

Bio-drilling, Compaction Alleviation, and Fate of Storm-Water Management

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Abstract: Compaction due to urbanization and farm operations disrupt natural soil profiles, increase impervious surface areas and decrease vegetative cover. These disruptions increase storm-water runoff at the expense of ground water recharge, degrading water quality and impairing aquatic habitats. A completely randomized experiment was conducted at the OSU/South Centers, Piketon, OH to assess the effect of Daikon radish (*Raphanus sativus* L. var. *oleiferus*) on alleviating compaction. Treatments included long-term tillage, long-term no-till (NT) and a fallow soil compacted with farm equipment with and without Daikon radish. Radish was sown in mid-August and plants were winter-killed at the onset of first frost when the temperature dropped to -2.22 °C (28 °F). To assess progress in compaction alleviation, a model was developed to extrapolate information on soil porosity as an indicator of hydrological properties of soils. Earthworm population dynamics were also considered as a bio-indicator of compaction alleviation. The adoption of radish used as *bio-drilling*, alleviated overall compaction by 40% with reductions ranging from 90% at 0-13 cm to 30% at 56-64 cm depth. The fallow compacted soil with radish had the highest population of earthworm with total body mass of 3.6 kg·m⁻³, followed by NT at 0.8 kg·m⁻³, and till at 0.4 kg·m⁻³ ($p < 0.05$). Mean values of soil porosity were increased by 44% with radish compared to the fields without radish. This increase ranged from 71% in the upper soil depths (0-13 cm depth) to 25% in the lower depths (56-64 cm depths). Use of bio-drilling has potential to synergistically alleviate the effect of compaction, minimize flash-flooding and improve water quality.

Key words: Bio-drilling, bio-indicator, decomposition, compaction, porosity, Daikon Radish (*Raphanus sativus* L. var. *oleiferus*), earthworm population dynamics, NT, conventionally tilled (CT), penetration resistance.

1. Introduction

Effective management of storm-water is a multidisciplinary and an integrated approach. Urbanization disrupts natural soil profiles, increases impervious surfaces as “asphalt is the land’s last crop” and decreases vegetative cover [1, 2]. These disruptions increase stormwater runoff at the expense of groundwater recharge, degrading water quality and impairing aquatic habitats. The repercussions of this non-point source pollution are being felt worldwide. Fate of stormwater does not belong to any political boundary.

Out of 414 million hectares (1,023 million acre) arable land in the United States [3, 4]; 4% (16 mill ha

or 40 mill acre) are represented by roads and parking lots, 7% (25 mill ha or 62 mill acre) by no-till (NT) farming system, and 89% (373 mill ha or 922 mill acre) by the conventionally tilled (CT) farming system (Fig. 1). Because of the benefits and sustained efforts, there are growing concerns that area under NT systems is doubled in the recent years. The area under different categories demonstrated to have a large impact on stormwater management in particular and hydrological cycle in general [5]. Inevitably, area under roads and parking lots will continue to increase to keep up with the pace of population growth and its needs. In the other hand, the huge area under CT shows at least 40% compaction in the United States mainly due to use of machinery and several other reasons [1, 6]. Ideally, in other word, 44% (174 mill ha or 430 mill acre) of the total can be estimated as

