteraceae	*Conyza bonariensis*
	Brassicaceae	*Raphanus sativus* L.
	Poaceae	*Panicum maximum.* Jacq.
	Poaceae	*Eleusine indica*

In the present study, all treatments suppressed the growth of *Conyza bonariensis* except for common vetch (*Vicia sativa*) and in fallow land. According to [25], *Conyza bonariensis* is positively photoblastic. Therefore, treatments with relatively higher DM production were more effective at controlling this plant than low-DM conditions like common vetch cultivation and fallow land.

Fodder turnip alone suppressed *Bidens pilosa* (Fam. Asteraceae) whereas the black oat-fodder turnip consortium did not. *Bidens pilosa* is a neutral photoblast [26]. Its germination rate varies with seed depth in the soil. Neither black oat alone nor the black oat-fodder turnip consortium could suppress *Bidens pilosa.* Fodder turnip may have been able to suppress this weed by producing large amounts of dry mass and by allelopathic action against it. According [26] brassicas contain glucosinolates, which are hydrolyzed to composts that are toxic to various microorganisms and plants. The fact tha fodder turnip-black oat did not suppress *Bidens Pilosa* may be explained by the black oat, which stimulates germination of the weed by positive allelopathic action or by suppression of the negative allelopathic effect of the fodder turnip.

Commelina benghalensis L. is not sensitive to the presence of light but it requires a temperature of ~25 ºC for germination [24]. The finding corroborates the results obtained in the present study. However, shaded plants may suffer morphophysiological changes that could make them more susceptible to the effects of chemical agents causing changes in leaf anatomy and foliage thickness and reduced cuticular wax deposition. In this way, herbicides can more readily penetrate and affect them [27]. These authors reported that shaded *Commelina benghalensis* were relatively easier to control with glyphosate and there was a positive correlation between shading and glyphosate dose. Only 5% of the solar energy incident on foliage is converted to carbohydrates [28].

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As solar incidence decreases because of shading, then, photosynthetic and respiration rates also decline. DM accumulation is reduced and recovery from stress, such as induced by herbicides, is hindered [27]. observed increased DM production and glyphosate control in *Commelina benghalensis* L. correlated with shading. The seed bank and the presence of glyphosate-tolerant plants increase in NTS as demonstrated by [15] for *Commelina benghalensis* L. and other weeds. *Commelina benghalensis* L. seeds can survive for up to 40 years and their survival rate is comparatively higher in NTS. Therefore, integrated weed management is essential and should include straw volume maintenance and timely herbicide application.

Weed Density

Weed density significantly differed ($P < 0.05$) among treatments after 40 d of the cover crop management. Black oat + fodder turnip, black oat, fodder turnip, and field pea had the lowest weed densities (33 plants m^{-2}, 37 plants m^{-2}, 41 plants m^{-2}, and 51 plants m^{-2}, respectively). These values were statistically significantly different ($P < 0.05$) from that for the fallow area (78 plants m^{-2}). The cover crops had relatively higher dry mass productivity, which promoted better soil surface coverage and created a physical barrier against weed seed germination and weed development. Germination is regulated by several factors including temperature [24] and light. Straw volume and permanence regulate temperature and humidity, thereby influencing germination [26]. Temperature extremes tend to retard germination and subject plants to longer periods of adverse events that can reduce total final germination [23].

There were no significant differences between common vetch and the other treatments in terms of weed density (Figure 3). Common vetch does not suppress weeds allelopathically. However, it produces substantial dry matter, which impedes weed germination. However, common vetch straw decomposes quickly and has low persistence. Therefore, it is insufficient to control harmful plants over a long time. In contrast, [26] reported that rapidly decomposing vegetative residues are potently allelopathic albeit this effect is of short duration.

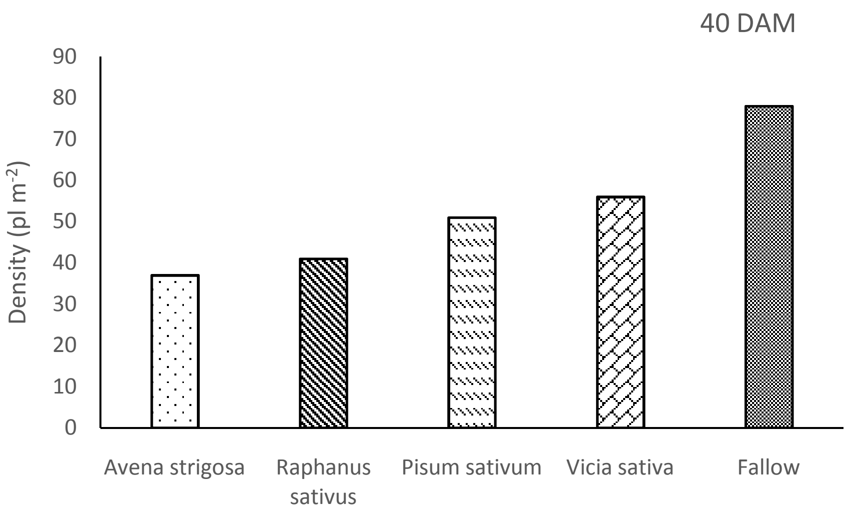

Fig. 3. Weed density measurements (plants m^{-2}) for each treatment 40 days after cover crop management (DAM).

