Weeds getting steamed-up in the tropics: climate change effects on ecosystem water use efficiency and woody plant range

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Summary Ironically, the aspect of global climate change that we are most certain about, that there will be increasing concentrations of atmospheric CO_2 is also the factor about which we know the least in terms of its impact on weed competition. Increasing concentrations of atmospheric CO_2 ($[CO_2]$) is thought to lead to the carbon fertilisation effect (CFE) and increasing water use efficiency (WUE). However, the extent to which desirable plants and weeds will benefit, and how these effects are distributed throughout the plant kingdom are uncertain. CLIMEX was used to explore the effect of increasing ecosystem water use efficiency (eWUE) on the potential distribution of three tropical weed species. In the tropics, increases in eWUE may have very little effect on weed distribution compared with the projected changes in temperature and rainfall if plants use the 'extra' soil moisture to fuel additional growth. The effects of increasing CO_2 on tropical shrubs requires urgent research attention in realistic, competitive field situations to assess the vulnerability of primary production and biodiversity conservation sectors.

Keywords CLIMEX, climate change, CO_2, water use efficiency.

INTRODUCTION

The rate at which humans have been emitting CO_2 into the atmosphere over the past 200 years has been increasing. It is ironic that it is this aspect of global climate change that we have the best knowledge, and yet, the ecological implications of this process are possibly the least well understood. The two documented responses of increasing atmospheric CO_2 are the carbon fertilisation effect (CFE), and increasing water use efficiency (WUE) (Morison and Gifford 1984a, 1984b). In the CFE, where other growth factors such as insolation, nutrients and water are not limiting, increasing atmospheric CO_2 concentrations $[CO_2]$ generally lead to increasing plant growth (Figure 1). In the WUE effect, increasing atmospheric CO_2 leads plants to operate with stomata closed to a greater degree for a given photosynthetic rate (Figure 1b). This leads to less transpiration, and increases in plant growth per unit water transpired. What we are uncertain about is the degree to which desirable plants and weeds will benefit most from CFE and the WUE effect and how these effects are distributed throughout the plant kingdom. There is also a large degree of uncertainty about how increasing leaf level water use efficiency translates into increased plant growth and increased ecosystem-level water use efficiency (eWUE).

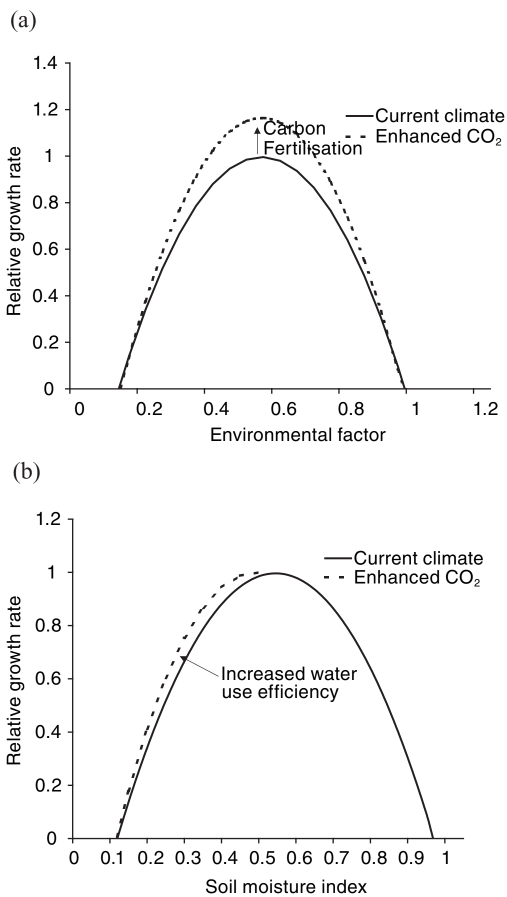

Figure 1. Schematic representation of (a) the carbon fertilisation effect, and (b) increased water use efficiency due to increases in atmospheric CO_2.

As plants with the C_4 photosynthetic pathway are more efficient in their use of CO_2 than those using the C_3 pathway, it has been generally thought that in the tropics, under enhanced CO_2 conditions, all else being equal, C_3 plants might enjoy an increased relative competitive advantage against C_4 plants; perhaps favouring woody vegetation over grasses (Bond and Midgley 2000). However, there is some debate about this conclusion (Wand *et al.* 1999) and there is evidence to suggest that under some circumstances, the competitive balance might even swing in the opposite direction (Williams *et al.* 2007). Despite this uncertainty, the finding that under enhanced [CO_2] conditions there is more soil moisture available below the rooting zone of grasses (C. Stokes, CSIRO pers. comm. 2007), presumably due to less transpiration losses, leads to the conclusion that the growing season for deep-rooted shrubs and trees in the seasonally wet-dry tropics may be extended (Field *et al.* 1997). Previous studies have suggested that changes in water relations and growing season length resulting from increases in [CO_2] could have significant impacts upon the potential distribution of woody weeds in the tropics (Kriticos *et al.* 2003a, 2003b).

