BIOAg Project Report

Report Type: Final

Title: Evaluating the contribution of soil organic carbon to improved water-holding capacity through increased compaction resistance

Principal Investigator(s) and Cooperator(s):
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Abstract:

Despite the influence of soil organic matter on plant available water (PAW) and compaction resistance and recovery being well recognized, recent work has shown that the former effect may be relatively limited and the body of evidence on the latter has not been conclusively synthesized to determine the magnitude and direction of this effect. To address this first knowledge gap, we relied on an established long-term field experiment to determine how changes in compaction resistance and recovery associated with differences in soil organic matter affect available water holding capacity after compaction. Study treatments included different biosolids application rates and the presence or absence of soil compaction. Biosolids application rate treatments included three levels: biosolids applied at a rate of 4.5 dry tons per acre (4.5DTBS), 2 dry tons per acre (2DTBS) and a non-fertilized control (0 DTBS), applied every 4 years to a winter wheat-fallow rotation that occasionally includes other grain crops (sunflower, oats, canola, etc.). The compaction treatment included two levels: in-field compaction from multiple tractor passes and no compaction. The long-term experiment was a randomized complete block design with three replications and the compaction treatment was applied as a single randomized strip. Three intact cores per subplot were collected and analyzed for the determination of saturated hydraulic conductivity, complete soil moisture release curves and bulk density. In addition, disturbed soil samples were collected for determination of Proctor maximum bulk density, critical water content, and for repacking of soil cores. Results showed that in general, the biosolids application increased the saturated hydraulic conductivity, the water content at saturation, and the water content at permanent wilting point, lowered the bulk density, and did not affect PAW. Field compaction of soils appeared to increase the bulk density, decrease the saturated hydraulic conductivity and water content at saturation, and increase the water content at field capacity and permanent wilting point, ultimately leading to no apparent difference in PAW. No differences were found between intact and repacked cores in relation to soil water retention.

Project Description:

Soil degradation takes many forms – compaction, crusting, erosion, organic matter loss, etc. – many of which impair the soil's ability to perform the vital functions of infiltrating and storing soil moisture for plant growth. This is particularly concerning in light of increases in extreme weather events and changes to precipitation patterns associated with climate change. The water-holding capacity (WHC) of a soil is determined primarily by soil texture, but it can be altered with management practices that affect soil organic matter (SOM) and soil structure. The potential for organic matter to increase WHC has been widely studied, most recently culminating in a meta-analysis that concluded increasing SOM has a modest effect on WHC: a 10 g kg^{-1} increase in soil organic C (SOC) translated to a 5 mm increase in plant available water (PAW, used here interchangeably with WHC to represent the difference in water content between field capacity and permanent wilting point) assuming the increase is throughout a 0.5 m root zone[1]. This is particularly noteworthy because increasing SOM through commercially practical management practices can be a slow process. Long-term experiments[2,3] in California and Washington with annual poultry manure applications at 4 Mg ha^{-1} (CA) or biosolids applications every four years at 9 Mg ha^{-1} (WA) have only increased SOC by 1.15 Mg C ha^{-1} yr^{-1} and 0.77 Mg C ha^{-1} yr^{-1}, corresponding roughly to a 0.39 – 2.73 mm increase in PAW over 19 – 20 years assuming a 0.5 m root zone. However, there is reason to believe that these values may be underestimating the true ability of SOM to increase PAW. First, the meta-analysis used data generated from intact soil cores, disturbed soil samples, and pedo-transfer functions[1]. The latter two methods don't account for the influence of SOM on macroscopic soil structure, which may well affect the response of PAW to increasing SOM. Second, increasing SOM has numerous other benefits, some of which may indirectly affect PAW. It has been shown that the addition of SOM may increase the ability of a soil to resist or recover from compaction[4,5]. While multiple literature reviews have addressed this topic[6,7], to our knowledge, this information has not been synthesized in a quantitative literature review that estimates the reduction in bulk density with a given increase in SOC after compaction at agriculturally-relevant pressures. Furthermore, we are not aware of any studies that evaluate how altered compaction resistance with increased SOC translates to changes in PAW after compaction. Given that soil compaction is a major challenge in diverse agricultural regions, the influence of SOM on PAW could be greater than previously thought. Better understanding this relationship will be essential in developing and promoting management practices that reduce compaction and improve soil moisture storage. To this end, this project sought to (1) quantitatively assess the influence of SOM on compaction resistance and recovery through an analysis of published peer-reviewed literature, (2) investigate the extent to which macroscopic soil structure (> 2 mm) affects the WHC of a soil and how this relationship changes with SOM, and (3) determine how changes in compaction resistance and recovery associated with differences in SOM affect WHC after compaction.

Outputs

Overview of Work Completed and in Progress:

Work completed:

- Complete soil moisture release curves have been developed for field compacted and uncompacted intact cores and lab saturated hydraulic conductivity and bulk density have also been measured with these cores
- Cores were repacked using disturbed samples, after sieving to 2 mm to break up large macroaggregates, to the bulk density measured on uncompacted cores. Then, complete soil moisture release curves were developed for these repacked soil cores using HYPROP 2 and WP4C (METER Group, Inc.).
- Proctor critical water content and the maximum bulk density of all disturbed soil samples have been determined.

Work in progress:

- Uncompacted intact cores will be compacted the in lab at the matric potential corresponding to the critical water content (using Proctor compaction curves and soil moisture release curves developed from disturbed samples and uncompacted cores, respectively), and complete soil moisture release curves will be developed for these lab compacted cores.
- A literature search for studies that assess the effect of differences in SOM on compaction resistance and recovery is in progress, as is a quantitative analysis of these studies.

