New perennial plant options needed to transform agriculture and manage salinity

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Summary While current levels of salinity are a major driver for change in agricultural land use, it is the predicted expansion in the area affected by salinity that is motivating an ongoing search for additional solutions. Slowing or reversing the rise of water tables is at the heart of salinity prevention. Wide-scale adoption of land uses based on perennial plants has been identified as a primary strategy to increase water use and reduce the volume of water entering ground water systems. Where salinity is already expressed there is a need to grow salt tolerant plants, particularly where they contribute to profitable and stable land use.

Given the past focus on exotic annual plants, many potentially useful native and exotic perennial species have received limited study and have not been the subject of systematic plant improvement programs. Plants with specialised traits such as salt and waterlogging tolerance are also likely to be increasingly in demand in the future.

A cautious policy imposing quarantine barriers to the introduction of further exotic plants (precautionary principle) is in place to prevent the introduction and proliferation of potentially weedy species. This approach works well where adequate data exist to allow accurate predictions. Further developments are needed to allow better evaluation of potential introductions with little baseline data. Weed risk assessment strategies are also required for exotic species already introduced to Australia and therefore not covered by barrier assessments, and for native species.

Weed risk minimisation approaches can be usefully applied to all stages of plant breeding and better and more widely accepted operating procedures need to be developed through the collaborative efforts of plant breeders and weed scientists.

Keywords Salinity, weeds, perennial, biodiversity.

INTRODUCTION

Farming systems in Australia have evolved continuously in response to an array of economic, social, environmental and political influences to reach their current diverse expressions (Reeves and Ewing 1993). A dominant feature of current systems is the heavy reliance on annual plants of exotic origin such as cereal crops. Perennial plants are only being used under a limited set of circumstances (Cocks 2003), particularly where rainfall is high and summer dominant. Current domination of the landscape by annuals is in stark contrast to pre-European conditions where perennial species were dominant. A key outcome of this change has been a shift in the hydrological balance with current systems being 'leaky' leading to wide-scale expression of salinity in the landscape (Clarke *et al*. 2002)

A key strategy to overcome salinity revolves around the development of land use systems involving an increased proportion of perennial plants (Cocks 2003). It has been suggested that managed systems that mimic native systems with a higher proportion of perennial species will be more hydrological stable (Lefroy *et al.* 1999). Despite the importance of salinity mitigation as an environmental driver, it is unlikely that new land use systems based on perennials will be adopted on a substantial scale unless they are also profitable compared with currently available options (Ewing and Dolling 2003).

The desire to enhance or at least maintain the biodiversity of natural ecosystems, particularly in undisturbed areas of remnant vegetation, is another major driver of current land management. Invasion by exotic 'environmental' weeds is seen as a key threat to this aspiration (Groves and Willis 1999). While relatively few plants have the potential to become weeds of undisturbed natural systems, a larger number are able to invade disturbed and fragmented natural systems and agricultural systems.

The threat imposed by exotic plants as weeds is well established but large numbers of exotic species are already widely distributed in Australia (Lazarides *et al.* 1997) and subject to limited control. A recent policy response has been to more strongly control, through quarantine processes, further introduction to Australia of exotic plants with likely weed potential (Walton 2001).

The wider use of perennials on agricultural land is likely to involve increased exploitation of native perennial species of all plant forms (herbs, shrubs and trees). Recent studies of the weed potential of a group of native species growing outside their zone of natural distribution indicates that some natives have weediness traits similar to those demonstrated with exotic introductions (Virtue and Melland 2003).

In developing and growing perennial plants to limit environmental degradation associated with salinity there is an associated risk that the same plants could become weeds (Bennett and Virtue 2004). There is clear potential for conflict amongst important environmental objectives within evolving land-use systems. This paper highlights the importance of salinity as a key natural resource management issue for Australia and the important future role that plant-based management strategies will play. It focuses on the ways in which risks of weed introduction are being dealt with in the context of tensions between salinity minimisation and threat of weeds.

SALINITY OUTLINED

Causes of salinity The extent and pattern of current water use contrasts significantly with that occurring in pre-European times. This results from a change from a dominantly perennial to a largely annual plant base. The result is a change in the seasonal pattern and extent of recharge to ground water systems. The amount of leakage under native vegetation is generally small (Nulsen *et al*. 1986) especially in low rainfall zones. By contrast, annual crops often produce substantial drainage below the root zone (Asseng *et al.* 2001).