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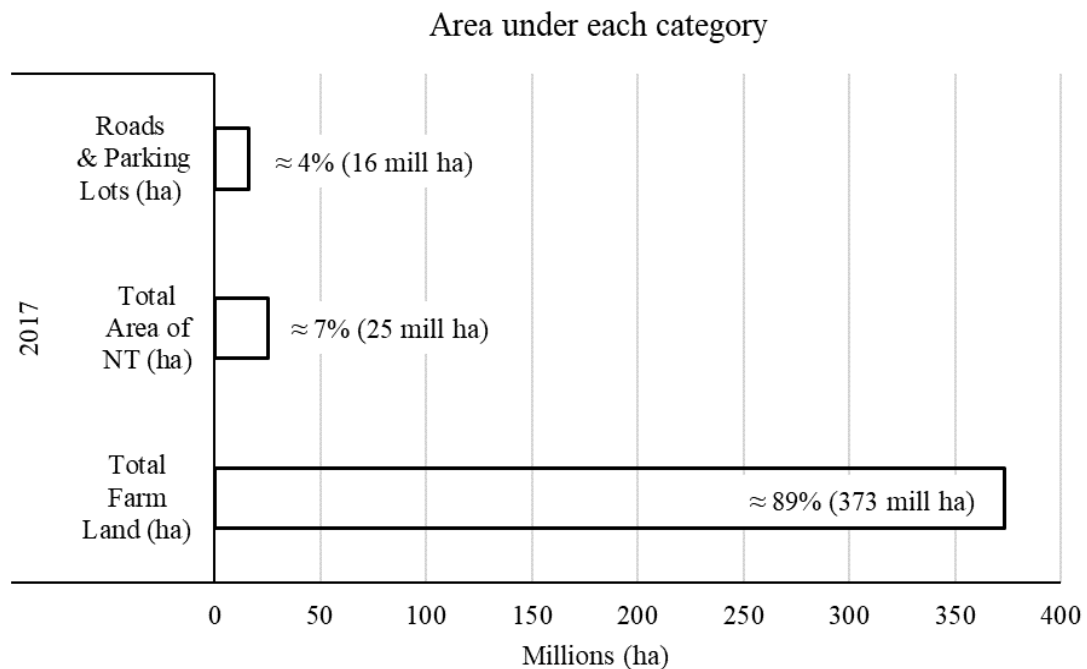


Fig. 1 Area under farmland, no-till, and roads & parking lots.

impervious surface area in the United States which would be depicted to have the same impact as roads and parking lots in stormwater management and hydrological cycle. This is a big challenge but also shows ample room to conserve huge amount of water if the situation alleviated.

In this report, an effort has been made to illustrate and persuade the authority about new, relatively less expensive, easy to follow, and most appropriately sustainable approach called *Bio-drilling* for stormwater management both in urban and rural areas. The objectives of the report are to: (i) appraise the rate of reduction in compaction inevitably caused by farm operations, and (ii) explore and extrapolate information improving rate of storm-water infiltration and increasing water holding capacity of the soil.

1.1 Rationale

Principal causes of stormwater management:

(1) Increasing blacktop in both urban and rural areas to satisfy the needs of population growth is inevitable.

(2) Area increasing under housing is proportional to population growth either in urban or rural

communities encompassing the same effect on water balance as compaction is inevitable.

(3) Use of machinery and heavy equipment performing agricultural operations is not an option but compulsion leading to soil compaction is inevitable.

(4) Raising livestock to fulfill anthropological demand for milk, meat, wool/fiber, and other needs, such as horse riding and hiking etc. is not an option but compulsion leading to soil compaction is inevitable [6, 7].

2. Methodology

A completely randomized experiment was conducted at the Ohio State University/South Centers, Piketon, OH (39°02'855"-39°02'873" N; 82°59'261"-82°59'355" W; Elevation: 176 meter: USA), to assess the effect of Daikon radish (*Raphanus sativus* L. var. oleiferus) on alleviating compaction. Treatments included long-term tillage (CT), long-term no-till (NT) and a fallow soil compacted with farm equipment with and without Daikon radish (Fallow Compacted with Radish: FCR). Radish was sown in mid-August and plants were winter-killed at the onset of first frost

when the temperature dropped to $-2.22\text{ }^{\circ}\text{C}$ ($28\text{ }^{\circ}\text{F}$). To assess progress in compaction alleviation, a model was developed to extrapolate information on soil porosity as an indicator of hydrological properties of soils. Earthworm population dynamics were also assessed as this was considered to be a bioindicator of compaction alleviation. SAS Ver. 9.4 was used for analysis of variance (ANOVA) for earthworm population dynamics between the three treatments (i.e. CT, NT, and FCR).

3. Results and Discussions

Decomposition process of Oilseed radish started with the sudden drop in temperature. This is also associated with the zero expense of energy for killing the plants in terms of herbicides. This also makes the procedure highly inexpensive (profitable with desired outputs), affordable, and sustainable approach. The

decomposition processes encompass primarily four major stages that start with January 25th; the first stage, March 14th; the 2nd stage, April 10th; the 3rd stage, and finally, April 17th; the 4th stage (Fig. 2). The 4th stage of decomposition on April 17th almost leaves the mark like a strip tillage which is later; all the holes are collapsed leaving an impression of regular tillage performed in the field.