Methods, Results, and Discussion (discussion for final reports only):

Methods:

Long-term experimental plots were established in 1994 on a commercial dryland wheat farm in Douglas County, Washington. The experiment consisted of three biosolids application rates, a synthetically fertilized control, and an unfertilized control. However, for the purposes of this study, only three of these five treatments were included, and a second treatment (compacted or not compacted) was super-imposed as a single randomized strip on the randomized complete block design with three replicates. The three biosolids application rate treatments were: 4.5 dry tons per acre (4.5DTBS), 2 dry tons per acre (2DTBS) and a non-fertilized control (0 DTBS), applied every 4 years to a winter wheat-fallow rotation. A 0.27 inch rainfall event was simulated over approximately 2.5 hours in two strips in all the plots, and in-field compaction was subsequently applied approximately one hour later with three passes of an 8-wheeled John Deere 9300 tractor in one of the two strips. The plots were 15 m wide and 215 m long and located within a commercial production field. Intact soil cores (8 cm internal diameter and 5 cm high) were extracted in triplicate from the field compacted and uncompacted strips in each replicate of the three treatment levels (4.5DTBS, 4.5DTBS, and 0 DTBS). In addition, three extra cores were taken in the uncompacted strips for lab compaction and three disturbed soil samples per biosolids treatment were collected in five-gallon buckets for determination of Proctor maximum bulk density and critical water content. Four additional disturbed samples were collected per plot for repacking of soil cores. These samples were sieved to 2 mm to break up large macroaggregates and used to repack soil cores to the bulk density measured on uncompacted cores. The intact cores were analyzed for saturated hydraulic conductivity (Ksat) using constant head apparatus and complete soil moisture release curves using HYPROP 2 and WP4C (METER Group, Inc.). The repacked soil cores were analyzed for soil moisture release curves. The bulk density was subsequently determined on these cores by oven-drying. Proctor maximum bulk density and critical water content were determined on disturbed samples using Modified Proctor test.

Results and discussion:

The results showed that averaged across compaction treatments, the saturated hydraulic conductivity (the rate at which soils can transmit water and a proxy for infiltration), increased with the biosolids application rate (Fig. 1). This increase with biosolids application is important for getting the limited rainfall in this dryland production region into the soil profile, particularly in sloping fields where rainfall might lead to run-off. Field compaction appeared to reduce the Ksat, when averaged across biosolids treatments. No clear trends among biosolids treatments have emerged in the data for water content at field capacity (-10kPa) (Fig. 2), or plant available water (Fig. 4), which is the water content at field capacity minus water content at permanent wilting point (Fig. 3). However, water content at saturation (0kPa) was higher in 2DTBS and 4.5 DTBS compared to 0 DTBS (Fig. 5), and water content at permanent wilting point (-1500 kPa) was higher in 2DTBS and 4.5 DTBS compared to 0 DTBS when the soil was compacted (Table 1). Field compacted soils tended to have a higher water content at field capacity and permanent wilting point, but lower water content at saturation compared to the uncompacted soils, when averaged across biosolids treatments (Figs. 2-5). However, because the water content at both field capacity and permanent wilting point was higher, plant available water did not show any difference (Fig. 4). Bulk density was lower in 2 DTBS (1.30 g cm^3) and 4.5DTBS (1.25 g cm^3) compared to the 0 DTBS treatment (1.40 g cm^3), averaged across the compaction treatments (Fig. 6). The application of biosolids lowered the bulk density as expected due to the mixing of lighter organic matter with mineral soil particles, but the change in density due to soil compaction did not appear to be affected by biosolids application. Field compacted soils had higher bulk density (1.38 g cm^3) than the uncompacted soils (1.25 g cm^3), averaged across biosolids treatments. Proctor critical water content was highest in 4.5DTBS, followed by 2DTBS and 0 DTBS (Fig. 7) and Proctor maximum bulk density followed the exactly opposite trend with that of critical water content (Fig. 8).No difference in soil moisture thresholds and plant available water was observed between intact and repacked cores, averaged across biosolids treatments (Figs. 9-12; Table 2).

In summary, the biosolids application increased the saturated hydraulic conductivity, the water content at saturation, and the water content at permanent wilting point, and lowered the bulk density. Field compaction of soils appeared to reduce the saturated hydraulic conductivity and the water content at saturation but increase the bulk density, the water content at field capacity and the water content at permanent wilting point. However, neither the biosolids treatments nor the field compaction had any effect on plant available water, contrary to our hypotheses. Despite the fact that Minasny and McBratney (2018)[1] found that increasing SOM generally increased PAW the most in coarse-textured soils, our results are not alone in finding no appreciable change in the plant available water with increasing organic matter in a sandy soil[8,9]. The quality of added OM can also play an important role in influencing water retention. For instance, hydrophilic compounds such as polysaccharides gums are important for soil aggregation[10]. While the relative proportion of hydrophobic and hydrophilic compounds in the biosolids used has not been characterized to our knowledge, the addition of organic matter having more hydrophobic compounds than hydrophilic compounds to soils may result in little or no increase in available water[10,11,12]. No differences were found between intact and repacked cores in relation to soil water retention in our study. Likewise, [13]Buccigrossi et al. (2010) [13] and Botula et al. (2012) [14] did not find any difference in water content at field capacity and permanent wilting point between undisturbed and sieved-repacked soils.

Table 1. Impact of biosolid application rates on physical and hydraulic properties of compacted and uncompacted soils.

BIOSOLIDS RATE (DRY TONS ACRE^{-1})	BULK DENSITY (MG M^{-3})	KSAT (MM HR^{-1})	Θ_{SAT} (%)	Θ_{FC} (%)	Θ_{PWP} (%)	PAW (%)
UNCOMPACTED						
0	1.36^{a}	49.2	44.2^{b}	31.8	5.1	26.6
2	1.21^{b}	82.2	49.1^{a}	31.8	5.8	26.0
4.5	1.20^{b}	92.0	50.2^{a}	31.5	5.3	26.1
P-VALUE	0.006	0.220	0.011	0.955	0.333	0.842
COMPACTED						
0	1.45^{A}	27.6^{B}	41.6^{B}	32.7	6.1^{B}	26.7
2	1.38^{AB}	38.6^{A}	45.4^{A}	33.7	6.7^{A}	27.0
4.5	1.30^{B}	42.6^{A}	47.0^{A}	33.9	6.8^{A}	27.1
P-VALUE	0.044	0.017	0.016	0.324	0.012	0.822

Table 2. Impact of biosolid application rates and soil core composition on soil physical and hydraulic properties.

