Climate change and weed management in Australian farming systems

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Summary Each year the level of uncertainty surrounding the evidence for a warming world and human influence on some of this warming seems to decrease amongst climate scientists and more recently, agricultural scientists and farmers. However, there will always be significant uncertainty on how increasing CO_2 and global warming will be translated to changes to regional climate and how these changes will influence weed management in agricultural systems in Australia. Weed management R&D and the practice of weed management needs to take into account worrying but uncertain projections from climate science.

There is a significant challenge in trying to understand the impacts and complex interactions of climate change on crops, weeds and management options. We also need to take an adaptive management approach and build resilience. We suggest that increasing CO_2 and temperature will enhance weed problems and conclude that sound weed management is one of the best ways that Australian farmers can build resilience and reduce their vulnerability to climate change.

Keywords Climate change, weeds, carbon dioxide, temperature.

INTRODUCTION

The Intergovernmental Panel of Climate Change (IPCC 2001) concluded that:

1. An increasing body of observations gives a collective picture of a warming world and other changes in the climate system;
2. Emissions of greenhouse gasses and aerosols due to human activities continue to alter the atmosphere in ways that affect the climate system;
3. There is new and stronger evidence that most (but not all) of the warming over the last 50 years is attributable to human activities; and
4. Since global warming cannot be avoided completely, adaptation will be necessary to complement efforts to reduce greenhouse gas emissions.

A survey conducted for the Australian Greenhouse Office found that over 90% of grain growers believed that climate change was a major issue for their enterprise. Farmers and their advisers seem to be shifting from asking questions along the lines of 'Is climate change real?' to 'What will the impacts be?' and 'What can we do about it?'. This shift in the balance of questions is a shift away from a topic solely in the domain of atmospheric sciences to impact and vulnerability studies that will need clear thinking from disciplines such as weed science and farming systems. This shift in questions is also a shift from global to local. The cause of the shift in thinking is due in part to the saturation media coverage on climate change and in part to recent weather events such as the hot spells in Eastern and Southern farming regions in February 2004, October 2004 and January 2006, the very hot and dry start to the 2005 cropping season and the slow and patchy recovery from the 2002 El Nino. Although single weather events add little to the scientific evidence for climate change, they focus attention.

The media tends to overplay the uncertainty in a debate that is not really continuing in the scientific community (Schneider 2004). Lowe (2005) rebutted some of the more common arguments from climate sceptics in the Australian context. In this paper, we: i) outline the increasing uncertainty of climate change projections from global to local scales; ii) illustrate the complexity of climate change impacts on weed-crop systems; and iii) emphasise the importance of adaptive strategies for weed management in a highly variable, non-stationary climate.

CASCADING UNCERTAINTY

Figure 1 is a framework to think about confidence and uncertainty with respect to climate change. The evidence for the vertical arrows has strengthened in recent times and most governments, including Australia's, accept the need to act on emission reductions rather than wait for more evidence. However, when it comes to actions on adapting to climate change, the uncertainty of impacts must be acknowledged and managed. The different emission scenarios provide an irreducible uncertainty which is further increased by the way different global circulation models translate an increase in greenhouse gasses to global warming. There are further differences from the projections of global circulation models on Australian climate and