Mode of action for strip tillage for compaction alleviation is illustrated in Fig. 3a. Radish used as *bio-drilling*, alleviated overall compaction by $> 40\%$ with reductions ranging from 90% at 00-13 cm to 30% at 56-64 cm (Fig. 3b). The heavy farm equipment also shows the classic phenomenon of getting soil compacted during the harvesting usually in fall season. The processes of soil compaction collapsing all the macro and micro pores are exacerbated by the higher amount of soil moisture which if not taken into

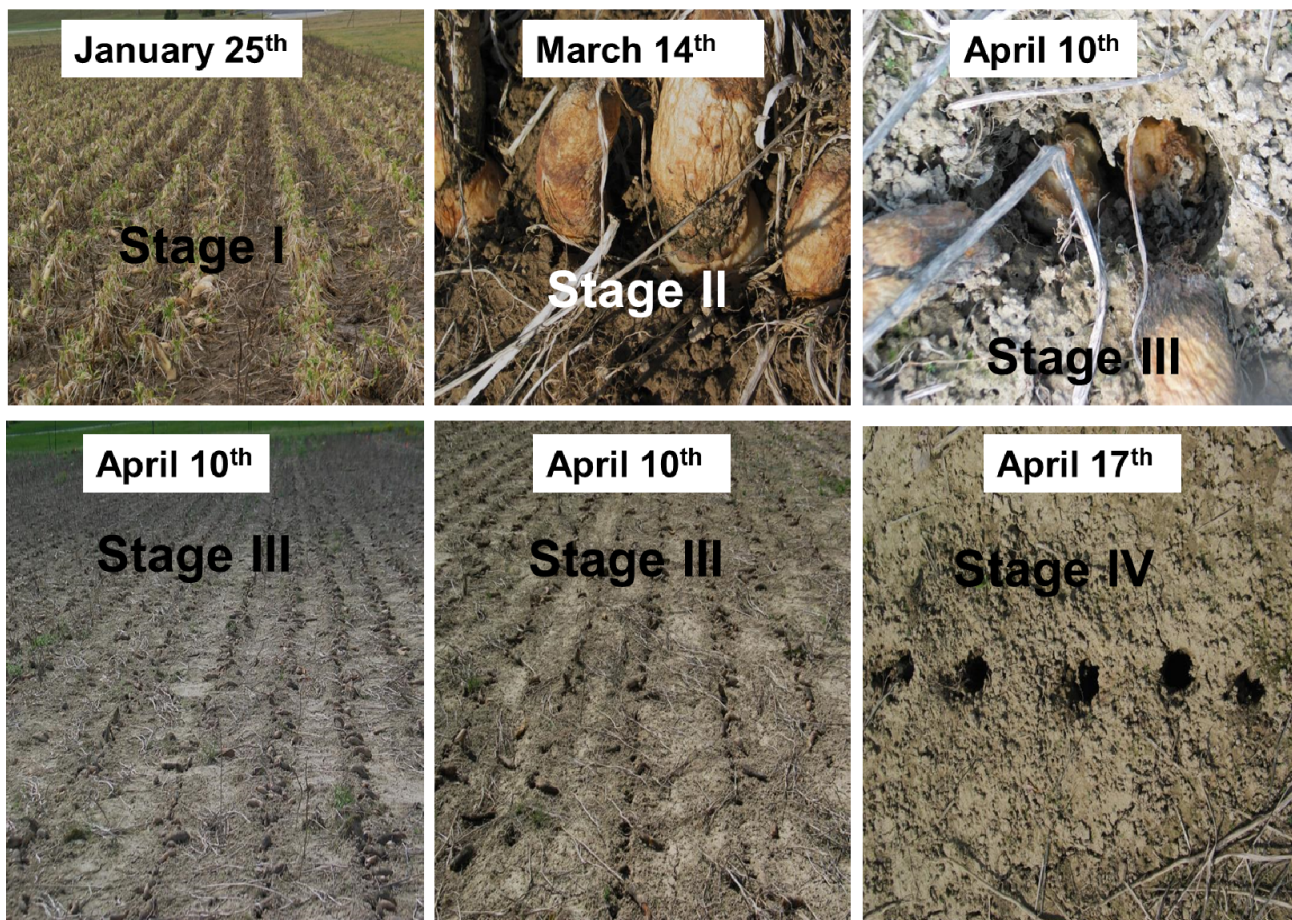


Fig. 2 Winter-killed oilseed radish showing decomposition stages at zero expense of energy.

