Summary

Zinc (Zn) and manganese (Mn) deficiencies occur on many soils of the wheatbelt. Applying trace element fertilisers can alleviate the problem but these are not always effective. There is a need to improve the ability of cereals to grow on soils with low available Zn and Mn. This project screened cultivars, breeding lines and genetic populations from national cereal breeding programs on selected Mn and Zn deficient soils. The outcomes of the work were:

- the Mn and Zn efficiency of advanced lines of wheat, barley and triticale were characterised and the information incorporated into fact sheets.
- the Mn screening resulted in the identification and release of a Mn-efficient barley cultivar, Maritime.

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Conclusion

The work clearly demonstrated that there are significant levels of genetic variation for micronutrient efficiency within the current germplasm used by the wheat and barley breeding programs in southern and western regions. This indicates that it is feasible to select for improved micronutrient efficiency in the breeding programs.

Varieties of wheat from the South Australian (SA) wheat breeding programs that have shown quite good broad adaptation tended to have a reasonably high level of Zn efficiency, suggesting that this may be a trait contributing to the success of the variety. Similarly, many of the barley varieties tested from the Western Australian (WA) program have had a reasonably high level of Mn efficiency. However, there is no consistent level of Zn efficiency within any of the breeding programs and genotypes showing a range of efficiencies have been developed.

Durum wheat is particularly sensitive to Mn and Zn deficiencies and the range in genetic variation for micronutrient efficiency appears more limited than in bread wheat. The most efficient durum wheat genotypes are still at the lower end of the range for bread wheat. The poor micronutrient efficiency of durum wheat may limit the productivity of the crop in parts of the southern and western regions where Zn and Mn availability in the soil may be low.

Based on the responses observed in these trials, yield increases of 2-5% may be expected from the use of an efficient genotype where micronutrient nutrition is marginally deficient. This will increase as the severity of the deficiency increases. Yield responses of 50% or more may occur under severe deficiency.

The reliability of field screening depends on the consistency of nutrient deficiencies developing during the growing season. The more reliable and consistent results from screening for Mn efficiency were due to the severity of Mn deficiency that developed each year at Marion Bay, SA. In contrast, the severity of Zn deficiency varied considerably from year to year, making reliable field screening difficult. Seedling bioassays for Zn efficiency are available and predict the field performance of genotypes and should probably be the focus of future screening work, with field testing used to verify the rankings of genotypes.

Screening for micronutrient efficiency can result in the development of improved genotypes. This was demonstrated in the current project by the identification and subsequent release of the barley variety, Maritime. Previous work on screening for Mn efficiency assisted in the development of Sloop.

Improvements in tolerance to Mn and Zn deficiencies can significantly increase grain yields without the application of specific fertilisers. These findings have not been adopted by the breeding programs as low priority seems to be placed on breeding for these traits. A focussed evaluation of early generation material for micronutrient characteristics may improve the frequency of micronutrient efficiency genes in populations more efficiently than is currently the case.
Recommendations

In areas where micronutrient deficiencies are likely to occur, the use of micronutrient fertiliser in combination with a micronutrient-efficient variety will maximise yield and help reduce yield variation caused by seasonal differences in micronutrient availability.

Particular attention needs to be paid to the micronutrient nutrition of durum wheat because of its greater sensitivity to Mn and Zn deficiencies. Improved sources of Zn and Mn efficiency are required to improve the productivity of durum wheat, particularly for the alkaline soils of the region.

Outcomes

Economic outcomes

The project work has highlighted the level of genetic variation in micronutrient efficiency in the germplasm of wheat and barley within the current breeding programs and identified efficient and inefficient genotypes. This information, if adopted by breeders, can lead to improved and more stable yields of wheat and barley when available soil Zn or Mn is low.

While it is difficult to estimate the exact benefit of enhanced micronutrient efficiency, based on relative yields of efficient and inefficient genotypes, it is estimated that a 2-5% yield improvement over a range of broadacre conditions is not unreasonable, with proportionately greater benefits as the level of deficiency increases.

The project resulted in the release of the feed barley variety Maritime\(^0\), which will improve the productivity and consequently the profitability of barley on soils in South Australia that are well watered but chronically deficient in Mn. These include the South-East (SE) of SA, the lower Yorke Peninsula (YP) and parts of the lower and central Eyre Peninsula (EP). The potential improvements in productivity are great. Under severe Mn deficiency, Maritime is 50% higher yielding than Sloop\(^0\) and 80% higher yielding than Keel\(^0\).