Ground waters, which are generally highly saline, are widely observed to be rising. When saline ground water approaches to within approximately 1 m of the surface, salt begins to accumulate in the soil surface as a result of evaporation of soil water which contains high salt concentrations. The soil surface continues to be fed by capillary movement of saline groundwater from below. This accumulation of salt results in soil conditions highly unfavourable for plant growth.

Scale of salinity It has been estimated that the area of land with the potential to develop salinity (hazard estimate) stands at 5.7 m ha and will increase to 17 m ha by 2050 (Anon 2000). Methods such as remote sensing that more directly measure the current area of salinity indicate that these may be substantial overestimates of area actually impacted by salinity. Despite the uncertainty it is clear that salinity is affecting large and growing areas. Salinity is by no means uniformly distributed across Australia. It is most prominent in Western Australia (75% of total) where 51% of farmers report expression of salinity on their properties.

Impact of salinity The salinisation of soils tends to initially occur in drainage lines and at the lowest points in the landscape. This is where the ground waters first reach the surface. As a result, where surface water flow occurs, salt is being transferred from the soil into streams and rivers. This is having the effect of damaging stream ecology and reducing the quality of water used for irrigation and human consumption.

The negative impact of salinity is wide ranging and complex (Pannell *et al.* 2004) and includes on and off farm impacts:

- land degradation (reduced productive capacity and increased erosion potential);
- biodiversity loss (particularly wetlands and valley floors);
- reduced water quality (impacts on water for human consumption and irrigation);
- degraded riparian systems;
- damage to infrastructure (towns, roads, railway lines etc.); and
- increased flood risk

The concentrated impact of salinity expression in low parts of the landscape means that certain native plant communities such as wetlands are at particular risk (George *et al.* 1999). In Western Australia it has been estimated that 450 plant species are at risk of extinction (Keighery 2000).

SALINITY STRATEGIES

Faced with the reality of a salinising landscape, one option that land managers can adopt is to adapt to increasing salinity by allowing their land to degrade and perhaps develop pasture systems suited to the increasing areas of saline land. Another option for land managers would be to enhance the rate of discharge of the saline water. In practice this usually means the use of drains placed low in the landscape. A further option could be to prevent or minimise recharge by growing deep rooted plants. In practice any combination of the three broad approaches might be logical depending on the circumstances. Strong reliance on engineering strategies would minimise the need to deal with the risks of weeds associated with plant-based strategies.

Discharge enhancement The use of engineering tools such as drainage and pumping to reduce the impact of waterlogging and salinity is currently successfully practised in some circumstances but appears to have limits to its application. However, it can be particularly effective in providing immediate protection to high value assets such as towns or nature conservation assets.

Cost/benefit is a key issue with drainage and this is influenced strongly by the extent of lateral impact of the drains in drawing down the water table. Much site to site variation has been observed in lateral impact of drains. Also of key importance are the costs and environmental impact of disposal strategies. This is of particular importance where drainage of effluent enters streams and regional drainage systems that are used for human consumption or irrigation as is the case for much of south eastern Australia.

Discharge enhancement using engineering techniques raises few issues directly related to weediness because it does not require the introduction of new plants. However, limitations to the circumstances under which engineering can be effectively applied means that plant-based strategies will often be necessary.

Adaptation to salinity One strategy, when faced with salinity, is to attempt to live with it (adaptation). This may mean doing nothing but will more commonly mean attempting to stabilise and gain some production from the increasing areas of saline land. Well adapted and productive plants are not yet available for all zones subject to secondary salinisation. This deficiency is creating demand for new salt and waterlogging tolerant plant options and their development and management has become an active area of plant-based research and development.

Strong consideration of environmental weediness potential is critical in evaluating options for areas of secondary salinity. This is based around the potential of sown plants to invade:

- adjacent areas of primary salinity and threaten natural biodiversity;
- riparian areas (exposed to ready transport of seed or other propagules); and
- nearby non-saline areas including remnant native vegetation.

Plants well adapted to saline sites can become dominant through lack of competition and provide a strong focal point for naturalisation if the introduced species is also adapted to non-saline settings. Native species offer good opportunities for development of saline environments. Since they will often be introduced from outside their natural range their lack of weediness cannot be assumed and requires empirical testing (Semple *et al.* 2004).

Recharge prevention A return to ground water recharge levels that prevailed prior to clearing appears to be impossible without substantial changes to current systems of agricultural land use. Most of these changes will need to take place in higher parts of the landscape (recharge zones) where salinity is not a problem directly limiting production. The proportion of land occupied by perennials for effective recharge management is likely to vary but will generally be greater than 50% and could be as high as 80% in some circumstances (George *et al.* 1999). These sorts of levels of perennial use imply a major transformation of agricultural land use.

