Aggregate coalescence and factors affecting it

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Table of Contents

List of Figures

List of Tables

Summary

The phenomenon called *soil aggregate coalescence* occurs at contact-points between aggregates and causes soil strength to increase to values that can inhibit plant root exploration and thus potential yield. During natural wetting and drying, soil aggregates appear to ‘weld’ together with little or no increase in dry bulk density. The precise reasons for this phenomenon are not understood, but it has been found to occur even in soils comprised entirely of water stable aggregates. Soil aggregate coalescence has not been widely observed and reported in soil science and yet may pose a significant risk for crops preventing them from achieving their genetic and environmental yield potentials. This project used soil penetrometer resistance and an indirect tensile-strength test to measure the early stages of aggregate coalescence and to evaluate their effects on the early growth of tomato plants. The early stages of aggregate coalescence were thought to be affected by a number of factors including: the matric suction of water during application and subsequent drainage, the overburden pressure on moist soil in the root zone, the initial size of soil aggregates prior to wetting, and the degree of sodicity of the soil aggregates. Seven main experiments were conducted to evaluate these factors.

The matric suction during wetting of a seedbed affects the degree of aggregate slaking that occurs, and the strength of the wetted aggregates. The matric suction during draining affects the magnitude of ‘effective stresses’ that operate to retain soil structural integrity as the soil drains and dries out. An experiment was conducted to evaluate the influence of matric suction (within a range of suctions experienced in the field) on aggregate coalescence using soils of two different textures. Sieved aggregates (0.5 to 2 mm diameter) from a coarse-textured and two fine-textured (swelling) soils were packed into cylindrical rings (4.77 cm i.d., 5 cm high) and subjected to different suctions on wetting (near-saturation, and 1 kPa), and on draining (10 kPa on sintered-glass funnels, and 100 kPa on ceramic pressure plates). After one-week of drainage, penetrometer resistance was measured as a function of depth to approximately 45 mm (penetrometer had a recessed-shaft, cone diameter = 2 mm, advanced at a rate of 0.3 mm/min). Tensile strength of other core-samples was measured after air-drying using an indirect “Brazilian” crushing test. For the coarse-textured soil, penetrometer resistance was significantly greater for samples wet to near-saturation, despite there being no significant increase in dry bulk density; this was not the case for the finer-textured soils, and it was difficult to distinguish the effects of

variable bulk density upon drying from those of the imposed wetting treatments. In both coarse- and fine-textured soils, the tensile strength was significantly greater for samples wet to near-saturation. Thus wetting- and draining-suctions were both found to influence the degree of soil aggregate coalescence as measured by penetrometer resistance and tensile strength.

Aggregate coalescence in irrigated crops is known to develop as the growing season progresses. It was therefore thought to be linked to the repeated occurrence of matric suctions that enhance the phenomenon during cycles of wetting and draining. An experiment was conducted to determine the extent of aggregate coalescence in a coarse-textured and two fine-textured (swelling clay) soils during 8 successive cycles of wetting and draining. Sieved aggregates (0.5 to 2 mm diameter) from each soil were packed into cylindrical rings (4.77 cm i.d., 5 cm high) and wetted to near saturation for 24 h. They were then drained on ceramic pressure plates to a suction of 100 kPa for one week, after which penetrometer resistance and tensile strength were measured as described above. The degree of expression of aggregate coalescence depended on soil type. For the coarse-textured soil, repeated wetting and draining significantly increased bulk density, penetrometer resistance and tensile strength. For the fine-textured soil, penetrometer resistance and bulk density did not vary significantly with repeated wetting and draining; on the contrary, there was evidence in these swelling clay soils to suggest bulk density and penetrometer resistance decreased. However, there was a progressive increase in tensile strength as cycles of wetting and draining progressed. The expansive nature of the fine-textured soil appears to have masked the development of aggregate coalescence as measured by penetrometer resistance, but its expression was very clear in measurements of tensile strength despite the reduction in bulk density with successive wetting and draining.