Another reason for the relatively lower weed incidence in the cover crop treatments is that phytomass decomposition and root exudates may have been strongly allelopathic against the weeds. Black oat is allelopathic because its roots exude scopoletin. It was

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empirically demonstrated that this substance inhibited radicle growth in *Euphorbia heterophylla*, *Lolium multiflorum*, wheat (*Triticum aestivum*), *Parthenium hysterophorus, Alternathera tenella*, and *Amarantus* spp [27] confirmed that black oat biomass accumulation on soil surfaces significant decreases weed incidence. Fodder turnip is allelopathic against *Bidens pilosa*.

The highest weed density was observed in the fallow treatment (78 plants m^{-2}). This observation can be explained by relatively low soil coverage and low C/N ratios (accelerated decomposition) of the weeds that developed during the period preceding cover crop management and by irregular soil surface coverage. All of these may have created conditions conducive to weed development following phytomass management.

Aggregate Stability

Both winter cover crop type and soil depth had significant effects (P < 0.05) on soil aggregate stability. The soil aggregates under the fodder turnip and fodder turnip + black oat treatments had the highest average GMD (1.39 mm and 1.26 mm, respectively), and these were statistically significantly different from that for the fallow treatment. However, there were no statistically significant differences (P > 0.05) among black oat, field pea, common vetch, and in terms of WAD. However, the forage turnip WAD was significantly different from those of the other treatments (Table 3).

The fallow treatment presented with a wide variety of weed species like *Commelina benghalensis* L., *Bidens pilosa*, *Conyza bonariensis*, *Raphanus sativus* L., and *Panicum maximum* Jacq. (Table 3). The total dry mass production for this treatment was 2,189 kg ha^{-1} (Figure 2). For this reason, there were no statistically significant differences among the green manure treatments in terms of WAD. All plants can physically improve the soil. In addition, Oxisol Ustox Haplutox soils are rich in iron and strongly aggregate because iron induces colloidal flocculation and cements the soil particles.

Table 3. Average soil geometric mean diameters (DMG) and weighted average diameters (WAD) for the various treatments and soil depths

Depth (cm)	Black Oat	Field Pea	Common Vetch	Fodder turnip	Oat + Fodder turnip	Fallow	**Average**
				GMD			
0-10	1.59 a	1.47 a	1.36 a	1.73 a	1.46 a	0.90 b	**1.42 a**
10-20	0.98 b	0.92 b	0.88 b	1.05 b	1.07 b	0.95 b	**0.97 b**
Average	1.29 AB	1.20 AB	1.12 AB	1.39 A	1.26 A	0.92 B	
				WAD			
0-10	1.81 a	1.77 a	1.74 a	1.98 a	1.75 a	1.24 b	**1.72 a**
10-20	1.21b	1.14 b	1.10 b	1.27 b	1.29 b	1.22 b	**1.20 b**
Average	1.51 AB	1.46 AB	1.42 AB	1.62 A	1.52 AB	1.23 B	

Averages in each row followed by the same uppercase letter and those in each column followed by the same lowercase letter do not significantly differ at the 5% level according to Tukey's test**.**

Fodder turnip has an aggressive root system that compresses soil particles. Its roots also release organic exudates that cement soil particles. These characteristics of fodder turnip roots combined with decomposer microorganisms may favor the formation of

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relatively more stable aggregates [28]. Therefore, soil aggregation was highest in all treatments including fodder turnip.

The 0-10-cm layer had ~50% higher GMD and WAD than the 10-20-cm layer because the former was directly affected by the plants on the soil surface. The high soil aggregation level observed on the soil surface layer is explained by the comparatively high organic matter content there, which was incorporated by the surface cover crops and is associated the lack of soil rotation in NTS. These conditions favor microbial activity in the 0-10-cm soil layer, which differs from that in the 10 20-cm soil layer. Moreover, the plant roots are concentrated within the 0-10-cm soil layer. Developing roots exert pressure on the soil and unite its particles in aggregates. Roots also release exudates that act as binding agents and increase microbial activity in the rhizosphere. All these factors acting in concert promote soil aggregation. [2] demonstrated that no-till (SPD) cover crops stabilize soil aggregates, especially in the superficial layer. However, contradictory results were reported by [29,30]. They attributed soil structure changes mainly to the management type rather than the cover crop used.

Aggregation of the soil affects its ability to store and stabilize carbon [31]. Soil aggregation influences water storage and distribution [32] as well as soil functions, reactions, processes, and systems [33]. It is, however, a sensitive indicator of the effects of the timing of soil management implementation and the changes it produces [34].

Soil aggregates in the presence of cover crops had larger average diameters than those under the fallow treatment. Therefore, cover crops are of vital importance in maintaining soil integrity and productivity. [34] evaluated NTS implementation for 14 years and observed increases in pore volume, permeability, and hydraulic conductivity over time. These were the result of higher soil aggregation and improvements in its physical structure, which, in turn, were realized by the action of plant roots.

4. CONCLUSION

Black oat obtained the lowest decomposition; therefore, a potential species to be used in the system of crop rotation in the no-tillage.

The consorted of fodder turnip and black oat provided relatively higher dry mass yields and improved soil aggregation.

Cover crops reduced the incidence of weeds, being important for no-till sustainability.

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