A summary of recent experiments on soil moisture, germination and crop establishment

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Key findings

- Soil type has a large bearing on how sown crops respond to rainfall and the patterns of emergence across a paddock.
- Pot experiments and field trials conducted in 2023-2024 indicate seed can remain in dry soil for 4-6 weeks without reducing germination and emergence significantly.
- Approximately 15-20 mm of rainfall is required for emergence on a loamy soil type. Germination of sown seed can occur with smaller rainfall events, but seedlings may not emerge.
- Sowing deeper than normal into dry soil generally has not improved establishment. Sowing at standard or shallower depths will result in the best establishment rates.

Introduction

Soil water content is an important factor in the decision to sow, but often the question is how wet should the soil be before germination and emergence are assured. Understanding how water is held and released for plant growth in different soils can help explain the effects of rainfall on germination and emergence and how it varies with soil type. The information on this article is drawn mainly from pot and field trials conducted over the last two years that examined the influence of soil moisture on emergence and yield in canola and wheat.

Soil water basics

Not all soil water is equally available; its availability (or how tightly it is held by the soil) varies with soil moisture content and soil texture. Water is held within the pores of the soil and how tightly it is held depends on the size of the pore. As the pore size gets smaller, the water is held more tightly and is less available. Soils have a range of pore sizes, and as soil dries, a higher proportion of the water is held in small pores, meaning water is more tightly held by the soil and less available to plants. The major influence on pore size distribution is soil texture; whether the soil is sandy, a loam or a clay, and how compacted the soil is.

The measure of how tightly water is held within the soil is termed the 'matric potential' which has units of pressure (mega Pascals (MPa)). Matric potential is a negative number, and as the soil dries and the availability of water in the soil for plant growth declines, the matric potential becomes more negative. The matric potential of a saturated soil is close to 0 MPa, at field capacity the matric potential is -0.03 MPa and at permanent wilting -1.5 MPa. The laws of physics mean that water will flow down a water potential gradient, that is from a less negative matric potential (e.g. -0.1 MPa) to a more negative number (e.g. -0.5 MPa), which is the same principle that explains why water flows downhill.

The relationship between the soil water content and how available the soil water (the matric potential) is described by the water release curve. Examples of these curves for different soils in the lower and Mid North are shown in Figure 1. The water that is available for plant growth is defined by the moisture contents between the field capacity and the permanent wilting point. Some points to note are:

- Sandy soils require very little moisture to wet up to the available range, however, they cannot store a lot of moisture.
- As the clay content increases, the soil water content needs to be higher, hence more rainfall is required to wet it up to the available range.
- The red and black soils from Giles Corner, which commonly occur together, show different moisture release curves. As a result, the black soil needs a soil moisture content about 50% higher than the red soil to wet it up above the permanent wilting point.
- The two soils from Bute are representative of soils from a dune and swale. The very different water release curves means that germination and emergence will be slower and may be lower in the swale under low rainfall.