BIOSOLIDS RATE (B) (DRY TONS ACRE^{-1})	Θ_{SAT} (%)	Θ_{FC} (%)	Θ_{PWP} (%)	PAW (%)
0	45.9^{b}	32.3	4.7^{b}	27.7
2	49.3^{a}	32.1	5.7^{ab}	26.5
4.5	50.9^{a}	31.2	5.8^{a}	25.4
CORE COMPOSITION (C)				
INTACT	47.8	31.7	5.4	26.2
REPACKED	49.5	32.0	5.3	26.7
P-VALUES				
B	0.006	0.756	0.034	0.226
C	0.115	0.789	0.816	0.659
B × C	0.439	0.865	0.092	0.370

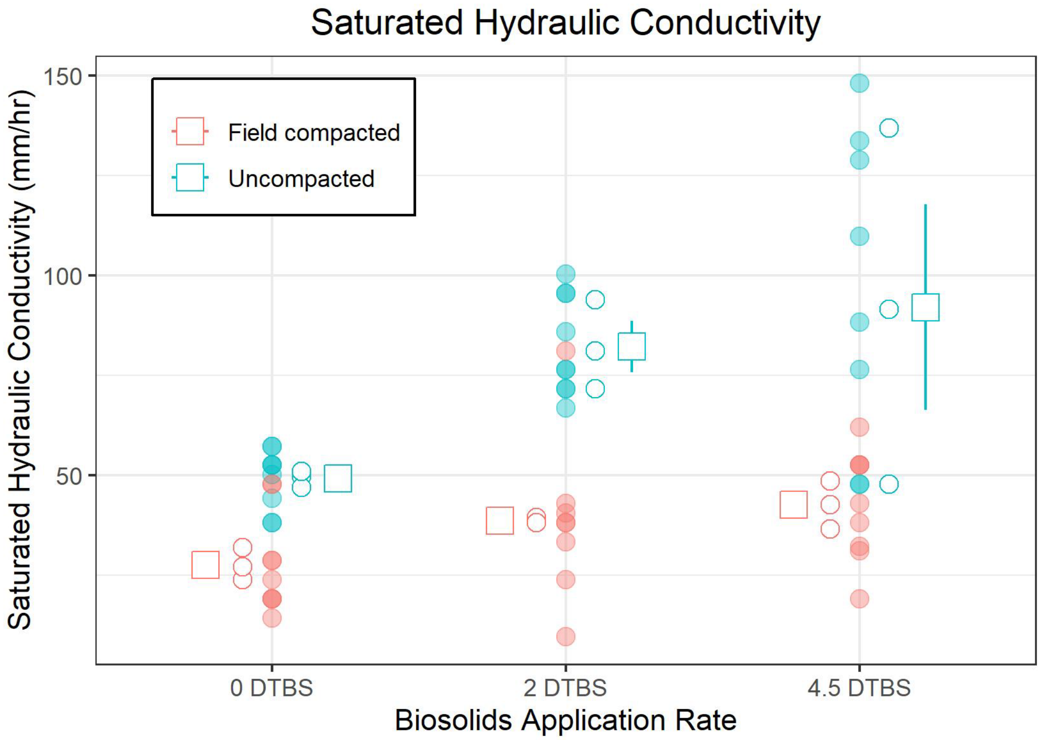

Fig. 1. Saturated hydraulic conductivity (Ksat, mm/hr) as influenced by biosolids application rate (4.5 dry tons per acre, 4.5DTBS; 2 dry tons per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and compaction treatments (field compaction and no compaction). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

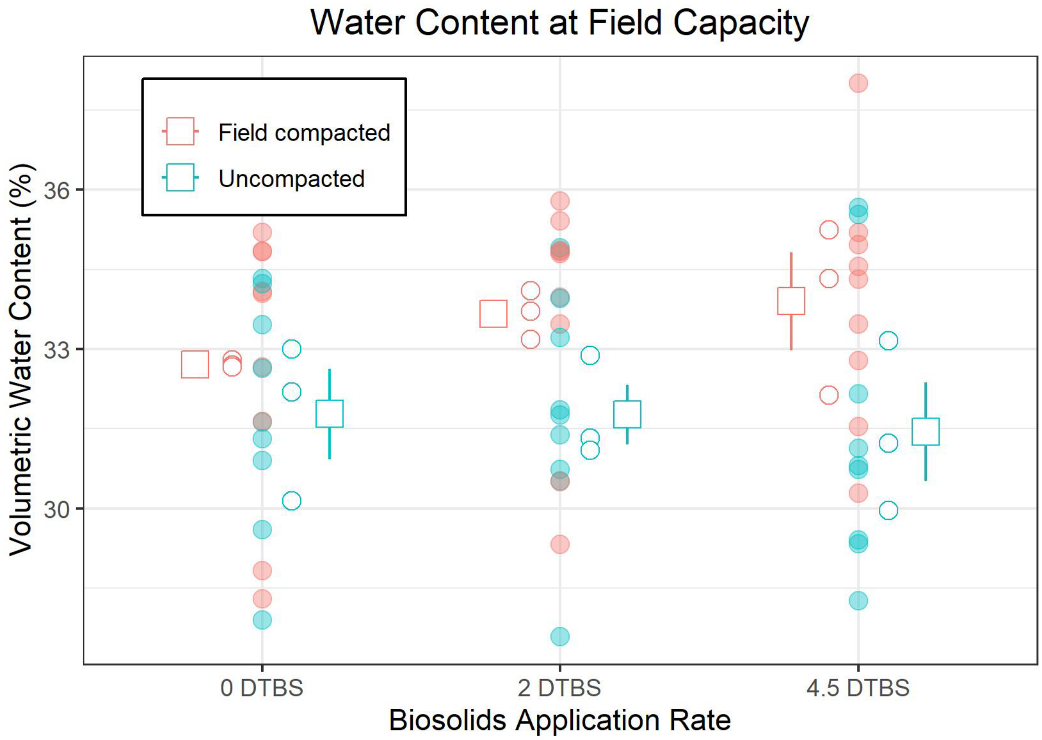

Fig. 2. Water content at field capacity as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and compaction treatments (field compaction and no compaction). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