Current use of perennials falls very short of this mark. A wide-ranging review of perennial plant use and profitability identified the lack of profitable options as a major constraint to salinity management (Kingwell *et al*. 2003). This has highlighted the need for continuing development of perennial plants for the wide array of climates, soils, production systems and industries.

The scale of required perennial use is likely to involve wider use of all forms of perennials (herbs, shrubs and trees) and in a variety of configurations. These will be grown separately (long term monocultures as in tree plantations), rotated (as for lucerne in rotation with cereals) or integrated as in alley systems with herbaceous species grown between trees or shrubs.

Herbaceous perennials Herbaceous perennial development is likely to be a combination of further development of existing well-known species (e.g. lucerne) by selecting for traits which overcome constraints to wider adaptation as well as a focus on completely new plant species. From a weed risk perspective, the established species will be exposed to a more diverse set of environmental conditions as they are grown more widely but there is likely to be sufficient experience to predict likely weed outcomes and provide the basis for management. Wider use of lucerne has been highlighted as an important opportunity (Cocks 2003) brought about by greater genetic tolerance to stresses such as acidity, aridity and grazing pressure. Lucerne has been shown to have low weed risks (Virtue and Melland 2003) and this is unlikely to change with wider use.

New herbaceous perennial prospects have been identified amongst both native and exotic genera (Dear *et al.* 2003, Bennett *et al.* 2003). Clearly the Weed Risk Assessment (WRA) protocols applied by Biosecurity Australia will play an important role in determining the set of material available for evaluation. It is likely that a lack of information as input to the WRA process will result in some promising plants falling into the 'further evaluate' category. A challenge exists to develop practical expression of the Tier III provisions of the WRA process that allows follow-up assessment based on specifically collected additional information.

Shrubs A poor past success rate in developing profitable production systems based on shrubs is under review. Past studies have indicated the difficulty of shrubs meeting productivity thresholds to be profitable in comparison with herbaceous alternatives (Lefroy 2002). In addition, shrubs and particularly leguminous shrubs were regarded as having high weediness potential but recent findings indicate that this is not always so (Virtue and Melland 2003). Most current interest is based on native species including *Acacia* spp. with potential for use in alley systems or for application in phase rotations.

Development of fodder shrubs based on exotic germplasm has low priority but use of native shrubs in novel systems is under consideration and sowing of species such as *Atriplex* is increasing. The need for well developed weed risk reduction protocols for native shrubs has been emphasised following the study of *A. saligna* (Labill.) H.Wendl. by Virtue and Melland (2003) which highlighted its weediness when grown in South Australia, outside its natural range.

Trees New initiatives in forestry and agro-forestry will be focused in areas with lower rainfall than is required for traditional saw log production systems. In such environments native species are most likely to provide plants of commercial value because of their adaptation and productivity in stressful conditions. Current research efforts are focusing on the identification of a group of species that can be used in large scale production systems with product characteristics that match the needs of industries such as pulp and particle board production (Bartle and Shea 2002).

Where studied, the weed risks associated with planting native trees outside their natural boundaries are generally low but should not be ignored. A less well understood risk is that associated with contamination of localised gene pools with exotic pollen from large scale plantings of native eucalypts. Development of effective strategies to minimise such risks needs to be informed by further research and development efforts.

Integrated strategy The strategies outlined above need not be applied in isolation. In fact, engineering outcomes will be most effective when combined with plant-based systems. Some adaptation to increased salinity is almost certainly going to be required, especially in catchments when there are substantial lag phases between the implementation of new management and hydrological response.

WEED RISK AND PLANT BREEDING

In examining most plant improvement programs the general chronological steps outlined in Table 1 can be distinguished. The relative importance and duration of each stage will vary greatly between individual programs. Consideration of the stages outlined will provide a useful basis for linking plant improvement to some of the main issues of weed risk minimisation.

Stage 1 The combination of high potential water-use, productivity and profit are key drivers in the selection of new plant targets (Stage 1 – Table 1) that will transform Australian agriculture (Pannell *et al.* 2004). It is now clear that an explicit goal of minimising the risk of weediness to agricultural and natural systems should be included as a specific objective of all such projects. This then provides a basis for the operational activities that occur later in the breeding process. Moreover, it would cement a shift in culture in breeding programs.

Stage 2 Germplasm acquisition (Stage 2 – Table 1) can take many forms. However, it must now as a minimum comply with the Biosecurity Australia list of approved species if it is of exotic origin. It is also desirable that use be made of WRA processes for material that falls outside this category (already introduced plants and natives). No well developed and tested system with national recognition is yet in place and this has been a disincentive to wide uptake of formal WRA protocols by plant breeders.