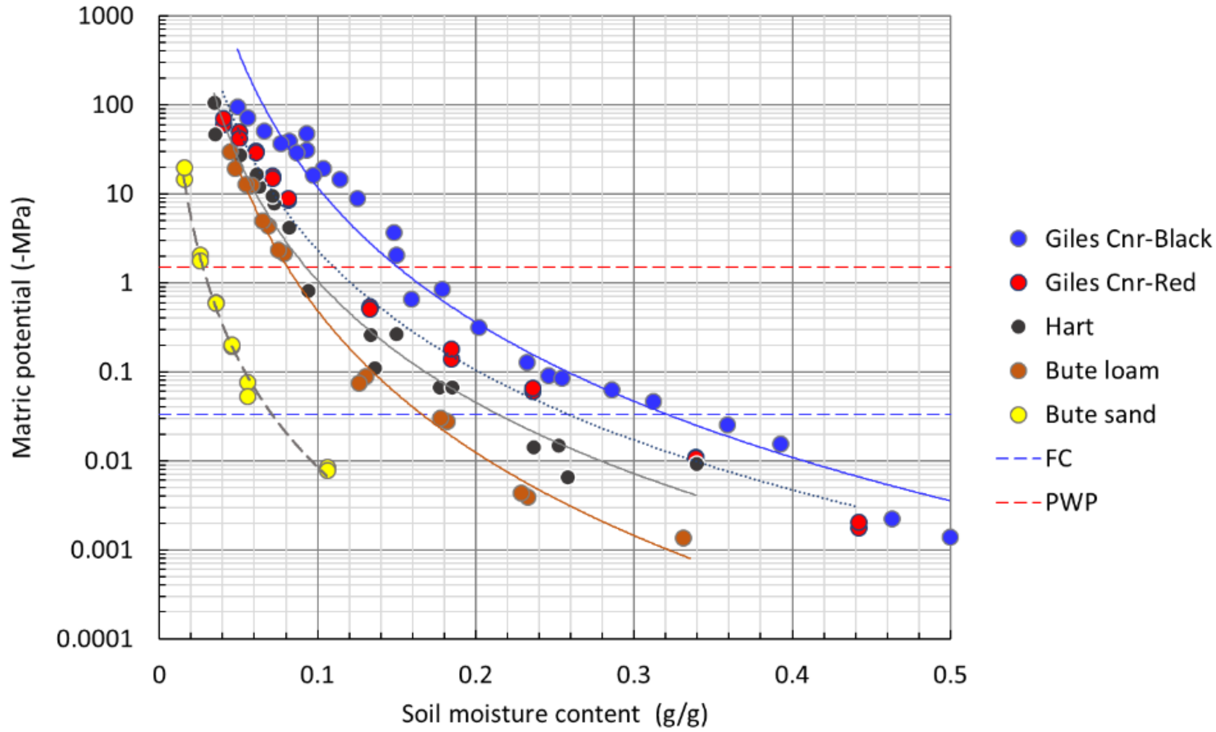


Figure 1. Soil water release curves for five soils with different textures. The field capacity (FC) and permanent wilting point (PWP) values are shown by the horizontal lines.

Can germination start in a dry soil?

Plants become stressed as the soil water content dries to permanent wilting point and plants can die from prolonged periods of very dry soil. Seeds are different; germination can occur even in soils close to the permanent wilting point (Figure 2). There are two reasons why this can occur:

- Dry seed has a very low water potential. A dry seed may have a water potential of -100 MPa while a soil at permanent wilting has a higher water potential (-1.5 MPa). Therefore, water will naturally move from the soil to the seed, even at permanent wilting point. This will occur even if the seed is dead.
- Seeds can absorb water as water vapour in the soil. In a very dry soil, for example: at permanent wilting, the relative humidity is close to 100% and dry seed can absorb water from the soil atmosphere even if it is not in direct contact with moisture.

Figure 2. Seed of Scepter wheat after three weeks in soil close to permanent wilting (top) compared to dry, unsown seed (bottom). The seed in soil has imbibed water, germination has started and the embryo has started to grow.

How does soil moisture affect germination and emergence?

The trigger for germination is the absorption of water by the dry seed, also called imbibition. As the seed absorbs water it goes through three distinct phases related to its seed moisture content (Figure 3).

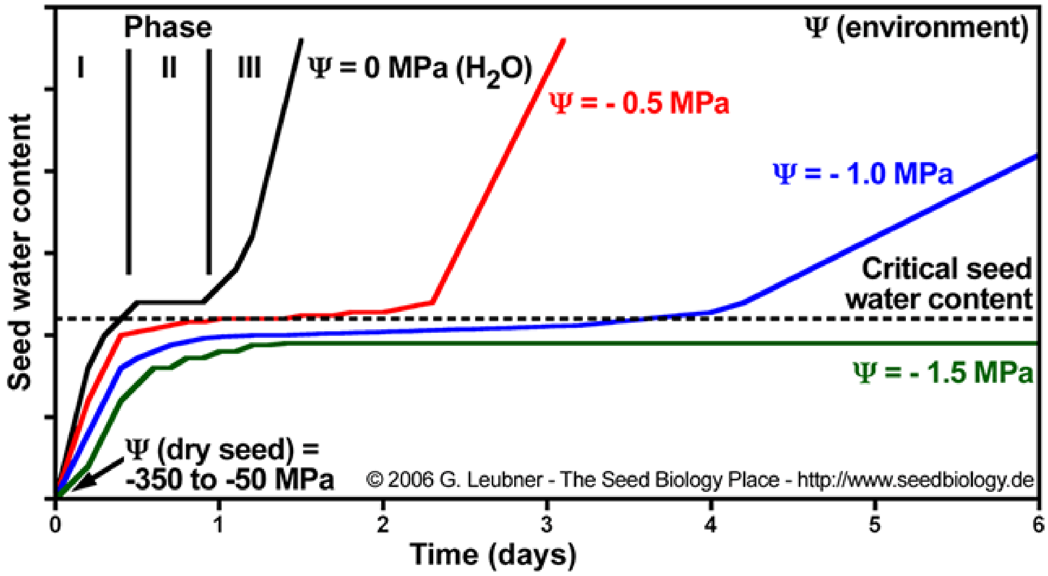


Figure 3. The uptake of water by a germinating seed. The three phases of water uptake are shown for a seed when water is not a limitation (black line, water potential = 0 MPa). As the soil becomes drier (red and blue lines, water potentials = -0.5 MPa and -1.0M Pa respectively) the rate of initial water uptake (Phase I) slows and the duration of Phase II increases delaying the growth of the root and shoot (Phase III). In dry soil (green line at the PWP, -1.5 MPa) the critical moisture content to allow complete germination and seedling growth is not reached.