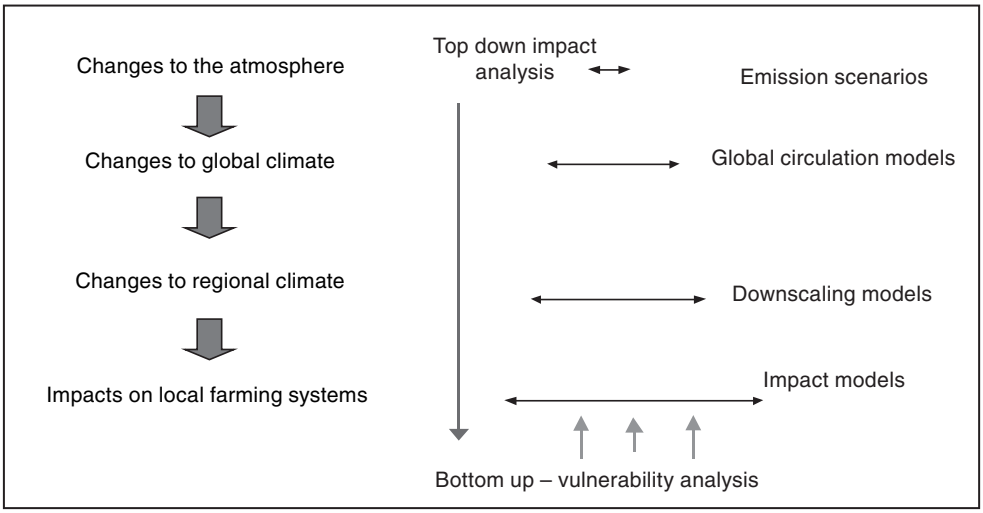

Figure 1. Cascading uncertainty (adapted from Schneider 2004).

then questions of how these multifaceted changes in climate will influence farming systems.

There is a high degree of confidence in some level of warming for Australia. Compared to 1990 conditions, Australia is expected to experience a warming of 0.5 to 2°C by 2030 with the much wider range of 1 to 6°C by 2070 (McInnes *et al.* 2003).

While a warmer world is expected to be a wetter world, southern Australia is expected to be drier. For agriculture this projection is the most worrying, but it is also the most uncertain aspect of the projections. There was a relatively high level of consistency between global circulation models used for the IPCC in 2001 on the drying trend in Southern Australia (McInnes *et al.* 2003). This consistency is repeated in the latest round of models used for the fourth assessment round of IPCC due in 2007 (Suppiah *et al.* in press). In general terms, the strongest drying indications are for spring, followed by winter and then autumn, with summer rainfall trends less certain (McInnes *et al.* 2003). Australia is well served by a series of regional projections which are available at the Australian Greenhouse Office website, and regional reports for all states and territories are available from CSIRO[A] and the Greenhouse Office in most states. Careful reading of these reports will indicate the much higher confidence in temperature projections compared to rainfall projections.

Footnote

[A] www.dar.csiro.au/information/climatechange.

The highest degree of confidence is in the changes to CO_2. There is substantial spatial uncertainty about temperature and rainfall impacts across the globe and due to lag effects, considerable temporal uncertainty. In contrast there is little spatial variation in CO_2 and the temporal uncertainty is a question primarily of demographics and energy sources rather than science.

EFFECTS OF CLIMATE CHANGE ON WEEDS, CROPS AND THEIR INTERACTIONS

Increasing CO_2 and temperature, and less certain changes in annual, seasonal and daily intensity of rainfall will affect weeds, crops and their interaction in multiple ways (Figure 2). There is a reasonable understanding of direct effects of single factors, such as CO_2, on the physiology of growth and reproduction of weeds and crops. The status of knowledge on CO_2 on crops and forestry in Australia is covered in Steffen and Canadell (2005). More is understood at the leaf and plant level over short time periods than the field or ecosystem level especially when competition for water, light and nutrients is considered. C_3 plants are likely to be more responsive to increasing CO_2 than C_4 plants. Because C_4 plants are generally more tolerant of heat and water stress, the simple notion that climate change will always favour C_3 plants must be applied with caution. While 14 of the 18 most problematic weed species in the world are C_4 only six of the 15 worst weeds in the US are C_4 (Fuhrer 2003). Of the list of 20 most common weeds of cropping in Australia only two, Barnyard grass *Echincoloa* spp. and sweet summer grass *Brachiaria eruciformis* (J.E.Smith) Griseb.

