Coping with waterlogging in the high rainfall zones of southern australia

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How does waterlogging damage crops?

Effects on plants

A root system needs oxygen to grow and function. Under normal conditions, oxygen can move freely from the atmosphere to roots, where it is absorbed, but when soil becomes waterlogged, the soil becomes filled with water and gas exchange between roots and the atmosphere can no longer take place at a rate capable of maintaining their growth and function. As a result, nutrient uptake is reduced to low levels, water uptake is impaired (wilting will occur if conditions favour rapid water loss), and much of the root system may die. Because of the stress placed on the root system, levels of many hormones in the plant may alter and further affect growth.

During winter, plant growth rates, overall metabolism and the demand for mineral nutrients are low and waterlogging therefore causes few visible symptoms. In spring, with higher growth rates and increased requirements for nutrients, damage however, becomes much more obvious. In effect, the top of the plant grows in the absence of a functional root system (1). Growth is most likely to be limited by nitrogen because it is required in greater amounts than any other element. The plant responds to the deficiency by mobilising nitrogen from lower leaves to younger growing tissue and crops, as a consequence, appear a light yellow colour. Other elements, such as calcium and copper, cannot be mobilised within the plant in this way but must be absorbed from the soil continuously. For example, withertip in flax is actually a calcium deficiency induced by waterlogging and usually occurs in spring (2) while responses to copper in the southern Wimmera have been shown to be related to the incidence of soil waterlogging (3).

Effects on the soil

Denitrification is one of the first consequences of waterlogging in soil, a process by which bacteria starved for oxygen, utilise soil nitrate instead, by converting it to gaseous nitrogen, which is of no use to plants. If waterlogging occurs in soils rich in organic material suitable for growth of Micro-organisms, bacteria will strip oxygen from manganese and iron oxides as well and produce toxic levels of manganous and ferrous ions. In severe cases, hydrogen sulphide (rotten egg gas) may be formed. In addition, microorganisms may also produce various organic compounds which are toxic to plants. Observations to date suggest that while some mobilisation of manganese and iron is occurring during waterlogging in South West Victoria, toxic by-product formation does not appear to be a major cause of crop damage.

The interaction between soil structure and waterlogging

Many people visualise waterlogging as akin to adding water to a bathtub containing soil until it is full. This would be a correct analogy if soils were underlain by a completely impermeable layer. Most soils in south-west Victoria, however, are underlain by heavy clay subsoils that are not impermeable, but allow water to flow through at rates estimated to be 1 to 2 mm/day. The bathtub analogy is more correct, therefore if we have the plug out, allowing water to drain. Thus, it is a question of the balance between water being added and removed from the soil. When rainfall exceeds the drainage rate, the water table will rise, when it is less the water table will

fall. So, in fact, waterlogging consists of intermittent periods of saturation and drainage and we have found that the degree of damage suffered by crops is related to the ability of the soil to re-aerate during these periods of drainage. This is related to the soil's structure which again, is best illustrated by way of analogy. If you have a bathtub full of gravel, water can be removed quickly by pulling out the plug, and air

will replace the water previously surrounding the gravel particles. This is akin to well structured soils. If, however, you have a bathtub full of porridge, removing the plug (having first placed a filter in the plug hole) accomplishes nothing and like a poorly structured soil, no water drains out, and no air enters the porridge. Unfortunately, many soils in south-west Victoria fall into this latter category and much of the variability in crops and effects of wheel tracks, etc., can be explained in terms of soil structure and waterlogging damage.

Soil structure can be considered at two levels. Firstly, there are micro-aggregates formed by electrostatic forces acting between very small soil particles. If a soil contains an excess of singly charged ions (Na^+ and K^+) to a doubly charged ions (Ca^{2+}, Mg^{2+}), the micro-aggregates are not stable but disperse in water. Such soils respond to applications of gypsum which increase the amount of doubly charged calcium ions thereby stabilising the micro-aggregates. Secondly, the micro-aggregates are cemented together into larger aggregates by various organic glues produced by soil organisms. It is the spaces between these larger aggregates which are important for soil aeration and drainage.

In 1984 at Hamilton in South West Victoria, it was found that grain yield of wheat was reduced by 0.29 t/ha for each 1% decline in mean air-filled porosity of the surface soil during the 30 days prior to anthesis (4) and at Lismore in 1987, improving soil macrostructure resulted in a similar yield increase of wheat to that achieved by sub-surface drainage alone (unpublished results). Practices such as gypsum application and minimum tillage which improve or maintain soil structure, will thus reduce plant damage by decreasing the severity of waterlogging.