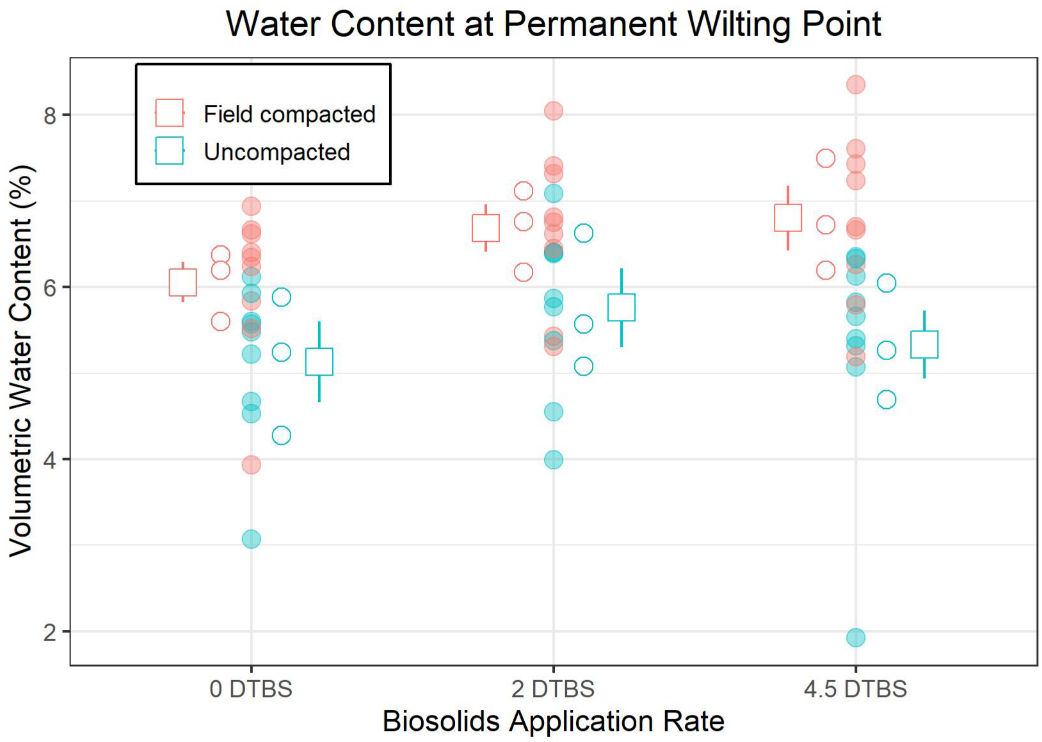
Water Content at Permanent Wilting Point
Field compacted
Uncompacted
Volumetric Water Content (%)
8
6
4
2
0 DTBS
2 DTBS
4.5 DTBS
Biosolids Application Rate

Fig. 3. Water content at permanent wilting point as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and compaction treatments (field compaction and no compaction). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

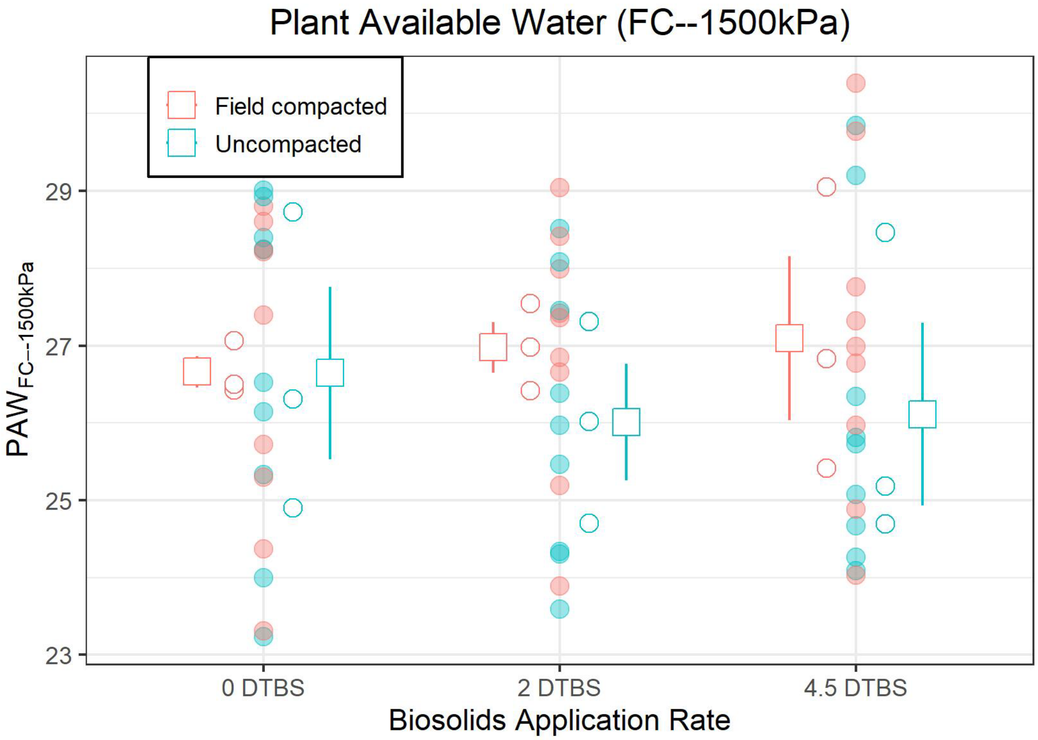

Fig. 4. Plant available water as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and compaction treatments (field compaction and no compaction). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

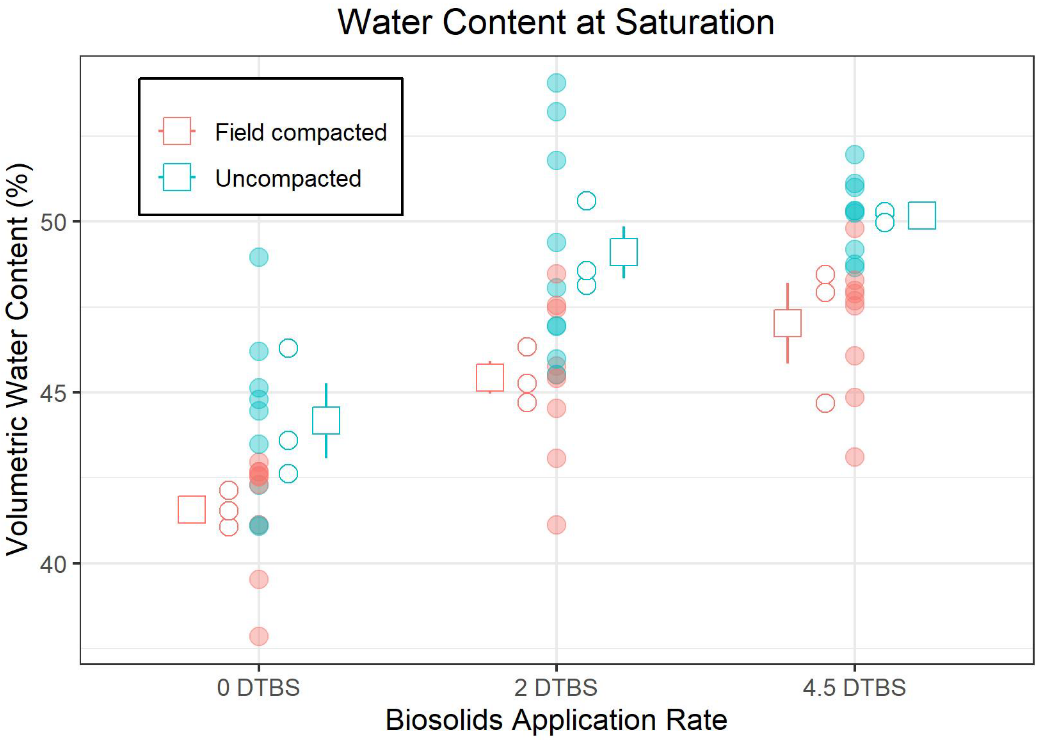

Fig. 5. Water content at saturation as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and compaction treatments (field compaction and no compaction). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