Phase I is the rapid influx of water during imbibition. This occurs spontaneously in seeds even under very dry conditions. Water uptake slows when an equilibrium is reached.

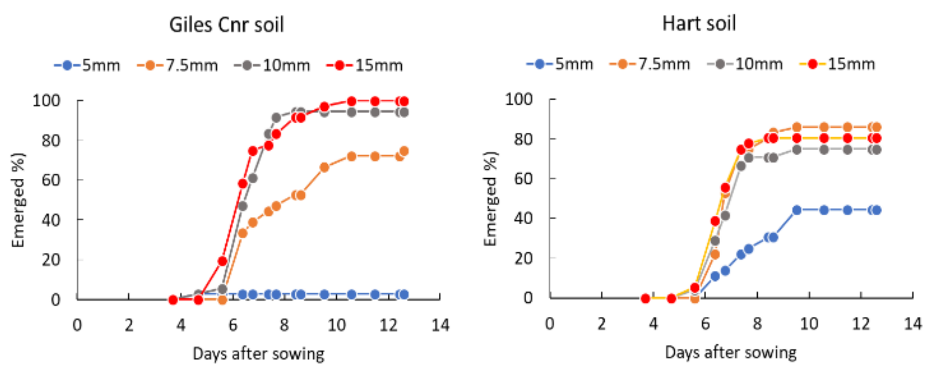
Phase II is the 'activation phase' when germination starts. The rehydration of the seed activates the enzymes that break down the seed food reserves, and the embryo starts to grow. The seed needs to reach a certain moisture content: the critical moisture content, for this to occur.

Phase III commences when the embryo in the seed expands and ruptures the seed coat causing uptake of water. During this phase the young root and shoot are clearly visible.

When seed is sown into dry soil, water is absorbed slowly and germination starts. Under these conditions, the length of Phase II is increased and the start of Phase III is delayed. In some circumstances the germinated seed remains in the soil swollen but the young root and shoot fail to grow (Figure 2).

Differences in soil moisture are reflected in the rates of emergence of seed from soil at different moisture contents (Figure 4). In drier soils, the time when emergence starts is delayed, the rate of emergence is slowed and the final emergence (%) can be reduced. Emergence may be staggered, with seedlings continuing to emerge 2-3 weeks after sowing. Soil texture has a large influence because it affects how tightly water is held by the soil particles. Compared to sandy soil, loams and clay loam soils require more rainfall to wet the soil up to the available range and low rainfall can have a larger effect on emergence from heavier textured soils. For example, when an equivalent of 5 mm of water was applied emergence failed in the heavy textured soil from Giles Corner in both canola and wheat whereas emergence occurred at Hart.

(a) Canola



(b) Wheat

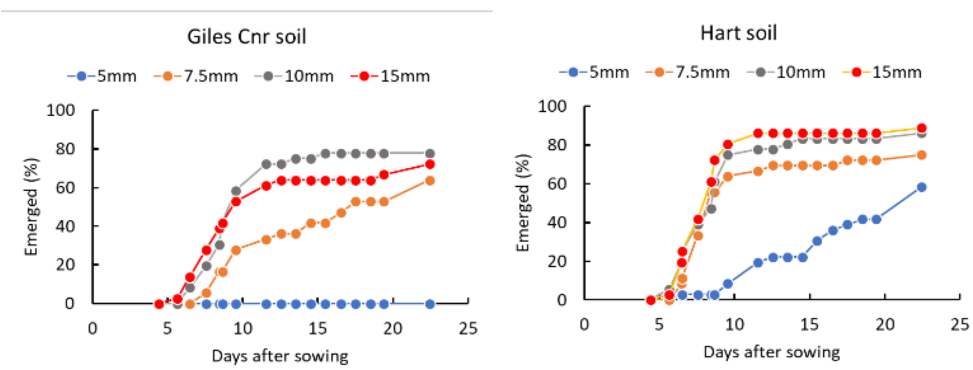


Figure 4. Results of a pot experiment showing emergence of (a) hybrid canola (Enforcer CT) and (b) wheat (Scepter) from two soils after different amounts of water were applied at sowing. The soil was from the surface 10 cm at each site. Soil from Giles Corner was a grey medium clay and the soil from Hart was a loam. In all cases evaporation from the soil was prevented to maintain a constant soil moisture content during germination. In the field higher rainfall would be required because of losses from soil evaporation.