Climate-based habitat suitability models such as CLIMEX™ (Sutherst and Maywald 1985, Sutherst *et al.* 2007) can be used to assess the effects of climate change on the potential distribution and relative abundance of species. CLIMEX has been used to assess the *sensitivity* of the effects of climate change and water use efficiency on a range of woody weeds (Kriticos *et al.* 2003b). In these previous analyses the effects of climate change were incorporated as a set of simplistic changes to the underlying climate database. Sensitivity analyses were employed in these early studies because global climate modelling was still too immature to support the use of future climate scenarios taken from global climate models (GCMs). More recently, GCMs projections appear to have stabilised to the point where it is worth employing them directly in climate change impact studies (Kriticos *et al.* 2006).

In this study, the sensitivity of the geographical range of some important tropical woody weeds to increases in eWUE is assessed in relation to future climate scenarios. At present, CLIMEX is unable to directly simulate the effects of CFE on a species growth rates. Indeed, the effects of CFE on species competitiveness and plant community composition are equivocal. For this reason, the effects of CFE on plant distribution are ignored in this study.

METHODS

Previously developed CLIMEX models for three tropical woody weeds found in Queensland were selected as case studies for use in this project: prickly acacia (*Acacia nilotica*) (Benth.) Brenan (Kriticos *et al.* 2003b), rubber vine (*Cryptostegia grandiflora*) Roxb. ex R.Br. (Kriticos *et al.* 2003a) and Siam weed (*Chromolaena odorata*) (L.) King & Robinson (Kriticos *et al.* 2005). *Acacia nilotica* and *C. grandiflora* are Weeds of National Significance, and *C. odorata* is the subject of an on-going eradication campaign. The ecology and distribution of these weeds is well known. These species models were firstly run using a reference climate dataset for 1961–1990 with a spatial resolution of 0.5 degrees of arc (Mitchell *et al.* 2004). To simulate future climate conditions, GCM projections for the 2080s from the CSIRO Mark2 model were extracted from the TYN SC 2.0 dataset of Mitchell *et al.* (2004) using techniques described by Kriticos *et al.* (2006). Given the findings of Rahmstorf *et al.* (2007) that recent global temperature increases are tracking at the high end of the IPCC scenarios (IPCC 2000), only the high emissions scenarios are considered here.

In the OzFACE experiment near Townsville it was observed that there was an accumulation of soil moisture at a depth below the rooting zone of grasses, but accessible by shrubs and trees (C. Stokes, CSIRO unpub. data 2007). In order to simulate the observed increases in eWUE on the distribution of the case study weeds, the rainfall in CLIMEX was adjusted upward by 5%. In the CLIMEX soil moisture model, this adjustment produces results that reflect the observed changes in soil moisture, with a slightly extended growing season in the seasonally wet-dry tropics.

RESULTS

Increased temperatures in the climate scenario for the 2080s leads to significant southward range extensions for all three species. In addition, this scenario includes a marked reduction in rainfall in the centre and west of Australia, leading to reduced climate suitability in these central regions and a generally more coastal range shift for all three species in the north (Figure 2, column 2). These coastal range shifts are not compensated by a 5% increase in rainfall to simulate the effects of increased eWUE (Figure 2, column 2 vs column 3).

DISCUSSION

For the three case study weeds examined in this study the relative insensitivity of their inland ranges to [CO_2] increases suggests that the inland spread of woody weeds could be minor compared to their likely poleward and altitudinal range expansions. However,