Nitrogen fertilisation

Nitrogen is the element needed in largest amounts by plants and is required throughout the growing season and a deficiency is a common feature of waterlogged crops. Amounts of nitrogen in the soil available to plants result from a dynamic interplay between soil reserves, environmental factors controlling the rate of their conversion (mineralisation), amounts added as fertiliser, plant and microbial uptake, leaching, denitrification and volatilisation. Crop requirement varies with growth stage and growth rate and deciding when and how much nitrogen to apply is a complex process and no simple recipe type answer is possible, however, the following guidelines may help.

1. The crop requires nitrogen throughout its life and in amounts related to its growth rate.

2. Nitrogen available in the soil is:

High in the first year following a clover based pasture and declines with successive years of cropping.

Is increased by warm, moist soil conditions such as occur in autumn.

Decreased by cold, wet conditions. Waterlogged soil results in denitrification and low levels of available nitrogen.

3. If a crop is deficient, its ability to respond to fertilisation is determined by:

(a) The amount of crop present, e.g., no crop, no response.

(b) The growth stage of the crop. Supplemental N will most affect those yield components which are vigorously growing at the time of application:

Growth stage	Effect of N
Sowing	Tiller number increased
Tiller production	Tiller survival
Ear initiation	
Spikelet production	Spikelets/ear
Floret production	Florets/spikelets
Grain set	Grains/ear
Grain growth	Grain weight

(c) Whether or not nitrogen is the sole factor limiting growth. If the crop is waterlogged, alleviating nitrogen deficiency may not result in improved growth. Similarly, if a moisture deficiency occurs, application of nitrogen fertiliser may result in decreased yield through haying off. High weed numbers may also reduce responses to nitrogen application.

In South West Victoria, consistent responses to nitrogen fertilisation were observed in experiments conducted during the 1930s and during 1983-85 (unpublished results). Nitrogen deficiency most commonly occurs in late winter and early spring when levels of available nitrogen are low as a result of denitrification due to waterlogging and slow rates of mineralisation while crop demand is appreciable as growth rates increase. Much of autumn applied nitrogen is lost during winter suggesting that strategic nitrogen applications in spring will be a better method of correcting the deficiency.

In reality, this is often not the case as crops are usually too advanced by the time waterlogging has ended and the soil dried sufficiently to permit side- dressing.

Placement of ammonium-type nitrogen (>10 cm) into the soil profile in autumn is showing promise in overcoming the problem. Under waterlogged conditions, ammonium-type nitrogen is not subject to denitrification processes and is also not leached (5). Crops treated in this manner have outperformed those receiving both conventional-autumn and spring-sidedressing nitrogen applications in trials in South West Victoria (6 and unpublished results).

Crop development pattern

There are several advantages in growing cultivars of longer season maturity type. Firstly, earlier sowing is possible, thereby reducing the risk of paddocks being too wet at seeding time. Secondly, the chances of achieving economic responses to side-dressed nitrogen in spring are higher (see above). Thirdly, later developing crops are better able to compensate for reduced growth and damage from waterlogging as more of their life cycle takes place after soil conditions have improved. Accordingly, we are investigating an "ideal" development type which can be sown early, grows slowly during winter (minimising nutrient demand from waterlogged soil) and grows vigorously in early spring with a rapid phase of stem elongation to flowering. In such a cultivar, most of the sensitive growth stages are delayed until waterlogging has ceased. An American wheat cultivar, Peck, which conforms to this ideotype, is presently being evaluated under commercial conditions and is showing promise, having performed well in several experiments (unpublished results). This development model also may explain the success of waterlogging tolerant pasture species such as Persian Clover.

Toadrush (Juncus bufonius)

Waterlogging favours the proliferation of several weeds, most notably Juncus bufonius (commonly known as toadrush or water grass). Considerable increases in pasture and crop production occur when it is controlled (7,8) and it must be regarded as major yield depressant on soils prone to waterlogging. Fortunately, it is readily and inexpensively controlled by several herbicides registered for use on field crops, although these are not commonly used in the traditional wheat belt.

Drainage

Drainage acts to directly reduce or eliminate the waterlogging problem. Measures range from sensible paddock selection for crop production, through strategically placed surface drains and surface drainage systems, to underground drainage systems. Paddock selection and strategic surface drainage are very effective and are fundamental to any farming system in high rainfall areas. In South West Victoria, surface drainage systems have had little impact on waterlogging as only excess surface water is removed and waterlogging still occurs to much the same extent. On sandy soils overlying unstable clays, surface drains to intercept lateral flow are of benefit (9), but they occupy an appreciable portion of otherwise arable areas causing losses in production and they incur considerable maintenance costs.