Achievements/Benefits

Australian soils are regarded internationally as the most micronutrient-deficient in the world, particularly those in southern Australia where lower soil temperatures decrease nutrient availability during the growing season. Zinc (Zn) deficiency is extensive in all Australian states, while manganese (Mn) deficiency is widespread in the western two-thirds of the southern region and in the western region. Wheat and barley are particularly sensitive to these deficiencies. Although Australian research has led the world in this area, the problem is far from solved. While the problem of micronutrient deficiency is well known, the extent of deficiencies is likely to increase in the future owing to increases in productivity, particularly through nitrogen (N). This will place greater demands on nutrient-poor soils to supply these micronutrients, the increased production of durum wheat which is more sensitive to the micronutrient deficiency than bread wheat and the gradual improvement in productivity of the highly calcareous soils through improved phosphorus (P) nutrition. The problem is not restricted to Australia. Sillanpaa (1990) showed in an extensive survey that 49%, 11% and 15% of the world's soils are Zn-, Mn- and copper-deficient, respectively, but half of these soils had other problems which needed to also be addressed in order to show a micronutrient response. It is this elimination of other limitations which is increasing the extent of the micronutrient problem today.

In southern Australia, micronutrient deficiency is not caused by a lack of micronutrients but by poor availability, often related to high pH. Efficient cultivars improve availability and uptake by the roots. Thus, deficiency is as much a property of the variety as it is of the soil itself. Breeding cereal cultivars more tolerant of micronutrient-deficient soils can increase production whether micronutrients are used or not. The need for micronutrient fertilisers will not be eliminated, however project work has shown that efficient cultivars have the potential to increase yields above those attainable with fertilisers alone, owing in part to the effects on diseases and infertile subsoils.

The application of trace elements as fertiliser can alleviate the problem, however it is not always effective as seasonal weather conditions and soil properties, such as high pH, can reduce the availability and uptake of the nutrients. Consequently, crops may suffer from transient nutrient deficiencies or micronutrient deficiencies may not be detected. Visual symptoms of deficiencies do not appear until there is a 20-50% reduction in growth. Such gross deficiencies are now probably quite uncommon. However, the critical nutrient concentration, which is used to define a nutrient deficiency, represents a 10%
reduction in growth. At this level of deficiency it is difficult to notice significant differences in crop growth. This subtle effect of nutrition is often termed ‘hidden hunger’. There is also currently a significant body of evidence to show that adequate micronutrient nutrition is important to help protect plants from heat and water stresses. Improving the ability of cereals to grow on soils where micronutrient availability is low (termed micronutrient efficiency) provides an insurance against environmental conditions that restrict the availability and uptake of micronutrient fertiliser.

This project applied the micronutrient expertise within the Waite Nutrition Program to help identify micronutrient efficient germplasm from the cooperating cereal breeding programs from South Australia, Victoria and Western Australia. The work involved field screening of material from local and interstate wheat and barley breeding programs and genetic populations on selected micronutrient deficient soils. Since the start of this project between 6000 and 9000 plots were sown annually at a Mn-responsive site at Marion Bay, (Yorke Peninsula), and at Zn-responsive sites at Horsham (Victorian Wimmera), Birchip (Victorian Mallee), and Lameroo and Tintinara (Upper South East, SA). Wheat, barley, durum and triticale varieties, advanced genotypes and early generation material from the breeding programs, were grown in replicated split-plot designed field trials (control plus the relevant fertiliser). The results from the Mn screening were more consistent than the results of the Zn screening. This was because the responses to Mn at Marion Bay were more reliable and the magnitude of the response greater than those of Zn. Overall, the results of the work showed that:

i. Barley germplasm from WA tended to have a higher level of Mn efficiency than germplasm from the SA and Victorian programs.

ii. There was a reasonably high level of Zn efficiency in much of the advanced germplasm from the SA and Victorian barley breeding programs. However, many of the breeding lines from Japan being used by the Waite program showed poor Zn efficiency.

iii. Barley tended to show a higher level of Zn efficiency than wheat.

iv. There was no consistent difference in the Mn efficiency of the bread wheat and barley germplasm examined and both showed a wide range in Mn efficiency.

v. Durum wheat in general showed poorer Mn and Zn efficiency than bread wheat.

vi. There was considerable variation in Zn efficiency within the bread wheat germplasm from SA and Victoria which was generally greater than that observed in barley.

vii. Seed Mn concentration was able to discriminate between Mn efficient and Mn-inefficient genotypes. However, there was no consistent difference in seed Zn concentration between Zn-efficient and Zn-inefficient genotypes.

Results from these trials have allowed the assessment of the relative adaptation of breeding lines to the nutritional problems of the soils concerned. The achievements of this work include:

i. Advanced lines of wheat, barley and triticale with potential to be released as cultivars were identified as efficient or inefficient. This information has been incorporated into the information provided to growers about the variety.

ii. Screening of early generation material from breeding programs has helped increase the frequency of efficient genes in the breeding programs.

iii. The screening of mapping populations helped the Cooperative Research Centre (CRC) for Molecular Plant Breeding map the efficiency genes and develop molecular markers to further increase the effectiveness of breeding programs.

iv. The database developed within the project was made available to the International Maize and Wheat Improvement Center (CIMMYT).