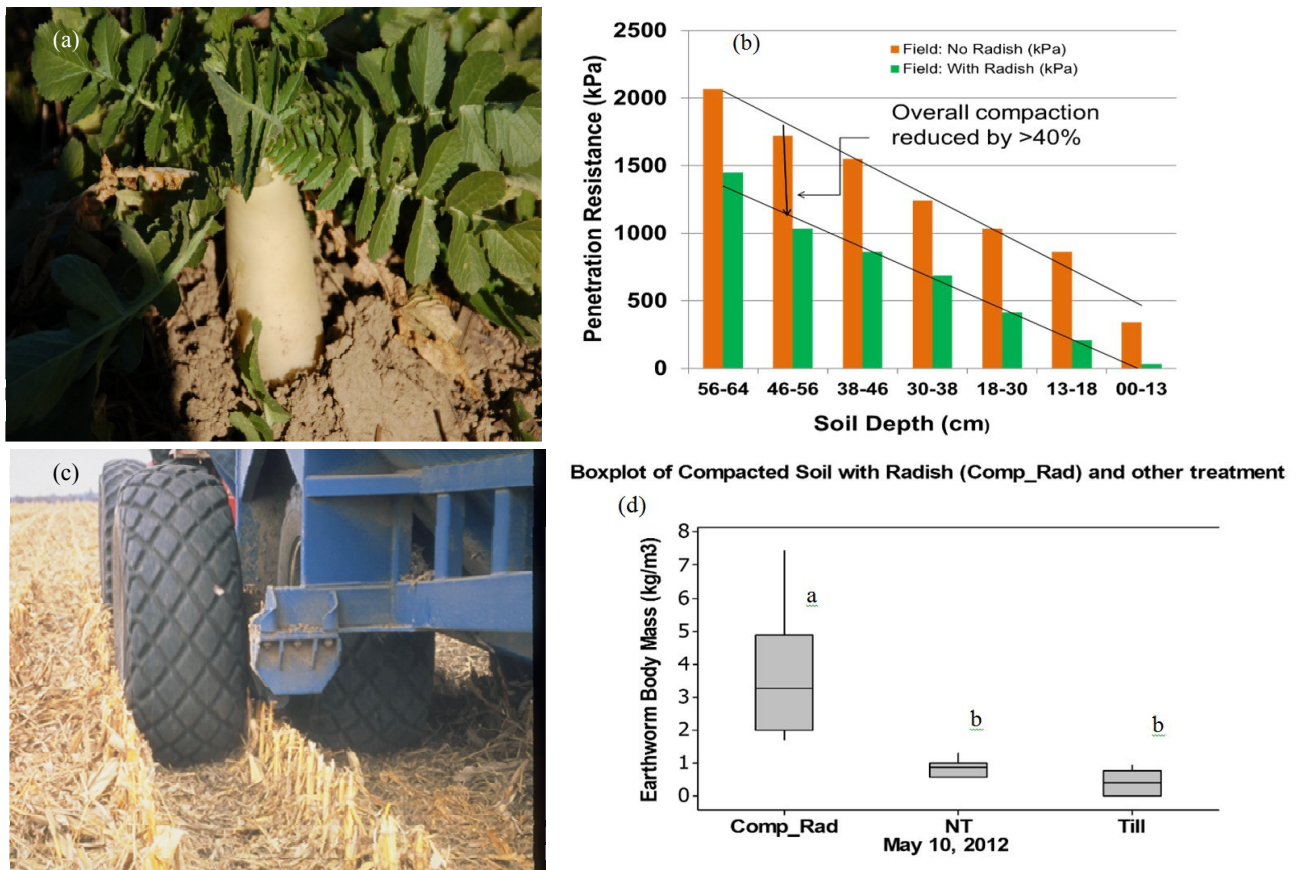


Fig. 3 Compaction alleviation and earthworm population: (a) use of radish as bio-drilling, (b) compaction alleviated at different depth due to use of radish as *bio-drilling*, (c) act of compaction during farm operations, (d) earthworm population dynamics in different management regimes. The whiskers with the same letters are not significantly different at $p < 0.05$. Source: Figs. 3a and 3c by Randall C. Reeder.

