Managing Crops for Excess Water Stress

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A review of literature on the effect of mid-season excess moisture on a growing crop was conducted to understand the processes affected by excess water and to quantify the impact on crop yields.

The soil and crop environment is affected by excess water through the depletion of oxygen, leading to reduced root respiration and other vital plant processes, as well as the production and accumulation of phytotoxic compounds, such as ethylene, in plant roots and soil. Saturated soil conditions change the soil's redox potential, favouring loss of nitrogen and production of ions that are toxic under certain soil conditions. These factors combine to hamper plant growth and cause significant yield losses. Manitoba Crop Insurance data from 1965-1972 revealed that clay soils subjected to excess precipitation in July experienced the highest yield loss (2-6 bu/ac/day) for barley, oats, wheat and flax.

Crop tolerance and adaptation to waterlogging is plant species dependent. Plant roots and shoots can adapt to short term reductions in oxygen levels by lowering respiration rates and slowing growth of shoots. Supplemental nitrogen fertilizer can offset a portion of the yield losses due to excess water because nitrate can act as a secondary source of oxygen for the plant. Prolonged exposure to excess water creates symptoms similar to those experienced by crops under drought conditions. In terms of relative crop tolerance for cereal crops, oats > wheat > barley; for pulse crops, fababeans > soybeans >>> field beans > peas; for forage crops, grasses > legumes, with reed canarygrass ≥ timothly > orchardgrass; and birdsfoot trefoil > alfalfa. The degree of impact excess water has on yield emphasizes the importance of improved field drainage and proper crop selection.

Introduction

The scope of the paper is to identify the effects of mid-season excess moisture, rather than the effects of early-season moisture excess and delayed seeding. The primary means of dealing with excess moisture – enhanced field drainage – will not be discussed in this paper.

Review of Literature

There are several factors that influence the magnitude of impact excess water stress has on growing crops, including: soil type, plant species, plant growth stage, temperature, day length and duration of the stress.

Under conditions of excess water, it is the lack of oxygen (O_2) that changes the soil and crop environment. Oxygen diffuses in water 10 000 times more slowly than in air, resulting in changes in nutrient availability and microbial activity, reduced plant respiration and energy production and the accumulation of compounds in roots and soil that may become toxic to plants.

Like oxygen, carbon dioxide (CO_2) and ethylene (C_2H_4) gases diffuse more slowly through water than through air, and accumulate around plant roots as a result. Ethylene is a root growth inhibitor with varying effects on different crops. Barley, which is highly sensitive to ethylene toxicity, experiences root death at relatively low concentrations. Several other crops will respond to a buildup of ethylene by initiating survival mechanisms, such as production of secondary roots and upward growth of roots in search of oxygen. Potatoes respond to ethylene by increasing the size of their tuber pores (lenticels) for increased air exchange. Legumes are indirectly affected by ethylene through its inhibition of N-fixing rhizobium formation and function.

To better understand the magnitude of the impact excess water can have on crop yield, Rigaux and Singh (1977) examined Manitoba Crop Insurance data from 1965-1972 for wheat, barley, oats and flax. They compared yield change (bu/acre/day of excess water stress) with soil texture and the month in which the excess water stress occurred (Table 1). It was found, for all four crops, that the largest negative impact on yield was the result of excess water stress on clay soils during the month of July (loss of 2-6 bu/ac/day). Excess water stress is greatest under conditions of rapid respiration, which usually occurs in July, and on soils with smaller drainable pore space (ie. slower hydraulic conductivity), which is characteristic of clay soils. By contrast, excess rainfall in May on some soils could result in yield increases for all crops.

Table 1. Yield response of crops to excess rainfall on different soils – MCIC Data 1965-72. (Rigaux and Singh, 1977).