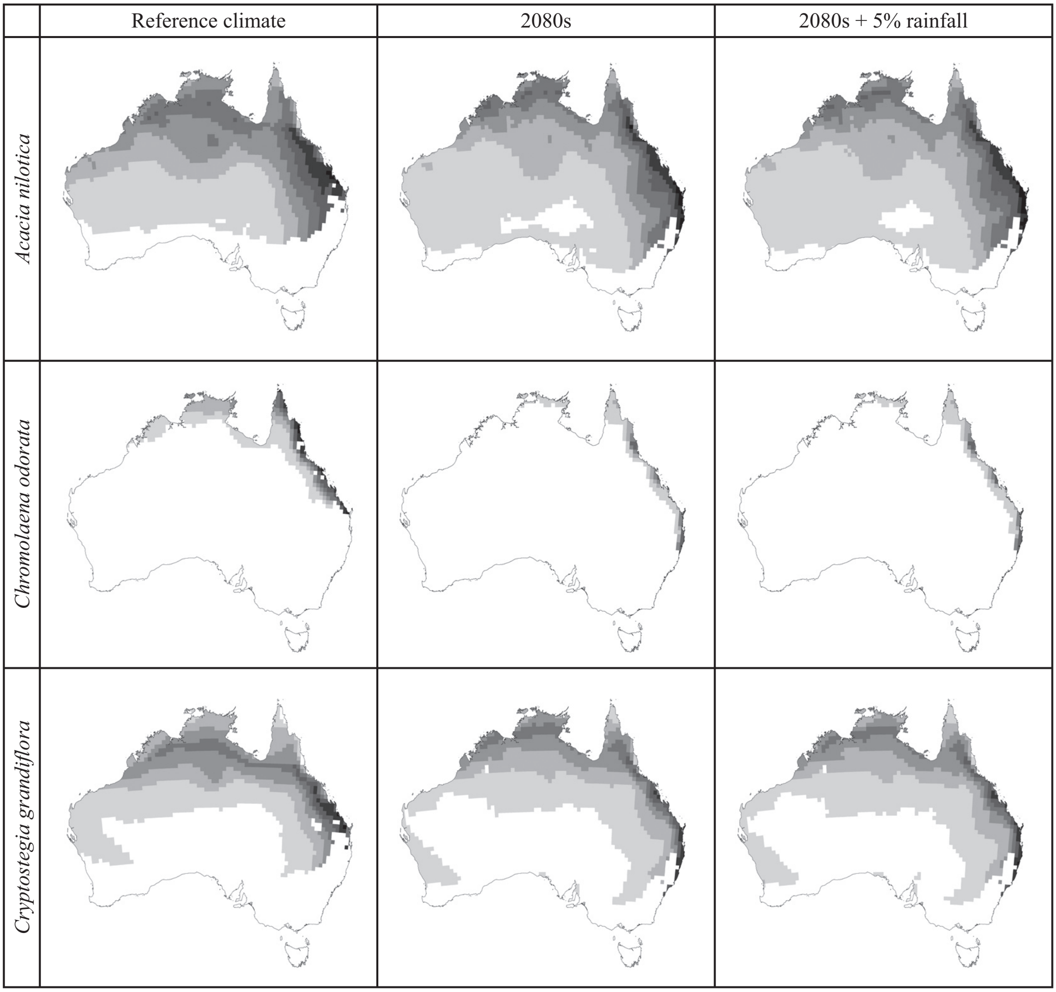

Figure 2. Modelled CLIMEX ecoclimatic index for *Acacia nilotica*, *Chromolaena odorata* and *Cryptostegia grandiflora* under three climate scenarios: reference (1961–1990), 2080s modelled using the CSIRO Mk 2 GCM, and 2080s modelled using the CSIRO Mk 2 GCM plus 5% rainfall to simulate the effects of increased water use efficiency. White shading is unsuitable. Increasing darkness indicates increasing climate suitability.

the simulated rainfall changes used in this study ignore the potential for spectacularly increased growth rates for these weeds within their future geographic ranges due to the CFE, and the potential for increased growth to improve their tolerance of stressful conditions at their range margins. The contrast with previous findings supports the need to gather more information on the effects of [CO_2] on plant water relations and plant growth phenology to inform the modelling of these impacts.

The equivocal results of experiments that examine patterns of species responses to climate change scenarios suggests that competition experiments between some important desirable plant species and weedy competitors under realistic field conditions may be highly informative.

Observations by Emmerich (2007) that under present CO_2 concentrations, water use efficiency was higher in grasslands than shrublands indicates that elevated CO_2 conditions could support the invasion of grasslands by woody C_3 species. Furthermore, these C_3 species could provide a positive feedback, further fuelling the invasion by using more water than the grasses that they would compete with.

The potential for substantial future range increases for *C. odorata* supports ongoing efforts to eradicate this weed. Similarly, the effects on the potential ranges of *A. nilotica* and *C. grandiflora* adds extra support for the policy of maintaining strategic control zones to restrict their spread.

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