Subsurface drainage is the accepted answer to waterlogging in much of England, Continental Europe and America and appears a viable solution in Australia. Benefits are difficult to quantify experimentally as previously impossible farming systems can he implemented. By way of analogy, it is similar to comparing agricultural production pre- and post-mechanisation. Benefits from drainage are very substantial, and are likely to persist for more than 80 years.

Table 1. Yield of triticale and lucerne (1986/87) and wheat (1988/89) on drained and undrained land at Hamilton in South West Victoria

Yield (t/ha)	Triticale 1986/87	Lucerne 1986/87	Wheat 1987/88
Drained	4.6	5.6	4.0
Undrained	1.7	2.4	1.4
LSD (P<5%)	1.6	-	2.0

At Hamilton, yield increases in cereals of between 2 and 3 t/ha have been measured and lucerne produced well on drained ground whereas on undrained areas, it performed poorly and the stand died out (Table 1). Assessing returns to drainage should be calculated over a long time period, and where this has been carried out, it is clear that such investment is profitable even at much lower increases in productivity and profitability. An additional benefit is that approximately 50% of excess water which would otherwise recharge underlying groundwaters can be intercepted and discharged to streamlines by subsurface drainage systems (10).

When soils are permeable to water throughout the profile, adequate drainage can be achieved by placement of pipes (usually flexible, corrugated PVC) surrounded by a small quantity of permeable fill (gravel, sand, scoria, bark chips) at intervals (20 to 80 m) through the area. More commonly, soils are underlain by relatively impermeable subsoils and artificial fissuring of this must take place to expedite the flow of water to the piped drains. This fissuring may be achieved by subsoiling or more often, by mole-ploughing. The most important factor influencing drainage design in permeable soils is the actual degree of soil permeability and the depth to which the pipes can be laid. Where subsoils are relatively impermeable, slope become the critical determinant of pipe spacing, and thus cost. Pipes are laid using either trenching or trenchless methods with laser control of grades whenever this is less than 1%.

In Victoria in 1988/89, approximately 50,000 m of drainage pipe was installed on farms in high rainfall areas and it is expected that more than triple this amount will be laid in 1988/89.

The costs of drainage can be apportioned approximately as follows: PVC drainage pipe - \$0.65 (65 mm) to \$1.50 (100 mm)

Backfill @ \$20/m^3 and 0.03 to 0.05 m^3/m of pipe = \$.60 to \$1/m of pipe Machinery and contractor costs = \$2 to \$3/m

Total costs/m = \$3.25 to \$5.50

Assume an average cost of $4.40/m

If a drainspacing of 60 m is required, this is equivalent to $733/ha. If main collector drains are also required, an allowance of 30% should be made, making a total cost for the system of $953/ha. This expenditure is fully tax deductable in the year it occurs.

Summary

The incidence of waterlogging can be reduced or eliminated by draiange but where this is not practicable, its effects can be mitigated by improving soil structure, strategic application of nitrogen fertilisers, use of longer season and late developing cultivars and by controlling Juncus bufonius.

References

1. Trought, M.C.T. and Drew, M.C. 1980. Plant and Soil 56 187-99.

2. Millikan, C.R. 1944. Vic. J. Agric. 42 79-91.

3. Flynn, A.G. and Gardner, W.K. 1987. Proc. 4th Aust. Agron. Conf., Melb. p. 265.

4. McDonald, G.K. and Gardner, W.K. 1987. Aust. J. Exp. Agric. 27 661-70.

5. Reddy, K.R. and Patrick, W.H. 1984. CRC Critical Reviews in Environmental Control 13(4) 273-309.

6. Gardner, W.K. and Fulton, M. 1987. Proc. 4th Aust. Agron. Conf., Melb. p. 241.

7. Reeves, T.G. 1969. Aust. Weed Res. Newsl. 13 24-5.

8. Avery, J.C. 1985. Proc. 3rd Aust. Agron. Conf., Hobart, p. 358.

9. Cox, J.W. and Negus, T.R. 1985. WA J. Agric. 26(4) 126-7.

10. Gardner, W.K., Carter, J. and Noonan, B. 1989. Proc. 5th Agron. Conf., Perth.