Soil texture	CLAY	CLAY LOAM	SAND LOAM	SAND
	Yield change – bu/ac/day			
Wheat				
May	+5.5	0	+1.5	0
June	-3	-0.5	+1	+1.5
July	**-4**	+1	0	**-2**
August	-1	+1.5	+1	-0.25
Barley				
May	+2.5	0	+1.5	0
June	-3	-0.5	0	+1
July	**-6**	+0.75	-1	-0.25
August	-3	-0.5	0	+0.5
Oats				
May	+7.5	0	+1.5	+8
June	+1	-1	+2	0
July	**-5**	+1	0	-1
August	-2	+0.5	+2	0
Flax				
May	+2	+0.5	+1	+6
June	+1.5	-0.25	+0.5	-0.25
July	**-2**	+0.5	0	-0.25
August	-0.5	-0.25	+1	-0.25

Early waterlogging may cause severe plant mortality but allows greatest opportunity for crop recovery and compensatory growth (Table 2).

Table 2. Relative stand and yield of winter wheat flooded for 6 days between germination and emergence (Cannel et al, 1980)

	Control	**Flooded for 6 days**
Crop Stand	100%	10%
Yield	100%	82%

Although soil texture has an influence on water holding capacity and hydraulic conductivity, the internal drainage of the soil is more important than texture as an indicator for soils most susceptible to conditions of excess water. In soil survey reports, soil series designated as having "poor" or "imperfect" drainage are those soils found in lower positions in the landscape and are more likely to experience saturated or reducing conditions. Furthermore, soil series most likely to experience excess water conditions will be designated with a wetness modifier "W" in their agriculture capability rating. While many medium and heavy textured soils in low-lying areas will have a wetness modifier in their ag capability rating (eg. Red River series = Class 2W), poorly drained sands that also have low water holding capacity ("M" modifier) may have both modifiers in their designation (eg. Pelan = Class 3MW). These soils have additional limitations in that they may be too wet after heavy rains, but they can rapidly become too dry during periods of limited rainfall to support crop growth. As a result, it is important to consider soil properties (texture, drainage, ag capability & limitations) when assessing risk and making crop management decisions (Canada-Manitoba Soil Survey, detailed soil survey reports).

Poorly drained soils that are saturated most of the time tend to have blue, green and grey colors in their subsoil due to reducing conditions. Under these conditions, the gain of electrons by iron (Fe) and other elements results in the above colors. By contrast, imperfectly drained soils that are saturated only periodically tend to have similar spots of color throughout their subsoil, but the colors are red and orange. Here, iron and other elements have lost electrons to oxygen, as conditions predominately favor oxidation.

For respiration to occur efficiently, sugars must be oxidized by the plant, using O_2 as the preferred electron acceptor, to produce energy. If no O_2 is present, there is a 95% reduction in the amount of energy produced from each sugar molecule; as a result, most of the plant's growth processes are impaired. To a limited extent, nitrate (NO_3^-), manganese (Mn), iron and sulfate ($SO_4^=$) can act as electron acceptors (listed in order of decreasing preference). This is why added nitrogen fertilizers may partially overcome yield losses associated with waterlogged crops (Tables 3 and 4).

Table 3. Relative wheat yield under waterlogging treatments. (Watson et al, 1976)

	No Nitrogen		**90 lb N/ac**	
N status	Intermittent waterlogging	Continuous waterlogging	Intermittent waterlogging	Continuous waterlogging
June 19	49	31	103	72
July 17	64	54	103	76
August 21	73	64	129	93
No flooding	100		142	

Table 4. Effect of Soil Water – Soil Oxygen Stress on Navy Beans (1974-75). Robertson & Frazier (1982).

