MICRONUTRIENTS - ARE THEY IMPORTANT UNDER WATERLOGGING?

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Background

Waterlogging can affect both the availability of micronutrients in the soil and the plant's ability to absorb nutrients from the soil. Together, these effects alter the nutrition of plants and consequently the productivity of crops. Waterlogging generally increases the availability of iron and manganese in the soil, but total plant levels sometimes decline because the roots cannot function efficiently when they are stressed for oxygen. Waterlogging generally decreases the soil availability of zinc and copper, and plant tissue concentrations of these micronutrients generally decline under waterlogging. However, concentrations of copper and boron may remain constant, decrease or increase under waterlogging. For example, in a waterlogging experiment on cotton at Narrabri in Jan.1987, when siphons were run for 32 h instead of 4 h per irrigation, the uptake of Zn, Mn and Fe was reduced by 28%, 15% and 8%, respectively. However, Cu uptake increased by 14%.

The special case for iron

Iron nutrition is complicated. The chemical form of Fe is most important, and this causes problems with tissue tests for diagnosis. The standard test measures total Fe content, which very often is misleading. It is the active Fe (Fe^{2+}) component of total Fe that is critical for Fe nutrition of plants, and this is a difficult quantity to measure routinely or commercially. The major problem is the need to digest fresh plant tissue within a few hours of sampling. This poses immense logistical problems for commercial laboratories. However, the importance of measuring active iron has been demonstrated many times by other researchers. When plants lack Fe, the young leaves become yellow in the areas between the veins. The veins usually remain green, unless the deficiency is severe, in which case the veins also go yellow, and the whole leaf can eventually turn white. The total Fe content of chlorotic leaves is often similar or higher than green leaves, which could mislead an observer to conclude that a deficiency of Fe is not the problem. However, when active Fe levels are determined, the opposite conclusion is frequently reached!

Iron research at Narrabri

Initial interest in Fe nutrition at Narrabri started several years ago during waterlogging studies of irrigated grain legumes. Some of the species tested are highly sensitive to waterlogging, and showed classic Fe deficiency symptoms of young leaves following furrow irrigations. Painting the yellow leaflets with a ferrous sulphate solution regreened them within 2-3 days. The symptoms were similar to the yellowing of young cotton leaves, which commonly follows the first 2-3 crop irrigations.

In the first experiments, foliar sprays of Fe chelates were applied to crops either after heavy rain or just before furrow irrigations. Despite burning of leaves at heavy rates, encouraging responses to 200g Fe ha^{-1} sprays were recorded (Table 1). A single spray before the first irrigation at Auscott in 1988-89 increased lint yield by 6%, whereas two foliar sprays on Oakville increased yield by 11%. In 1989-90, foliar sprays changed yields by 1% at Myall Vale and 2% at Oakville, whereas soil application before sowing increased yields by 5% and 6%, respectively. In commercial test-strips conducted by Stuart Murray in 1989-90, responses to three foliar sprays of 200 g Fe ha^{-1} were 5% and 16% on Doreen and The Myalls, respectively. These responses to Fe gave an average return of \$90 ha^{-1} when costs of Fe fertilizer and application were subtracted from the extra lint yield, valued at \$1.60 kg^{-1}. The soil treatments were not cost-effective.

More spectacular results with grain legumes at Breeza were recorded by Hodgson, Holland and Rogers in 1989-90. Soil applications of 20 kg Fe ha^{-1} increased grain yields of soybean by 10% and pigeon pea by 456%. Foliar application of 200 g Fe ha^{-1} increased respective yields by 9% and 10%. High correlation between early season dry weight of shoots and active Fe levels of soybean were also found (Fig. 1). Importantly it was observed that iron deficiency delayed the time to flowering of pigeon peas by a few weeks; this delay would be important if it occurred in cotton.

Interaction between iron and lime

The cracking clay soils of northern N.S.W. are often described as being calcareous, or containing moderate levels of lime (calcium carbonate). Soil pH is usually alkaline. Both of these properties predispose the soil to deficiencies of nutrients such as Zn and Fe. In the case of Fe, a high content of soil lime can saturate the soil solution with **bicarbonate** ions. When plants absorb high concentrations of bicarbonate, the pH of leaf tissues rises, and the Fe is rapidly converted from the active (Fe^{2+}) to the inactive form (Fe^{3+} and others). For each unit increase in pH, the availability of Fe decreases

100-fold! Thus, although the plant might contain high concentrations of Fe, most of it will be unavailable for use in producing chlorophyll, and the leaves lose their green colour. These symptoms have frequently been reported on calcareous soils of Europe, such as in vineyards, and the syndrome is referred to as **lime-induced iron chlorosis.**

For this reason and others, the practice of applying lime to our calcareous soils as a source of calcium is not recommended. Gypsum would be a much better source. One disadvantage of using lime is that it is only slightly soluble in these soils anyway - that is why we see lime nodules below the 0.2-0.3 m depth of these soils in the natural state, because lime is coming out of solution since there is so much of it there! The other reasons are those of lime-induced iron chlorosis and similar effects on Zn availability. I have heard of cotton farmers who apply lime and also apply micronutrients, including Fe and Zn. This is a vicious circle where one practice of doubtful value is necessitating another, both costing the farmer money!