How long can seed remain viable in dry soil?

We have seen that even in a dry soil, seed can absorb moisture from the soil, albeit very slowly, and cause germination to commence.

How long can seed remain in soil without affecting its viability? Experiments with canola and wheat found that seed can remain in dry soil for six weeks without significantly affecting emergence once the soil was watered (Table 1). In canola, there was an indication that emergence may have been enhanced when seed was in dry soil for two weeks.

In wheat more than 80% seed germination was measured for seed kept in dry soil for up to six weeks, however when seed remained in dry soil for four or six weeks a higher proportion of the germinated seed had not emerged after 2-3 weeks. Failure to emerge is not just related to seed gemination because the growth of the seedling through the soil before it emerges is also affected by soil moisture. Seeds may germinate but fail to emerge.

Table 1. The effect of length of time in dry soil on emergence (%) after watering in canola and wheat. The values are the averages across three soils. In wheat, seeds that did not emerge were recovered and classified as germinated but not emerged or not germinated.

	Time in dry soil (weeks)					
	0	**1**	**2**	**4**	**6**	Significance
			Canola			
Emerged	84^{ab}	75^{a}	90^{b}	71^{a}	79^{ab}	P=0.035
			Wheat			
Emerged	73	72	72	72	68	NS
Germinated, not emerged	13^{a}	13^{a}	10^{a}	16^{ab}	25^{b}	P=0.045
Not germinated	14	15	18	13	8	NS

How much rainfall is required for emergence?

If the soil is dry, pot experiments suggest 15-20 mm of rainfall is required to achieve maximum emergence in loam and clay loam soils. Little to no emergence would be expected if rainfall is less than 10 mm.

In sandier soils published data suggests approximately 10 mm may be sufficient for crops to emerge. Seed can germinate at lower soil moisture levels but may not emerge. An example is shown in Table 2 for hybrid canola.

Maximum establishment occurred with 15-20 mm, however all seed had germinated with as little as 7.5 mm of rainfall but had not emerged.

Table 2. The response in germination and establishment in hybrid canola to different rainfall equivalents in a loam soil from Hart. Seed was sown at 20 mm depth and was recovered 21 days after sowing.

Rainfall equivalent (mm)	Emerged	Germinated, not emerged	Not visibly germinated
		(%)	
5.0	0	43	57
7.5	0	93	7
10.0	3	97	0
12.5	37	63	0
15.0	67	33	0
20.0	63	33	0

Results from field experiments over two seasons illustrate the effect of soil type on soil water accumulation in the seedbed after rain (Figure 5). The loam at Hart was quicker to wet up and reached field capacity with less rainfall than the heavier soil at Giles Corner. At Hart 20 mm was required to reach the maximum soil water content whereas at Giles Corner 35 mm was required (Figure 5a). At Hart 15-20 mm of rainfall wet the soil up to field capacity whereas at Giles Corner there was insufficient rain received over the last two seasons to wet the soil completely to field capacity (Figure 5b).