Field observations have indicated that aggregate coalescence is first expressed at the bottom of the seedbed and that it develops progressively upward to the soil surface during the growing season. This suggests that overburden pressures may enhance the onset of the phenomenon by increasing the degree of inter-aggregate contact. Soils containing large quantities of particulate organic matter were known to resist the onset of aggregate coalescence to some extent. An experiment was conducted to evaluate the effects of soil organic matter and overburden pressures, by placing brass cylinders of various weights (equivalent to static load pressures of 0, 0.49, 1.47 and 2.47 kPa) on the top of dry soil aggregates (0.5 – 2 mm diameter) having widely different soil organic carbon contents placed in steel rings 5 cm high and 5 cm i.d. With the weights in place, the aggregates were wetted to near-saturation for 24 h and then drained on ceramic pressure plates to a suction of 100 kPa for one week. Bulk density, penetrometer resistance and tensile strength were measured when the samples were removed from the pressure plates and they all increased significantly with increasing overburden pressure in the soil with low organic matter content, but not in the soil with high organic matter content.

The amount of tillage used to prepare seedbeds influences the size distribution of soil aggregates produced – that is, more tillage produces finer seedbeds. The size distribution of soil aggregates affects the number of inter-aggregate contact points and this was thought to influence the degree of aggregate coalescence that develops in a seedbed. Previous work has shown that soil organic matter reduces aggregate coalescence and so an experiment was conducted to evaluate the effects of aggregate size and organic matter on the phenomenon. For soils with high and low organic matter contents, aggregate size fractions of < 0.5, 0.5 – 2, 2 – 4, and < 4 mm were packed into soil cores (as above) and wetted to near-saturation then drained to 100 kPa suction as described above. Penetrometer resistance and tensile strength were measured and found to increase directly with the amount of fine material present in the soil cores – being greater in the < 0.5 mm and < 4 mm fractions, and being less in the 0.5 – 2 mm and 2 – 4 mm fractions. In all cases, penetrometer resistance and tensile strength were lower in the samples containing more organic matter.

The rate at which soil aggregates are wetted in a seedbed affects the degree of slaking and densification that occurs, and the extent to which aggregates are wetted influences the overall strength of a seedbed. Both wetting rate and the extent of wetting were believed to influence the onset of aggregate coalescence and were thought to be affected by soil organic matter and irrigation technique. An experiment was therefore designed to separate these effects so that improvements to management could be evaluated for their greatest efficacy – that is, to determine whether management should focus on improving irrigation technique or increasing soil organic matter content, or both. The rate of wetting was controlled by spraying (or not spraying) soil aggregates (0.5 – 2 mm diameter) with polyvinyl alcohol (PVA). Samples of coarse- and fine-textured soils were packed into steel rings (as above) and subjected to different application rates of water (1, 10 and 100 mm/h) using a dripper system controlled by a peristaltic pump. Samples were brought to either a near-saturated state or to a suction of 10 kPa for 24 h, and then drained on a pressure plate at a suction of 100 kPa for one week. Measurements of penetrometer resistance and tensile strength were then made as described above. As expected, penetrometer resistance was lower in samples treated with PVA before wetting (slower wetting rates) and in samples held at a greater suction (10 kPa) after initial wetting (greater inter-aggregate strength). The effects were more pronounced in the coarse-textured soil. In both coarse- and fine-textured soils, tensile strengths increased with increasing wetting rate (greatest for 100 mm/h) and extent of wetting (greater when held at near-saturated conditions). The rate of wetting was found to be somewhat more important for promoting aggregate coalescence than the extent of wetting.