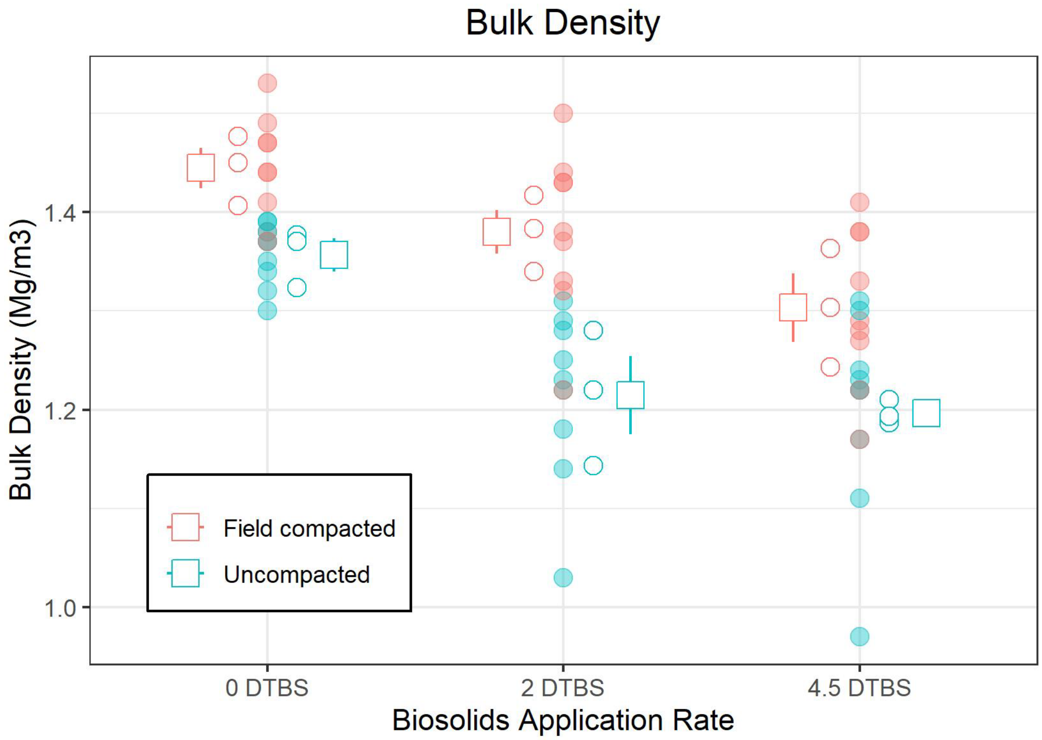

Fig. 6. Bulk density as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and compaction treatments (field compaction and no compaction). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

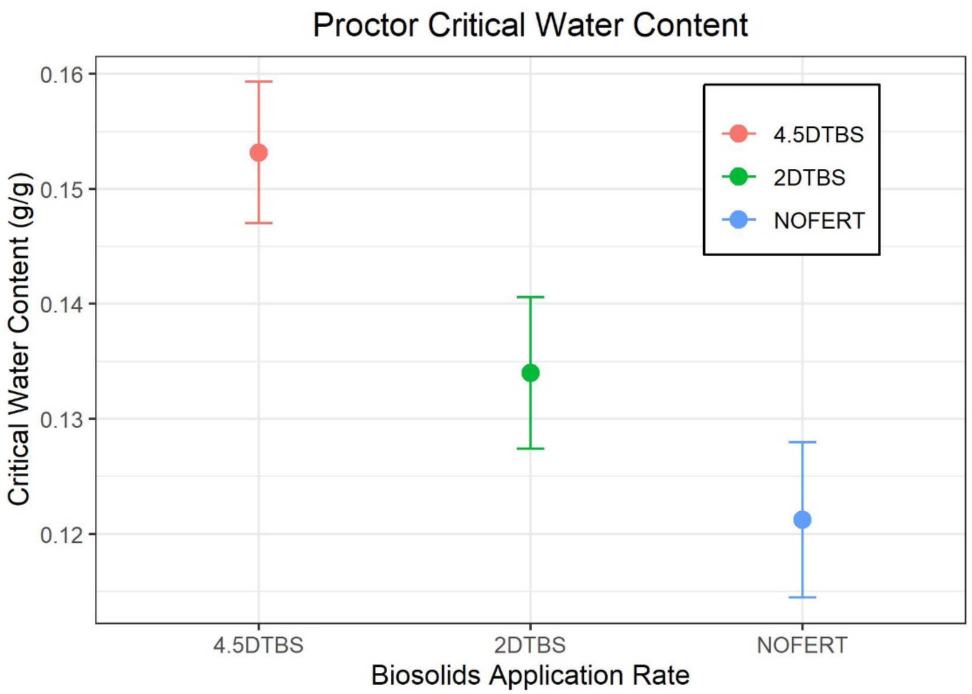

Fig. 7. Proctor critical water content as influenced by biosolids application rate (4.5 dry tons per acre, 4.5DTBS; 2 dry tons per acre, 2DTBS and a no-fertilizer control, 0 DTBS). Each point is an average of three field replicates.