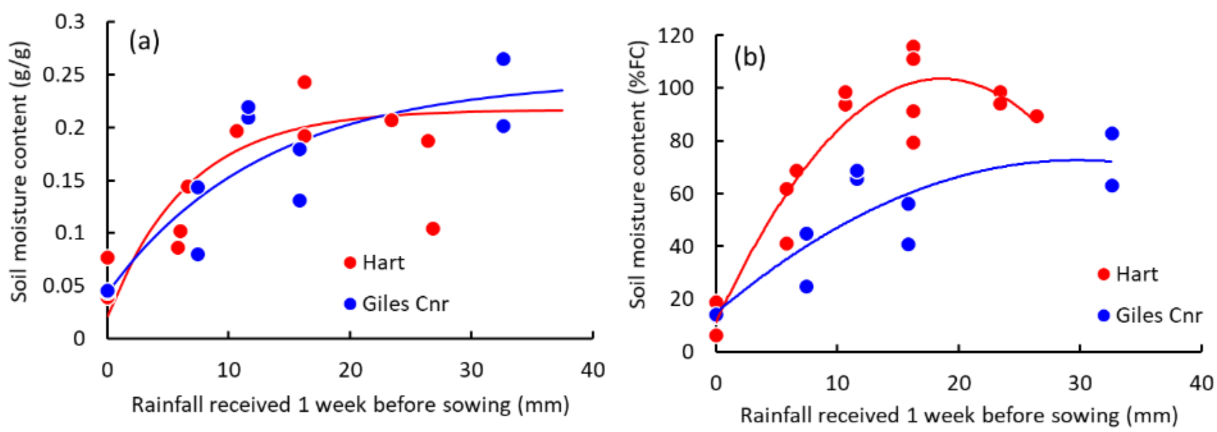


Figure 5. The relationship between soil moisture content in the surface 10 cm and rainfall received immediately prior to sowing from field experiments at two sites in 2023 and 2024. The soil at Hart is a loam and at Giles Corner a clay loam.

How important is sowing depth?

Unless it improves access to soil moisture, sowing deeply into dry soil will generally not improve establishment. Rainfall needs to infiltrate to the depth where the seed has been placed to allow seed to germinate quickly and for the seedling to grow through the soil to emerge. The rate of infiltration and the depth of initiation after rain are also influenced by soil texture: infiltration is more rapid with sandier soils and slower with heavier-textured soils. In a preliminary experiment using a column of surface soil from Hart, adding water equivalent to 5 mm rainfall resulted in water infiltrating to a maximum depth of 24 mm, while applying 15 mm resulted in infiltration to 71 mm. Additional water would be required when evaporative losses from soil are considered.

A field trial conducted in 2021 with OP and hybrid canola from the Victorian mallee demonstrated the penalty that can occur with deep sowing under low rainfall when there is no moisture at depth (Figure 6). There was little difference in emergence between sowing at 10 mm or 20 mm, however both were superior to a 35 mm sowing depth. Emergence of the OP variety Stingray occurred about 30 days after planting when approximately 10 mm of rainfall had been received but shallower sowing allowed emergence to occur after a smaller amount of rainfall. Emergence was earlier and occurred with less rainfall in the hybrid variety.

The observation that final establishment was high after the seed had been in dry soil for 29 days again shows that seed can survive dry conditions for long periods without greatly reducing seed viability.

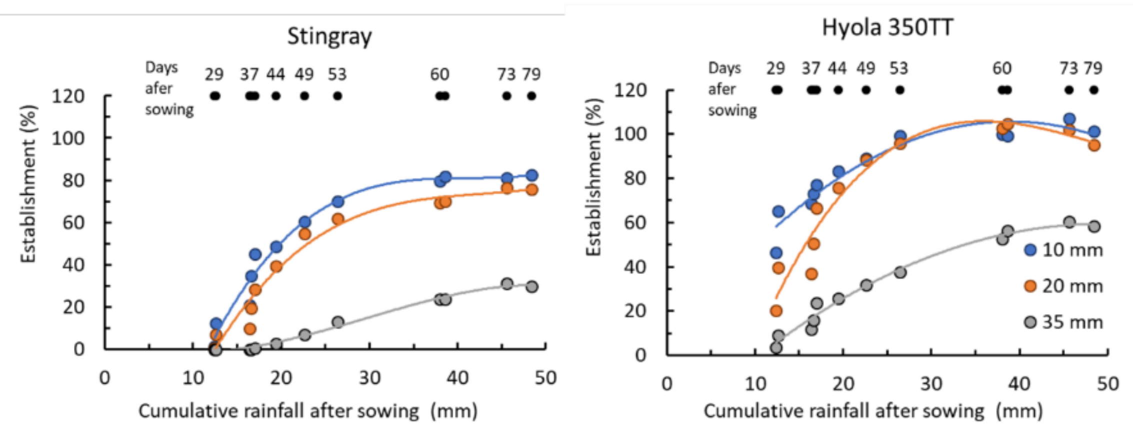


Figure 6. The responses to sowing depth in dry-sown Stingray (OP canola variety) and Hyola 350TT (hybrid canola). The experiment was conducted on a sandy-clay loam at a sowing rate of 50 seeds/m^2 and sown on April 19.

Surface structure

Emergence can also be restricted by physical barriers in the soil and high bulk density. Observations from the pot trials highlighted the importance of surface structure to emergence after low rainfall. In soils that are prone to slaking and dispersion, a hard crust can form as the surface dries after wetting. This can sometimes create a barrier to seedling emergence, which may already be slowed by the dry soil, causing further reductions in emergence. Maintaining good surface structure and minimising the potential to develop surface crusts are also strategies that can enhance emergence under dry conductions.

Acknowledgements

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