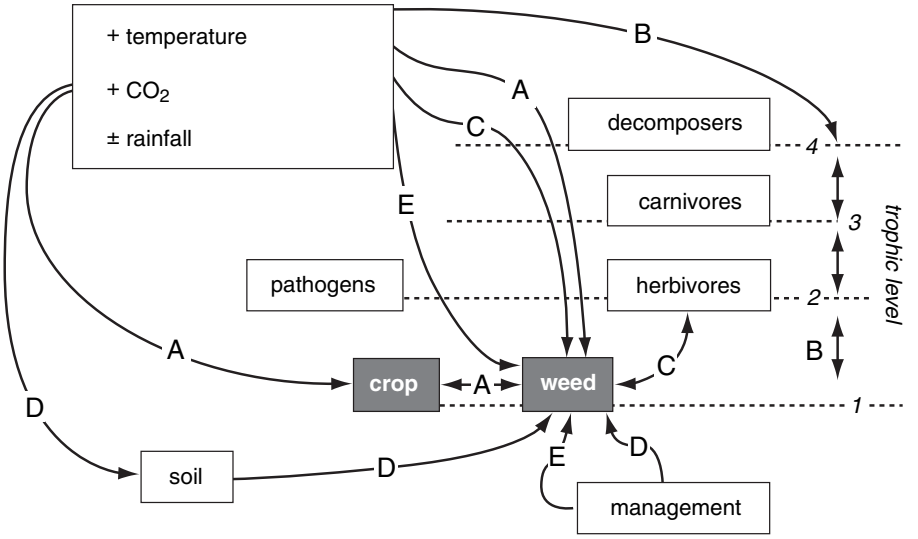

Figure 2. Direct and indirect effects of climate change on crops, weeds, and their interactions. Letters indicate pathways that are discussed in the text.

are C_4. The majority of economic crops globally are C_3 plants with sorghum (*Sorghum bicolor* (L.) Moench), maize (*Zea mays* L.) and sugarcane (*Saccharum officinarum* L.) being important exceptions.

Interactions between two or more factors, e.g. temperature × CO_2 × water, are poorly understood for single plants. Importantly, any environmental effect that differentially affects weeds and crops will alter their competitive interactions (pathway A in Figure 2), as illustrated by experiments where soybean (*Glycine max* (L.) Merr.) was grown under current and enhanced CO_2 in competition with a C_3 (*Chenopodium album* L.) or a C_4 (*Amaranthus retroflexus* L.) weed (Ziska 2000). Increased CO_2 concentration enhanced growth of *C. album* by 65%, whereas loss of soybean yield attributable to competition with this weed increased from 28 to 39%. Conversely, *A. retroflexus* growth did not respond to CO_2, and loss of soybean yield attributable to competition with this weed decreased from 45 to 30% with increasing CO_2. A modelling study on current and projected distribution of *Acacia nilotica* (L.) Willd. ex Delile, an invasive woody legume currently established in Australia, indicated the potential for a significant increase in the area at risk of invasion: 1) further southward, favoured by increasing temperature that would allow for completion of reproductive cycle, and; 2) further inland, favoured by increased water use efficiency expected from increased CO_2 (Kriticos *et al.* 2003).

In addition to the complexity derived from direct effects of multiple interacting factors, climate change may have dramatic, unexpected indirect effects on weeds and crops, and on components of the systems at higher trophic levels. Through differential changes in phenology, increasing temperature may decouple trophic webs in some ecosystems (pathway B in Figure 2) (Hays *et al.* 2005). Phenological change is a critical element in the response of agricultural systems to climate change for two reasons. First, phenology is the single most important attribute of crop adaptation, and phenological synchronisation is significant for weed-crop interactions. Second, owing to the cumulative effect of temperature on plant development, small changes in temperature can have large impacts on phenology. A very small, statistically undetectable increase in temperature ~0.02°C y^{-1} is sufficient to cause significant shortening of time to flowering and season length in wheat (Sadras and Monzon in press). Increased CO_2 can change the profile of secondary compounds in weeds (Ziska *et al.* 2005) with the potential to affect weed-herbivore interactions (pathway C in Figure 2). The agronomic importance of the interaction between weeds and arthropod herbivores is twofold. First, herbivores play a role in checking weed populations naturally, or in targeted programs of biological control. Second, weeds host both herbivores of crops, and natural enemies of crops' herbivores.