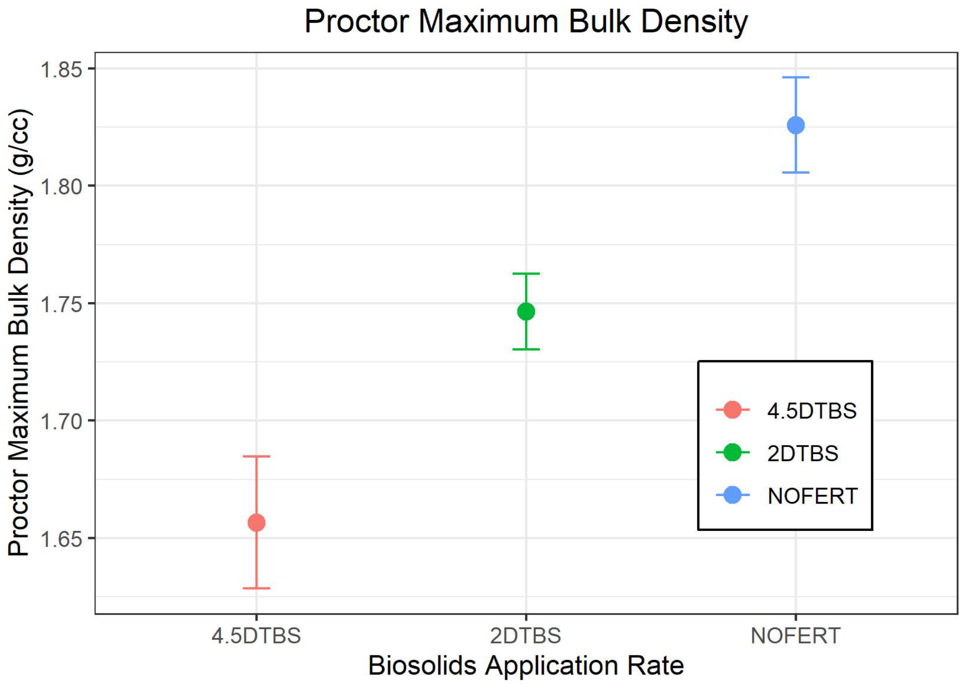

Fig. 8. Proctor maximum bulk density as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS). Each point is an average of three field replicates.

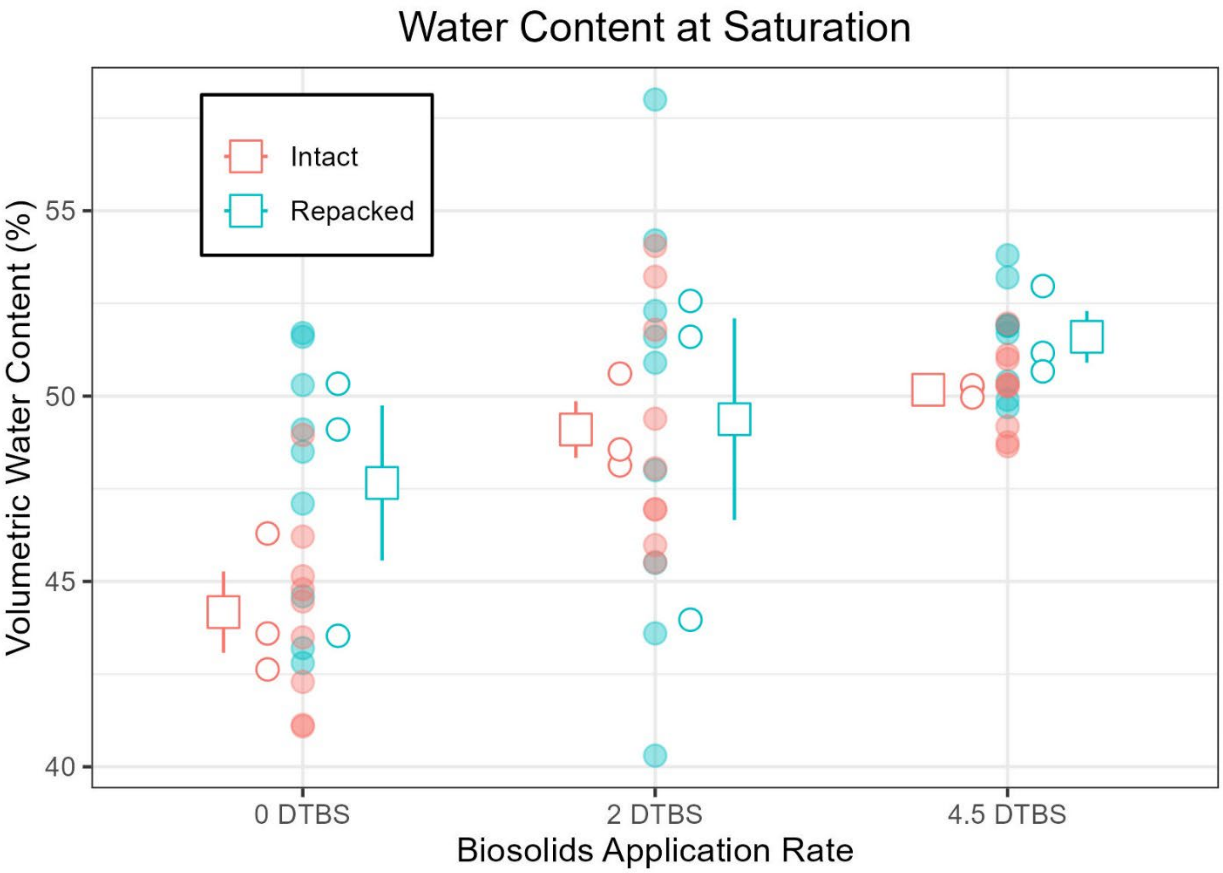

Fig. 9. Water content at saturation as influenced by biosolids application rate (4.5 dry tons per acre, 4.5DTBS; 2 dry tons per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and soil core composition treatments (intact and repacked). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