consideration usually leads to impervious layer (Fig. 3c). The fallow compacted soil with radish had the highest population of earthworm with total body mass of $3.6 \text{ kg} \cdot \text{m}^{-3}$, followed by NT at $0.8 \text{ kg} \cdot \text{m}^{-3}$, and till at $0.4 \text{ kg} \cdot \text{m}^{-3}$ (Fig. 3d). Mean values of soil porosity were increased by 47% with radish compared to the fields without radish. This increase ranged from 71% in the upper soil depths (00-13 cm) to 25% in the lower depths (56-64 cm) (Table 1).

3.1 Penetration Resistance vs. Porosity

The relationship between penetration resistance and porosity is depicted taking a number of measurements and analyzing them in the Lab. Plotting both the readings together leads to yielding a model equation (Fig. 4) which shows a highly correlated results with the variability coefficient, $R^2 = 0.9712$. This also

indicates that the relationships between the two variables are highly negatively correlated. The porosity (ϕ) of being a dependable variable (y) is highly dependent on penetration resistance, the independent variable (x). The model equation seems to be exceedingly beneficial deriving the porosity reading without in fact analyzing the samples in the lab and sampling in the field. This will also prove to be the non-destructive approach to be used by the students and other scientific workers.

3.2 Transformation of Compaction Readings into Porosity

In order to test the model equation from Fig. 4, the two contrasting fields (i.e. field with no Radish vs. field with Radish) were selected. Compaction readings were taken using penetrometer in the fields. Using the model

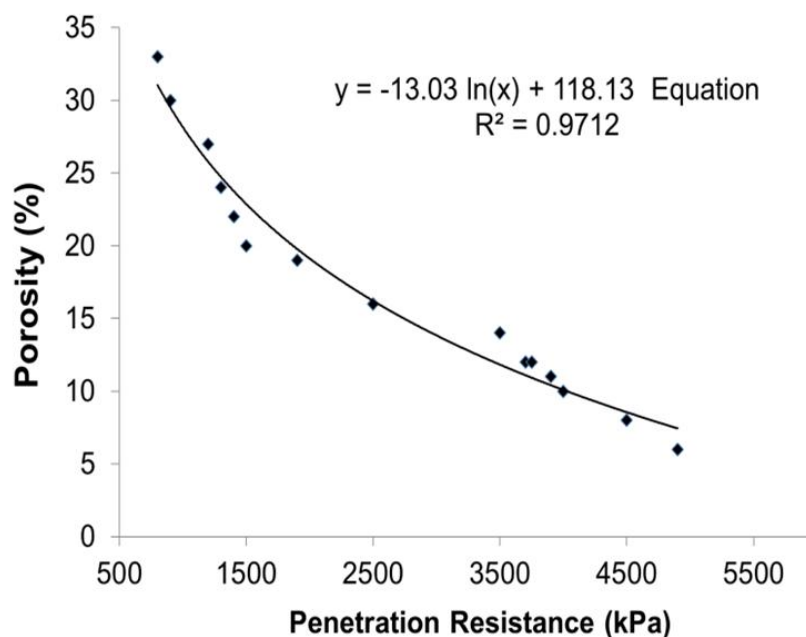


Fig. 4 Relationships—penetration resistance (kPa) vs. porosity (%).

Table 1 Transformation of compaction readings into porosity using equation (from Fig. 4) for modeling (modified and adapted from Ref. [8]).