The transformation of Australian agriculture with perennial plants will require some novel elements exploiting little studied plants. If such plants are exotic in their origin they are evaluated using the standard WRA protocol. Where information about a species is scarce there may be uncertainty about aspects of its weediness status which can lead to it being placed in the 'further evaluate' class (neither allowed entry nor rejected). There is a need to develop the operational arrangements under which plant material can be handled to allow the collection of the information needed to finalise the classification. This process has been allowed for in the system but is not yet operational. This currently makes the 'further evaluate' class a quasi rejection.

A further complication to barrier WRA processes is the variation that commonly exists within species

Table 1. Stages in the implementation of a plant improvement program.

Stage number	Plant improvement activity
1	Problem definition and analysis – targeting broad plant improvement goals and objectives
2	Germplasm acquisition – accumulation of appropriate genetic diversity (including symbionts where applicable)
3	Selection and breeding – development of elite lines from amongst the diversity
4	Testing under field circumstances to identify the best locally adapted lines from amongst the elite material (potential cultivars)
5	Cultivar commercialisation (seed production, release, demonstration and adoption support)

in characteristics that can be critical to weediness potential. If past studies on which the WRA for a species is based have dealt with a subset of plant material it may under or over estimate weed risk. Post-entry processes are needed to eliminate risks associated with under rating and Tier 3 provisions of the WRA to provide a basis for demonstrating the lower risk of specific genotypes.

Stage 3 Selection within species for characteristics that reduce weed risks is feasible and will sometimes enhance plant performance in an agricultural context. Typically this involves reproductive traits where selection for ease of seed harvest is often associated with reduced weediness and manipulation of plant chemical constituents giving rise to increased palatability. Seed dormancy is a characteristic that favours persistence of 'wild' plants but is less important for perennials grown in managed systems where establishment is a managed process. Selection of legumes without or with low dormancy is an example of a readily selected character that would reduce a plant's capacity to naturalise.

Stage 4 Plants being developed for use in salinity mitigation are currently being regionally evaluated in nationally coordinated programs. This provides an opportunity to develop and implement standard protocols for weed risk assessment relevant to specific plant groups and forms. Empirical evidence of weed potential is an important supplement to previous weed risk assessment which is often based on information from unrelated environmental settings.

The absence of well developed field based protocols has encouraged the CRC for Plant-based Management of Dryland Salinity to co-invest with the CRC for Australian Weed Management in the development of suitable guidelines for breeders to follow. This is an emerging partnership between weed science and plant breeding and will test approaches to field evaluation that could have wider application.

Observations, measurements and experience gained during field testing often provide a basis for the development of general management strategies including weed management. Given that plants are generally tested in the context of the land use systems to which they apply, issues of agricultural weed management are often encountered and resolved during testing. These details subsequently become a valuable component of information packages defining management options and constraints.

Stage 5 The transition from the experimental breeding phase to commercial distribution provides an opportunity to review likely commercial benefits and risks. Evaluation protocols for Stage 4 need to be sufficiently detailed and focused to inform this process. A 'duty of care' review including an assessment of weed potential is being applied as a standard pre-release process by some institutions as part of their wider risk management strategies. Development of standard approaches to this issue would allow more coordinated and effective data collection, especially where breeding programs cross state and institutional boundaries.

CONCLUSION

A substantial increase in the use of perennial plants in Australian agricultural systems is desirable to reduce salinity. To have the required impact on salinity, perennial plants will need to be used very widely and this will only be possible if they are productive and profitable in the hands of land users. Without such changes we can expect a decline in the land resource base and substantial loss of natural biodiversity.

Currently available perennial plants will not stimulate the scale of adoption needed for effective salinity management so new options are needed. Plant scientists and breeders continue to identify new options that might meet the dual criteria of high profitability and high water use.

There is growing awareness, based on past experiences, that the introduction of new plants to agricultural systems has an associated risk that these plants will become weeds, either within agricultural systems or off site in natural settings.

Current weed risk minimisation efforts are concentrated towards the important objective of preventing the introduction of additional exotic species with weed potential. Efforts to develop a framework covering the full array of weed risk minimisation issues have been less coordinated. Such a framework needs to cover plants sourced from the Australian flora which are of growing commercial importance as well as exotic species already in Australia. In many cases the issues will be wider than acceptance or rejection of particular plants and will include the definition of management requirements to minimise the potential of plants to become established in natural systems.

In practice there is a requirement for development of national accepted weed risk management guidelines covering key plant groupings which will guide the practice of plant breeders during the breeding and testing of new plants.

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