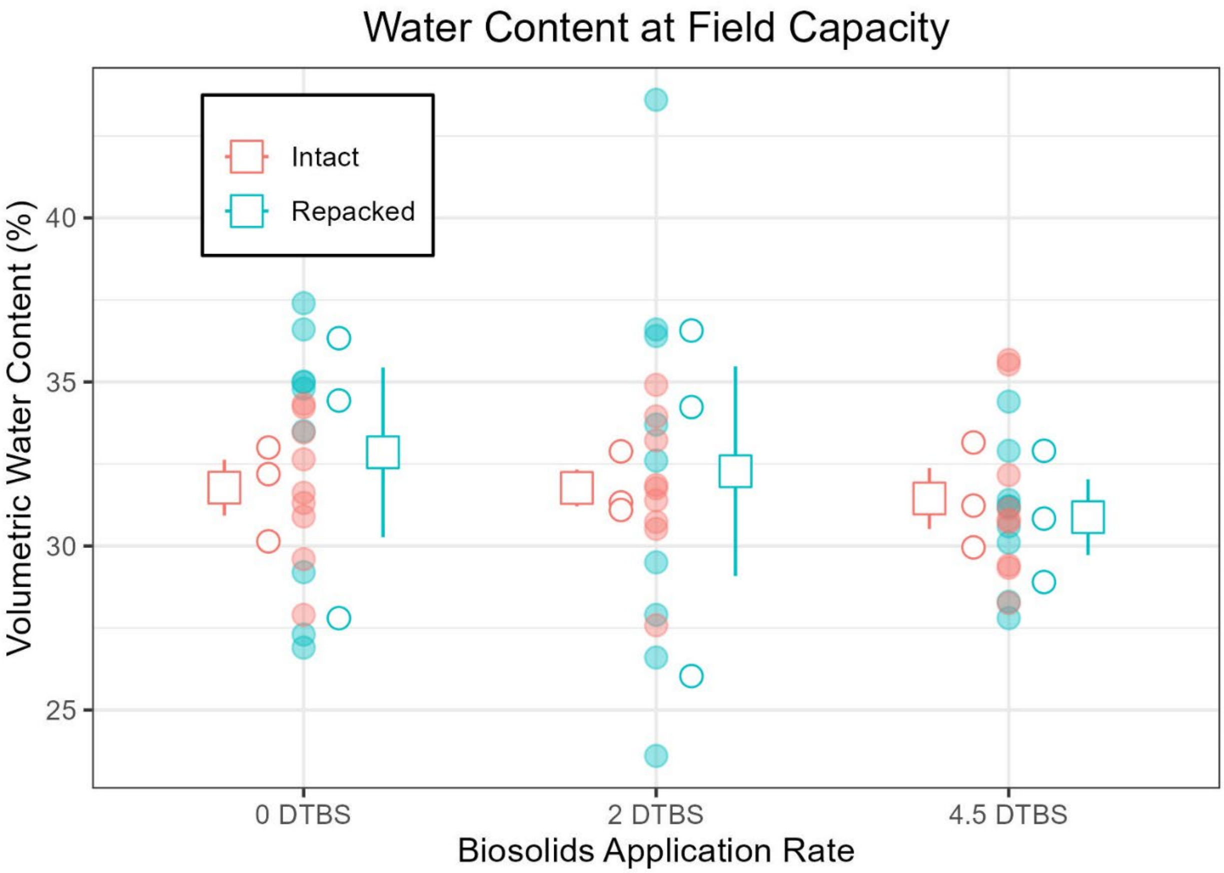

Fig. 10. Water content at field capacity as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and soil core composition treatments (intact and repacked). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

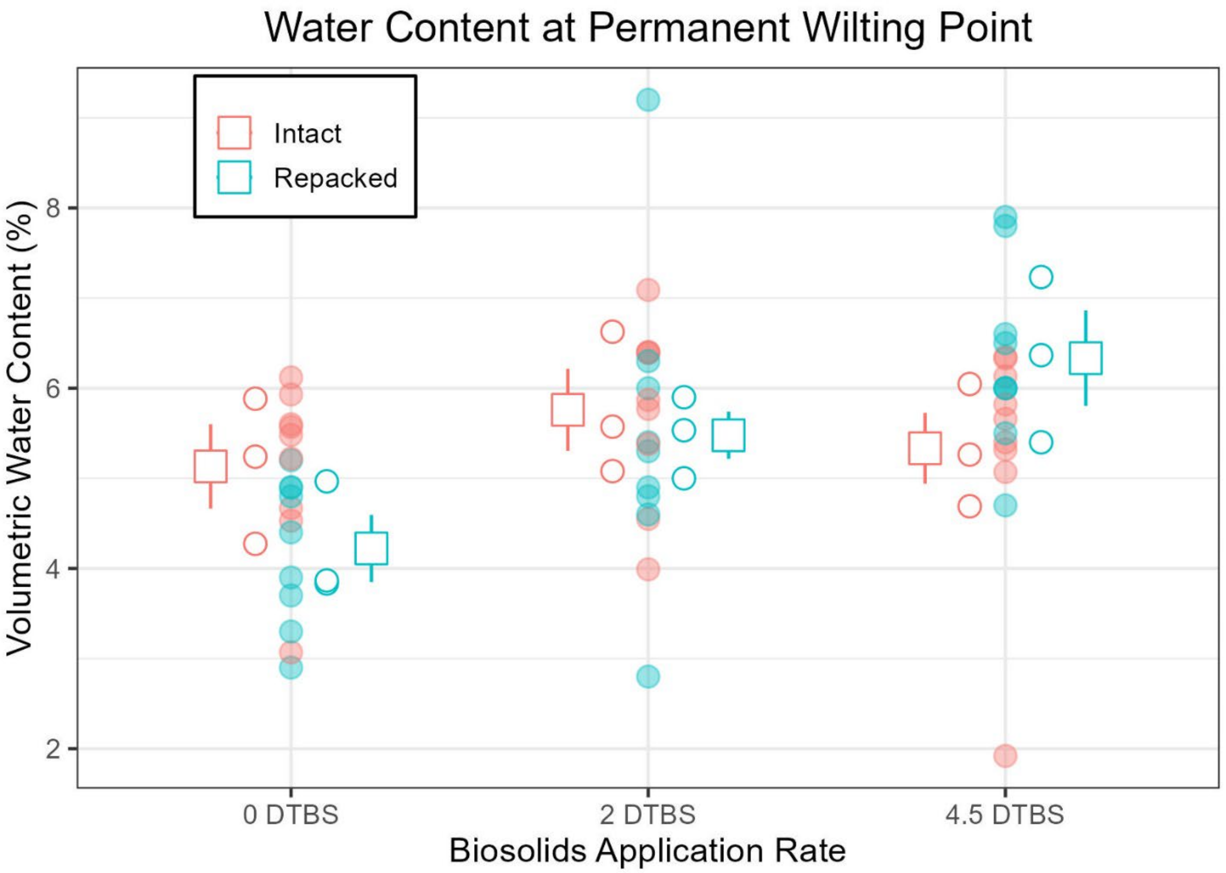

Fig. 11. Water content at permanent wilting point as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and soil core composition treatments (intact and repacked). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