Depth range (cm)	Field no radish (kPa)	Porosity (%)	Field with radish (kPa)	Porosity (%)	Change in porosity (%)
56-64	2,069	19	1,448	23	25
46-56	1,724	21	1,034	28	32
38-46	1,552	22	862	30	34
30-38	1,241	25	690	33	30
18-30	1,034	28	414	40	43
13-18	862	30	207	49	62
00-13	345	42	34	72	71
Mean		27		39	47

equation from Fig. 4, the readings were calculated to find out the corresponding porosity. This calculation shows the inverse relationships between penetrometer reading and porosity by soil depth (Table 1) showing deeper the soil, the higher penetrometer reading and correspondingly lower the porosity. Evidently, field with Radish shows lower penetrometer reading and higher porosity. The changes in mean values for the porosity are 47% and 27% for field with radish and field with no Radish respectively.

3.3 Required Growth of Oilseed Radish for Significant Impact

In order to manifest the noticeable impact of *biodrilling*, the proper growth of oilseed radish needs

to be maintained. Fig. 5 shows the growth pattern for two years average of biomass production which includes both roots and shoots means of randomly selected twenty-five samples. The average production required to be about 4-5 Tons·ha⁻¹ for roots and shoot and total needs to be about 11 Tons·ha⁻¹ to have the compaction alleviation effect ~40%; although this would be presumably dependent on soil types and other factors as well. The results in this study are based on the *Omulga* soil series silty clay loam (i.e. fine-silty, mixed, active, mesic *oxyaquic fragiudalfs*; with a pH of 5.7-6.0, total organic C of 8-12 g·kg⁻¹, total N 0.8-1.1 g·kg⁻¹, and available P 1.0-4.0 mg·kg⁻¹; soil quality rating was poor with an active C concentration of less than 400 mg·kg⁻¹ [9].

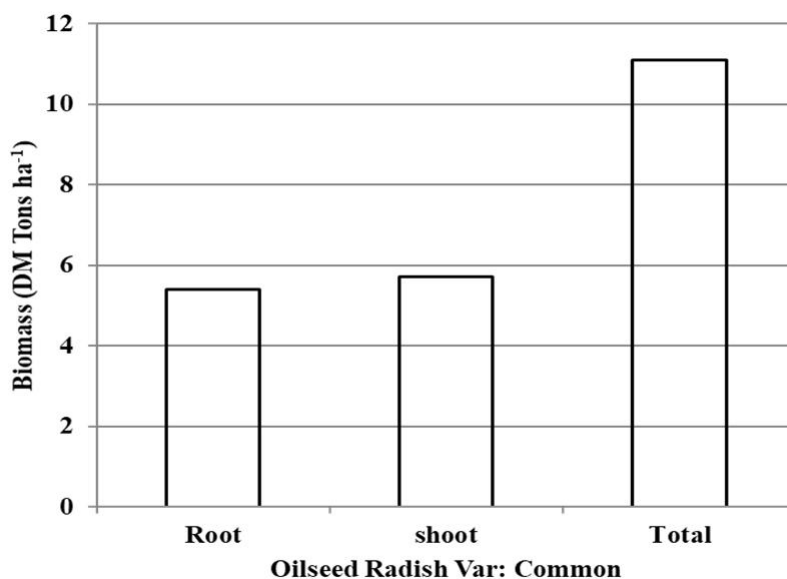


Fig. 5 Two years average of oilseed radish above and belowground biomass expressed in dry matter (DM) oven dried at 105 °C for 24 hrs harvested during an active vegetative growth stage (mid-August-September). The mean values were derived from twenty-five randomly selected samples from the experimental units.

4. Conclusions

(1) The adoption of radish as *bio-drilling*, reduced compaction by 90% at upper depth (00-13 cm depths) to 30% at lower depths (56-64 cm depths).

(2) Transformation of compaction information results increased in porosity by 71% at upper depths to 25% at lower depths.

(3) Earthworm population dynamics considered as a bio-indicator of compaction alleviation were found the highest total body mass of 3.6 kg·m⁻³ in the fallow compacted soil with radish, followed by NT at 0.8 kg·m⁻³ and till at 0.4 kg·m⁻³.

Acknowledgment

The support for the study was provided by the Ohio State University, South Centers Soil, Water, and Bioenergy Program in Piketon OH. Authors also acknowledge the assistance in carrying out the field works and earthworm biomass processing and quantification by the centers' staff members primarily Ms. Beth A. Rigsby, Ms. Jay Bauman, and Ms. Charissa E. Gardner. The study was a part of the author's PhD program (Major: Environmental Science,

2017) at The Ohio State University.

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