	Yield	**(lb/ac)**
Treatment	**0 lb N/ac**	**60 lb N/ac**
No irrigation (water stress)	1500	1710
Optimum irrigation	2290	2795
Excessive irrigation (O_2 stress)	1955	2475

Reduction of nitrate to nitrous oxide (N_2O) and nitrogen gas (N_2) can result in N fertilizer losses of 2-4 lb/ac/day when soil temperatures are greater than 5^oC. Reduction of Fe^{3+} to Fe^{2+} and Mn^{4+} to Mn^{2+} may be toxic to plants on acid soils. On soils high in carbonates and/or soluble salts, Fe chlorosis may be a problem for flax and soybeans.

The ability of different plant species to tolerate low O_2 levels is due to several mechanisms of plant adaptation, including lowered respiration rates of roots and changes in metabolic pathways to produce less toxic end products, such as malic acid rather than the more toxic ethanol. Roots may adapt to lower O_2 levels through the development of interconnected airspaces within the roots (aerenchyma) or by producing replacement roots. The development of aerenchyma in roots of species such as rice and corn results in a lower root respiration rate and lower resistance to air movement from the shoot. In corn, aerenchyma formation is accelerated by ethylene production. The production of replacement roots, which grow in well-aerated surface soil, does not guarantee plant survival, in that roots developed this way still need O_2, and these roots tend to grow horizontal rather than vertical, so these plants are shallow rooted and more susceptible to later season drought.

Plant shoots adapt to excess water stress by slowing overall growth – stem elongation still occurs, but plants do not fill-in. The senescence and abscission of older leaves takes place, often remobilizing mobile nutrients such as N to younger tissue. Rapid closing of stomata reduces water loss and minimizes “drought” symptoms, such as wilting.

General tolerance periods for excess water stress varies according to plant type. Most annual crops can tolerate 3-7 days of water stress; forage legumes tolerate 9-14 days of water stress; forage grasses can tolerate excess water for 10-49 days. However, it is important to remember other factors that can influence the tolerance period, such as soil type, plant species, soil temperature, etc. For example, after establishment, winter cereals can tolerate several weeks of waterlogging during periods of low temperature with comparatively small losses in grain yield (about 15%). However, corn can tolerate excess water stress for only 24 hours when soil temperatures are greater than 24^oC (Verhallen & Tenuta, 2001).

Relative crop tolerances to excess water stress vary according to plant species. Part of these differences may be due to varying levels of resistance to disease, while most of the differences are due to physiological characteristics. For cereal crops, oats are the most tolerant of excess water stress, followed by wheat and then barley. Barley plants are particularly vulnerable in the 5-8-leaf stage, because head formation is initiated at the 5th leaf stage and waterlogging decreases pollen viability.

For pulse crop tolerance to excess water stress, fababeans>soybeans>>>field beans>peas.

Table 5. Effect of water stress on peas at different growth stages (Cannel et al, 1979).

Treatment	Relative Yield
Control (non-flooded)	100%
Waterlogged for 5 days @ 4-5 leaf stage	48%
@ 6-7 leaves (pre-flower)	7%
@ 9-10 leaves (flowering)	25%
@ pod filling	42%
**Waterlogging for 2 days had little effect on yield*	

With forage crops, grasses are more water tolerant than legumes; of the legume forages, birdsfoot trefoil is more tolerant than alfalfa; for grass forages, reed canarygrass is most tolerant, followed by timothy and then orchardgrass.

Sometimes the amount of excess water stress is tempered by the ability of the soil to store rainfall without becoming waterlogged. Figure 1 compares typical water use from various crops (from June – August) with rainfall events from Carman in 2001.