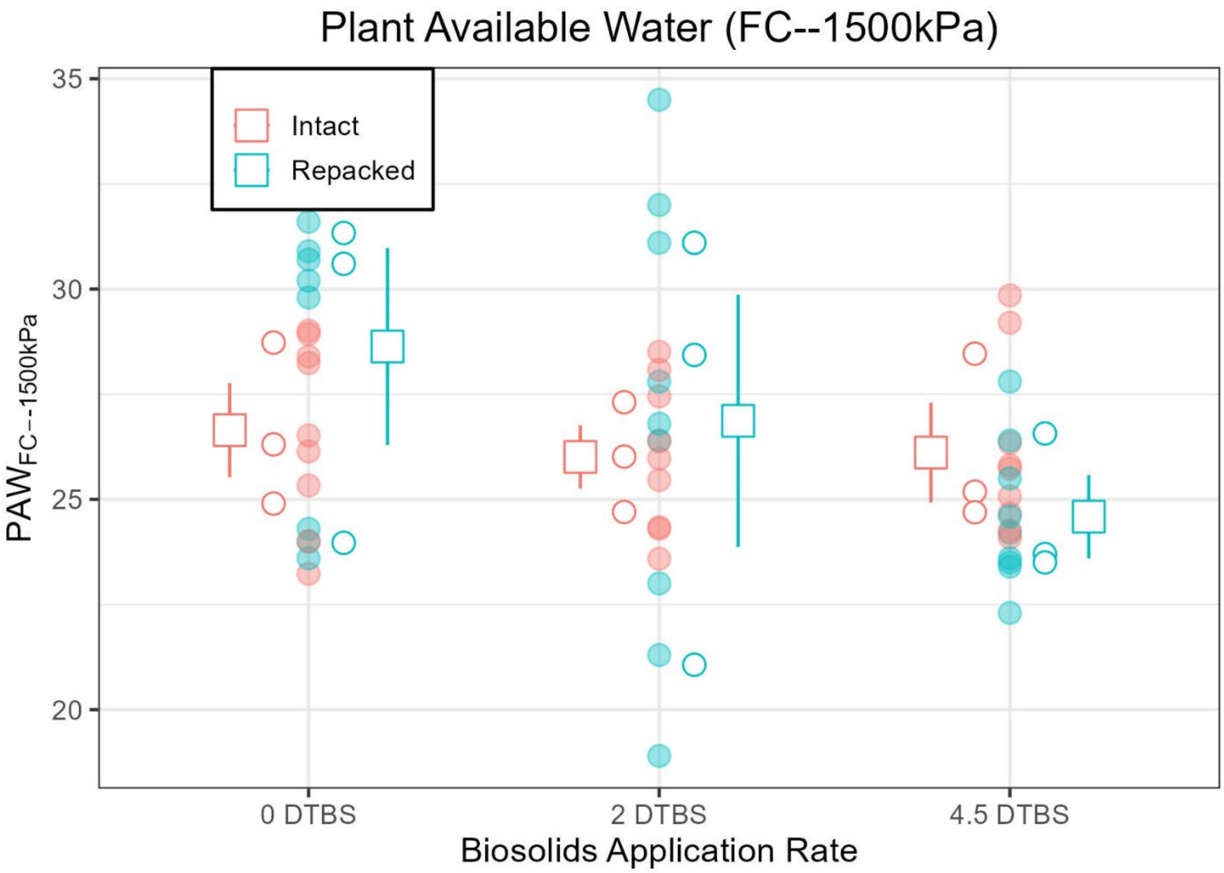

Fig. 12. Plant available water as influenced by biosolids application rate (4.5 dry ton per acre, 4.5DTBS; 2 dry ton per acre, 2DTBS and a no-fertilizer control, 0 DTBS) and soil core composition treatments (intact and repacked). *Note:* Filled circles represent individual datapoints; Hollow circles represent experimental replicates (average of subsamples); Hollow squares represent final average values (average of experimental replicates); Bars represent standard error of mean.

Publications, Handouts, Other Text & Web Products:

The results of the lab analyses have been compiled and the preparation of an academic journal article for submission to Soil & Tillage Research is in progress. A second academic journal article will be generated from the quantitative literature review. On a more local level, the results of this work have been used to inform treatment impact pathways for the design of the Mount Vernon Long-term Agricultural Research and Extension site.

Outreach & Education Activities:

A research short story entitled “Impacts of long-term biosolids application on soil compaction and plant available water” was published as a blog on Northwest Biosolids website[15] on May 5, 2022. Results will still be shared with farmers through local field days, such as the Skagit Ag Summit and the WSU NWREC Annual Field Day and local conferences (e.g., BioFest). Lastly, the preliminary data generated from this research will be used to develop a larger proposal (NRCS CIG, WSARE) that relies on additional long-term study sites to explore the relationship between SOM, compaction resistance, and soil-water relations (especially hydraulic conductivity) in greater detail and initiates on-farm research to investigate the influence of SOM-building practices on soil water-relations in compaction-prone soils.

Impacts

In the short-term (< 3 years), this research will help farmers understand how declining SOM in their fields is tangibly affecting plant available water, especially by quantifying that change and the amount of irrigation required to compensate. In the medium-term (3 – 10 years), we expect the combination of this research and other aligned research efforts will increase the adoption of management practices that build SOM (e.g., biosolids/compost/manure application, green manures, etc.). The long-term (10+ years) aim is to reverse declining SOM levels and to build SOM, thereby increasing green water utilization (stored soil moisture from precipitation) and reducing irrigation requirements. Realization of the latter will reduce labor and fuel costs for irrigation, increase environmental in-stream flows, and help farmers adapt to a changing climate.

Additional funding applied for/secured:

Ongoing funding was secured for the establishment of the Mount Vernon Long-Term Agroecological Research and Extension site, which will also explore the relationship between SOM, soil compaction, and PAW. Given that this will require considerable time to allow differences in SOM to develop (8 – 12 years), additional funding is being sought to address these questions in other systems with different edaphic and climatic conditions.

Graduate students funded: None

Recommendations for future research:

As the results from this study were based on samples from a single field with a coarse-textured soil, additional field and lab experiments are needed to study the impacts of soil organic matter and agricultural traffic on soil hydro-physical properties under different soil texture and environmental conditions, particularly in fine-textured soils and higher rainfall environments. Additional research should also focus on how SOM and compaction impact readily available water and therefore irrigation water requirements in irrigated systems.

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