In experiments at Narrabri in 1989-90, the application of 5 t ha^{-1} of lime to cotton decreased photosynthesis of young leaves by 16%, whereas applying Fe increased photosynthesis by 24%. Both treatments did not significantly affect lint yield, but the short-term implication was obvious. If lime was applied regularly over several seasons, I would expect more severe damage to the crop and lower yield. Conversely, regular application of foliar Fe would probably be more effective in increasing yield than the two early applications in this experiment. In three other experiments in 1989-90, where lime was applied, no increase in yield was observed.

Interaction between iron and waterlogging

When a soil is waterlogged, not only the passage of oxygen into the soil is blocked, but the passage of carbon dioxide out of the soil is also blocked. The trapped CO_2 builds up in concentration and dissolves in the soil solution, forming bicarbonate ions. This accentuates the effect of a high lime content, leading to alkaline leaf tissue, Fe unavailability, and chlorosis. This is why the effects of iron chlorosis are clearest after waterlogging of these soils, although the deficiency may still occur at a lower level of damage when the soil is not waterlogged.

In an experiment on respiration of the cracking clay at Myall Vale, we observed that negligible CO_2 was evolved from waterlogged soil cores into chambers surrounding the cores. When we injected CO_2 into the chamber atmosphere, the injected CO_2 was rapidly depleted, presumably entering the soil solution and forming bicarbonate! This soil appears to have a propensity for forming bicarbonate ions, and hence the associated physiological disorders mentioned above.

Interactions between iron and other nutrients

It is well documented in the scientific literature that iron availability is lowered by the presence of P and Zn. In an experiment on soybean at Breeza in 1989-90, we found negative interactions between applied Fe and Zn and between Fe and P (where adding both was worse than adding each alone), and a positive interaction between Fe and lime (where adding both was better than adding each alone) on early-season dry matter production. The reasons for these interactions are as follows. Antagonism between Fe and Zn results from competition for uptake sites on plant roots. Soluble P tends to react with soluble Fe to form iron phosphates, rendering the Fe unavailable. When lime is applied, the plant tends to become deficient in available Fe, thereby increasing its responsiveness to applied Fe.

Conclusions

These experiments and observations have confirmed that Fe deficiency occurs in the cracking clays of northern N.S.W., and that the problem is accentuated by waterlogging from either heavy rainfall or furrow irrigation. The problem is therefore not restricted to irrigated crops, and experiments are already underway on other species including wheat to determine the importance and extent of the problem. More expertise on methods of application and refinement of optimum rates is required. I suggest farmers may find these answers before researchers, so some feedback from the industry will be sought from those who apply Fe to their crops in the near future.

Acknowledgements

This is the first time that Fe deficiency has been demonstrated on the cracking clays of northern N.S.W., and the first plausible explanation of the cause of the chlorosis associated with waterlogging of many crops in the area. I thank my co-workers John Holland, Donald MacLeod and Liz. Rogers, my students from U.N.E. Susan Forsell and Ivan MacLeod, my part-time assistants and the farm staff at Narrabri and Breeza, the Cotton Research Council and the National Irrigation Research Fund.

Table 1. Summary of results from applying iron in field experiments and commercial test strips, including relative and absolute yield responses, costs of treatment, value of returns and estimated profit.

Treatments	Yield increase %	Yld increase kg ha^{-1}	Costs \$ ha^{-1}	Return \$ ha^{-1}	Profit \$ ha^{-1}
Field experiments					
Auscott '88-89 foliar 200 g Fe ha^{-1} x 1	6	127	48	203	155
Oakville '88-89 foliar 200 g ha^{-1} x 2	11	190	53	304	251
NARS '89-90 foliar 200 g Fe ha^{-1} x 2	1	6	40	10	-35
Oakville '89-90 foliar 200 g ha^{-1} x 1	2	28	20	45	25
Average	5	88	40	141	99
NARS '89-90 soil 5 kg Fe ha^{-1} x 1	5	59	384	94	-290
Oakville '89-90 soil 5 kg Fe ha^{-1} x 1	6	69	1076	110	-966
Average	6	64	730	102	-628
Test strips					
Doreen '89-90 foliar 200 g Fe ha^{-1} x 3	5	96	144	154	10
The Myalls '89-90 foliar 200 g ha^{-1} x 3	16	175	144	280	136
Average	11	136	144	217	73

Costs include the cost of Fe plus \$5 per application. Returns assume \$1.60 kg^{-1} lint.

Figure 1. The increase in soybean dry matter relative to active iron levels of youngest mature leaf tissue on 31 Jan. 1990.