Because aggregate coalescence often occurs with little or no increase in bulk density, an explanation for the increase in penetrometer resistance and tensile strength is unlikely to be explained by a large increase in the number of inter-aggregate contacts. An increase in the strength of existing points of inter-aggregate contact was therefore considered in this work. For inter-aggregate bond strengths to increase, it was hypothesized that small increases in the amount of mechanically (or spontaneously) dispersed clay particles, and subsequent deposition at inter-aggregate contact points could increase aggregate coalescence as measured by penetrometer resistance and tensile strength. An experiment was devised to manipulate the amount of spontaneously dispersed clay in coarse- and fine-textured soils of high and low organic matter content. The degree of sodicity of each soil was manipulated by varying the exchangeable sodium percentage (ESP) of soil aggregates (0.5 – 2mm) above and below a nominal threshold value of 6. Dry aggregates were then packed into steel rings (as above) and subjected to wetting near saturation, then draining to a suction of 100 kPa for one week as described above. Measurements were then taken of penetrometer resistance and tensile strength, both of which were affected by ESP in different ways. In the coarse-textured soil, sodicity enhanced aggregate slaking and dispersion, which increased bulk density. While penetrometer resistance also increased, its effect on aggregate coalescence could not be separated from a simple effect of increased bulk density. Similarly, the effect of sodicity on aggregate coalescence in the fine-textured soil was confounded by the higher water contents produced by greater swelling, which produced lower-than-expected penetrometer resistance. Measurements of tensile strength were conducted on air-dry samples, and so the confounding effects of bulk density and water content were eliminated and it was found that tensile strength increased with sodicity in both coarse- and fine-textured soils. The presence of dispersed clay was therefore implicated in the development of aggregate coalescence in this work.

Finally, a preliminary evaluation of how the early stages of aggregate coalescence might affect plant growth was attempted using tomatoes (*Gross lisse*) as a test plant. Seeds were planted in aggregates (0.5 – 4 mm) of a coarse- or fine-textured soil packed in steel rings. These were wetted at a rate of 1 mm/h to either near-saturation (for maximum coalescence) or to a suction of 10 kPa (for minimum coalescence) and held under these conditions for 24 h. All samples were then transferred to a ceramic pressure plate for drainage to 100 kPa suction for one week. Samples were then placed in a growth-cabinet held at 20C with controlled exposure to 14 h light/day. Germination of the seeds, plant height, and number and length of roots were observed. Germination of the seeds held at near-saturation in both coarse- and fine-textured soils was delayed by 24 h compared with seeds held at 10 kPa suction. Neither the number nor the length of tomato roots differed significantly between the different treatments and soils. In the coarse-textured soil, however, the total root length over a period of 14 days was somewhat greater in the un-coalesced samples than in the coalesced samples, but this difference was not statistically significant. These results suggest that aside from delaying germination, aggregate coalescence may not have a large effect on early growth of tomato plants. However, this is not to say that detrimental effects may not be manifest at later stages of plant growth, and this certainly needs to be evaluated, particularly because aggregate coalescence increase with repeated cycles of wetting and draining.

In conclusion, the primary findings of the work undertaken in this thesis were:

- Rapid wetting of soil aggregates to near-saturation enhanced the onset of soil aggregate coalescence as measured by (in some cases) penetrometer resistance at a soil water suction of 100 kPa, and (in most cases) tensile strength of soil cores in the air-dry state. The rate of wetting appeared to be more important in bringing on aggregate coalescence than how wet the soil eventually became during wetting. This means reducing the rate at which irrigation water is applied to soils may reduce the onset of aggregate coalescence more effectively than controlling the total amount of water applied – though both are important.

- The literature reports that aggregate coalescence occurs in the field over periods of up to several months, involving multiple wetting and draining cycles, but the work here demonstrated that this can occur over much shorter time periods depending on conditions imposed.
- Aggregate coalescence occurred in coarse-textured soils regardless of whether the bulk density increased during wetting and draining. In finer-textured soils, the response to wetting conditions varied and was complicated by changes in bulk density and water content due to swelling.
- Small overburden pressures enhanced the onset of aggregate coalescence, but these effects were diminished in the presence of high soil organic matter contents.
- Finer aggregate size distributions (which are often produced in the field by excessive tillage during seedbed preparation) invariably led to greater aggregate coalescence than coarser aggregate size distributions. The effects of aggregate size were mitigated to some extent by higher contents of soil organic matter.
- Sodicity enhanced aggregate coalescence as measured by tensile strength, but when penetrometer resistance was measured in the moist state, the effects were masked to some extent by higher water contents generated by swelling and dispersion. This work suggests that tensile strength (in the air dry state) may be a more effective measure of aggregate coalescence than penetrometer resistance.
- Early plant response to aggregate coalescence was not large, but the response may become magnified during later stages of growth.

Statement

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference is made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Signed: .... Date: ....

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