Manganese

Severe manganese deficiency has been expressed in all trials at Marion Bay for the duration of this project and the results correlated strongly from year to year. Increases in grain yield with the application of Mn fertiliser range from 12% or 0.3 t/ha (WA73S276, Amagi Nijo13, WI 3297 and WI 3400) for the most efficient genotypes to more than 230% or 2.6 t/ha (Barque21, Skiff17, WI 3584 and WI 3586) for the inefficient lines. Single plant selections were taken from WI 3297 at Marion Bay in 2001 and multiplied and tested for cereal cyst nematode (CCN) resistance. This selection was released as a new feed barley variety, Maritime21, in 2003/04.

Data from inductively coupled plasma (ICP) analyses of grain from barley trials indicates that the more efficient lines have the ability to extract more Mn from deficient soils with the efficient lines having 5.2-8.4 mg/kg of Mn compared to 2.6-4.9 mg/kg for the inefficient lines. Results from the 2003 trials have shown an increase in grain Mn and this is probably attributed to the drier season.
Results from wheat trials indicate yield increases ranging from 30% or 0.6 t/ha for efficient genotypes (RAC-891, WI-94091 and Stylet\textsuperscript{(6)}) to more than 112% or 1.2 t/ha (Cranbrook\textsuperscript{(6)}, WI-99069 and Yanac\textsuperscript{(6)}) for the inefficient lines. ICP data for wheat indicates that concentration of Mn in the grain is fairly constant whether genotypes are efficient or inefficient, with a range between 3.9-4.6 mg/kg.

Zinc

Zinc deficiency was observed at both Birchip and Horsham in 1998 and this was reflected in grain yields. The 1998 results from Birchip were affected by a severe drought with yields ranging from 0.5 to 1.2 t/ha. Barley and wheat genotypes grown at Horsham gave increased yield with the application of Zn fertiliser, between 1.1 t/ha for inefficient lines to 0.3 t/ha for the more efficient types. Deficiency symptoms were evident at Birchip in 1999, 2000 and 2001 where grain yields for efficient genotypes increased by 5-10% or 0.2 t/ha (Stylet, Trident and RAC-893) to 25-30% or 0.7 t/ha for the inefficient lines (Goldmark\textsuperscript{(6)}, Kukri\textsuperscript{(6)} and VM506). The 2002 trials at Birchip failed due to the severe drought.

ICP data indicates that there are no significant differences in the concentration of Zn in the grain from plots where zinc fertiliser had not been applied with a range from 9.7-11.8 mg/kg across all genotypes. Barley genotypes appear to be more efficient than wheat in their ability to grow on soils low in zinc with most of the current genotypes from SA and VIC not giving any significant increase in grain yield. However, testing of Japanese material introduced and used in a collaborative trial of the Waite barley program has shown that many of these lines are Zn inefficient. This needs to be monitored if further development of this germplasm is used in Australian breeding programs. Symptoms have been much less evident at Horsham and there has been no significant difference between genotypes in 1999, 2000 and 2001. This area has also been prone to frost for two of these years and with the poor data collected trials were not planted at this location in 2002. All analysed data has been forwarded to and discussed with the appropriate breeders.

Other research

During the course of the project, Mr Jim Lewis was invited to address the Salmon Gums (WA) Field Days. While there were a number of micronutrient problems identified during the farm walks, there was a poor appreciation of the potential importance of micronutrient deficiency by some of the advisers and growers. With the recent focus on nitrogen nutrition, it is easy to overlook the need to maintain adequate supplies of micronutrients in areas of chronic deficiency. Therefore it may be timely to reinforce the need for balanced macro- and micro-nutrient in cereal production and the revision of relevant information available to grain growers.

In associated work (funded by the MPBCRC), a putative quantitative trait loci (QTL) linked to Zn deficiency symptoms in wheat was identified. This QTL also corresponds to a marker linked to boron (B) tolerance (symptoms expression and relative root length) in wheat. These observations indicate that there are interactions between different nutritional problems that are not fully understood but which warrant further investigations.

The work demonstrated that there is genetic variation in grain nutrient concentrations within wheat and barley. There is a major worldwide effort to breed cereals with high concentrations of the micronutrients, iron (Fe) and Zn, for improved human nutrition. The potential benefits of biofortified grain to the livestock industries have yet to be fully explored. Local cereal breeding groups have shown little interest in improving grain nutrient concentration and the work is being conducted within the Consultative Group on International Agricultural Research (CGIAR) centres. However, grain with improved nutritional value may provide additional markets for Australian grains.

Intellectual property summary

This project was a service provider to the wheat and barley breeding programs to test cultivars, advanced lines and mapping populations. The subsequent development of germplasm into commercial cultivars was the domain of the respective breeding programs. This was the case for the barley cultivar, Maritime\textsuperscript{(5)}.

Additional information