Weather, chiefly temperature and radiation, and soil factors including moisture and temperature, play a recognised, partially understood role in modulating herbicide efficacy and persistence through their effects on plants (pathway E in Figure 2) and soil microflora (pathway D in Figure 2). Examples of these influences include soil freezing and thawing cycles affecting microbial activity and glyphosate degradation (Stenrød *et al.* 2005). It is likely in the Australian context that changes to the wetting and drying of soil profiles will have an impact. Another important environmental factor is temperature, which has shown to effect the efficacy of flumetsulam on *Raphanus raphanistrum* L. (Madafiglio *et al.* 2000), and clodinafop-propargil on *Avena* spp. (Medd *et al.* 2001). While the mechanism is unknown, high CO_2 may also directly reduce the efficacy of glyphosate on perennial weeds (Ziska and Teasdale 2000). Changes in temperature, CO_2 and rainfall are therefore expected to affect both efficacy and persistence of herbicides. A modelling study in the UK found a relevant effect of increasing temperature and faster herbicide degradation (pathway D in Figure 2) whereby 1.5 kg ha^{-1} of isoproturon applied in November gave approximately three months of weed protection in the late 1990s compared with four months in the early 1980s (Bailey 2004). Less persistence of herbicides may complicate weed control in autumn and winter. Conversely, drier summers may slow down herbicide degradation leading to carry-over problems (Bailey 2004). Changes to herbicide persistence will be beneficial to some farming systems. A difficulty for farm managers will be deciding when a change in seasonal rainfall is a shift in climate rather than an expression of variability.

In summary, there is a hierarchy of knowledge of the potential effects of climate change on crop-weed interactions. Effects of single factors are reasonably well understood, whereas interactions remain elusive. The effects of temperature and CO_2 are relatively straightforward, whereas the effects of rainfall, however important, are closely linked to other factors – such as soil and evaporative demand – influencing the water budget of the system. The greater uncertainty in terms of climate projections for rainfall is therefore compounded by its more complex role in agricultural systems. There is a poorer knowledge of environmental effects on perennial crops and weeds, partially due to incomplete understanding of acclimation and life-long trade-offs between reproduction and survival. Rising CO_2 and temperature can alter yield losses caused by weeds and weed control is likely to be critical to realise the potential benefits of CO_2 fertilisation for crops. Faster degradation of herbicides driven by high temperature and tolerance to herbicides enhanced by high CO_2 may complicate and increase the cost of weed control.

Archembault *et al.* (2001) found that herbicide efficacy was reduced on some important Canadian weeds under increased CO_2 and temperature. However the loss in herbicide efficacy due to increased CO_2 were likely to be more than offset by CO_2 induced gains in crop yield. This highlights the point that for Australian grain farmers to gain some of the benefits of CO_2 fertilisation to offset the early stages of climate change, weed management will be essential. If the expenditure on weed management in the grains industry in 2001 was $3.3 billion per annum (Pratley and Stanton 2003), an increase in the cost of weed management may be one of the more important impacts of the early stages of climate change.

VULNERABILITY AND ADAPTATION

Vulnerability to climate change is a function of sensitivity to climate change and ability to adapt. Weed management in Australia is sensitive to temperature and rainfall and will also be influenced in complex ways by changes to carbon dioxide. Most of the changes will make weed control more demanding. Australian advisers and farmers are also highly adaptable. Madafiglio *et al.* (2000) points out that broadleaf weed control in spring in NSW is practiced under conditions varying from −6°C to 25°C. Summer weed control especially in western regions of Queensland and NSW is conducted under extremely high temperature and low humidity. The guidelines for reducing spray drift recommend not spraying when temperatures are over 28°C or delta T (difference between wet and dry bulb temperature) is greater than 10°C (Storrie 2004). Even the lower end of global warming is likely to further reduce the opportunities for spraying summer weeds. Farmers using controlled traffic have been able to spray at night and there are operational efficiencies that enable maximum use of the short windows of opportunity.

Another challenge has been the run of late starts to the season in Southern Australia, which have made sowing and weed control difficult. The autumn of 2005 was the hottest and for many regions driest on record and 2005 was the warmest year ever in Australia. Yet crop yields were average to above average, largely due to good spring rainfall. However, it is important to note that farmers were able to benefit from this spring rainfall because so many had sown a large portion of their cropping area prior to the break of season on the 10th of June.

Night spraying with the aid of controlled traffic and dry sowing with more refined weed control methods are two examples of the way in which growers are currently tackling weather-related constraints.

Challenges ahead include better understanding of the influences of the complex effects of CO_2, temperature and water on key biophysical processes, integration at the system level combining bottom-up and top-down approaches, and innovative adaptive thinking fostered by close collaboration between industry and researchers. This move to more adaptive management involves a greater emphasis on learning than knowing. A challenge for weed management is to identify which aspects of the substantial knowledge base in the research, advisory and farming community does not need readjusting with a changing climate and which aspects need to be reassessed.

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