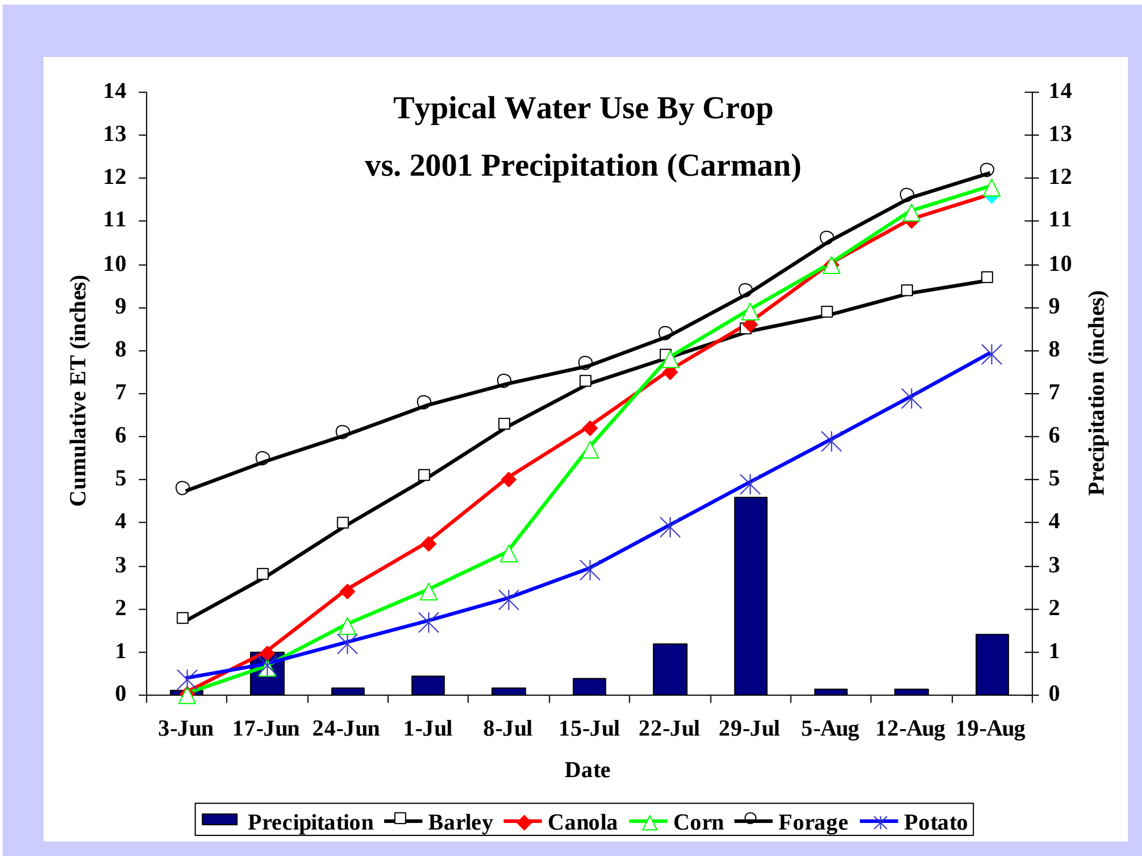

Figure 1. Typical Water Use By Crop vs. 2001 Precipitation at Carman

From this it is obvious that the same amount of water received on different crops would produce differing levels of saturation, and hence aeration stress. Potatoes would be expected to use less water than corn, and so already have more water filled pore space than most crops. However, the water storage capacity in soil only explains a portion of differences in crop tolerance to waterlogging. Consider the following:

- Plants at the seedling and early vegetative growth stages have not consumed as much soil water – so soils may waterlog sooner with less rainfall. In addition, due to the lower oxygen demands from plants at this growth stage, soil oxygen depletion is slower, soils are cooler, and root biomass is smaller.

- Larger plants at flowering stages have used up much more soil moisture so the soil can absorb more water before approaching waterlogging. These plants are photosynthesizing and respiring at their greatest rates and have the greatest need for water – which cannot be moved to the shoots under waterlogged conditions. Furthermore, soil oxygen depletion is at a rapid rate – large root biomass and warm soil temperatures encourage microbial respiration

As a result, high water use crops may be more buffered against the negative impacts of late-season rainfall events than low water use crops. However, once the soil becomes saturated, high water use crops will be negatively impacted more quickly and at a larger magnitude that low water use crops.

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