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Climate change impacts on agro-ecosystem sustainability across three climate regions in the maize belt of South Africa

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Abstract

The Highveld region in South Africa is an important area for its food production for the nation, as 70% of country's cereal crops and 90% of the commercially grown maize is cultivated there. The sustainability of these agro-ecosystems is, therefore, of vital importance for the nation's food security. The western part of the Highveld is characterised by relatively low mean annual precipitation (MAP) and highly variable yields, and while rainfall increases towards the east, inter-annual yield variability remains high. Variability of yields is already a concern for agro-ecosystems and it is hypothesised that it could be exacerbated by future climate changes.

A sustainability framework was used to assess the sustainability agro-ecosystems under plausible future climate scenarios. Three Quaternary Catchments were assessed ranging from relatively dry (MAP 432 mm) to relatively moist (MAP 903 mm). A sensitivity analysis of plausible scenarios was performed with incremental increases in temperature by 1, 2 or 3 °C, increases/decreases of rainfall by 10% and a doubling of pre-industrial atmospheric CO_2 concentrations to 555 ppmv.

From the present and nine plausible future climate scenarios which were modelled using CERES-Maize over a 44-year period, it is shown that climatic changes could have major negative effects on the already drier western, and therefore more vulnerable, areas of the South African Highveld. An increase in temperature increases the variability of yields in the relatively moist Piet Retief area (MAP 903 mm), while at the more sub-humid Bothaville, with a MAP of only 552 mm, the inter-annual variability remains the same but mean yield over 44 seasons is reduced by 30%. A simulated increase in temperature coupled with a doubling of CO_2 increases the rate of soil organic nitrogen depletion from the agro-ecosystem. Therefore, long-term perspectives in regard to human well-being and ecological integrity need to be applied to policies and actions for sustainability of both commercial and smallholder agro-ecosystems, particularly, in the western Highveld.

Keywords: Agro-ecosystem; Climate change; Sustainability; Food security; South Africa

1. Introduction

Agro-ecosystems are ecological systems modified by human beings in order to produce food, fibre or other agricultural products (Conway, 1987). The agro-ecosystems in the Highveld region of South Africa (Fig. 1) produce 70% of the country's commercially grown cereal crops, with 90% of its maize being cultivated there (du Toit et al., 2000). The sustainability of the maize producing agro-ecosystems is of huge consequence to food security in South Africa and to the well-being of the rural economy of the Highveld. A change not only in the mean climate, but also in its variability, can have significant impacts on an agro-ecosystem.

Chambers (1997) recognises that humans are at the centre of agro-ecosystems and that their well-being is a key issue for the sustainability of agro-ecosystems. Based on this concept, a general definition of sustainability used by the authors in this paper is: 'Sustainability is applying long term perspectives, in regard to human well-being and ecological integrity, to policies and actions'. (Walker and Schulze, 2006a).

The sustainability of agro-ecosystems in the region will be influenced, *inter alia*, by the El Niño phenomenon, by climate change and by land use changes resulting from the above two and other market or politically related factors.

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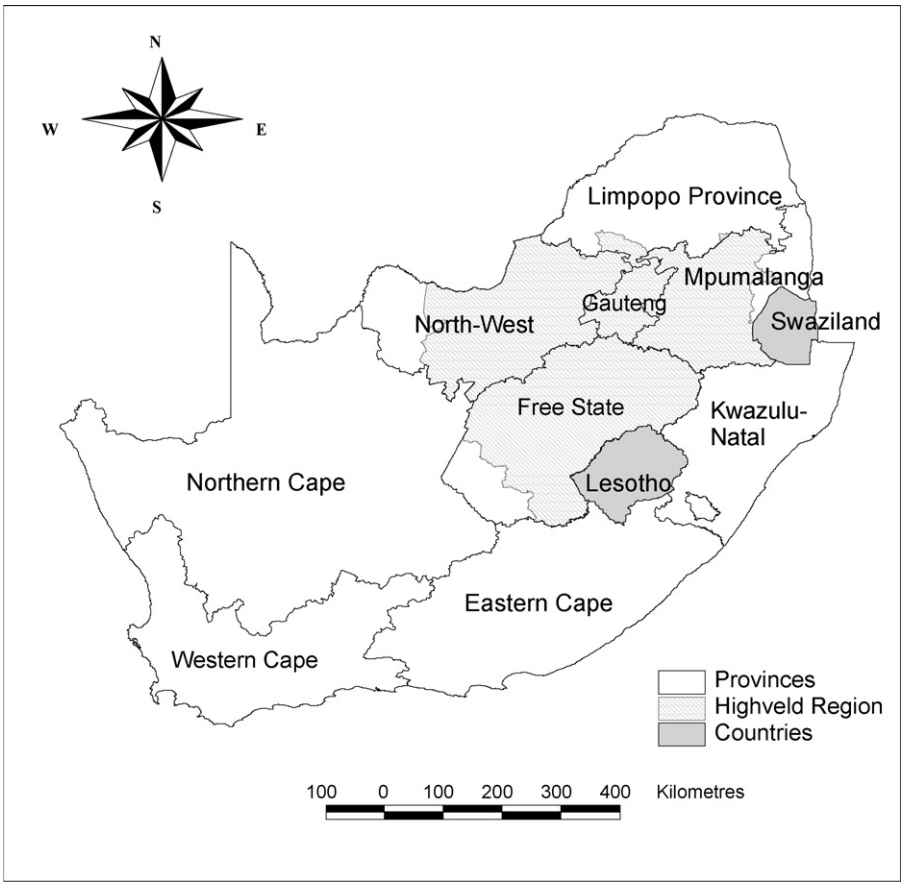

Fig. 1. Highveld region shown in the context of the provinces of South Africa (after du Toit et al., 2002).

The influence of El Niño on the seasonal rainfall in the Highveld region is a reality for farmers (du Toit and Prinsloo, 1998), since it influences directly both their economic security in the long term and local food security in the shorter term. Superimposed climatic changes of enhanced concentrations of CO_2 in the atmosphere and resultant increases in temperature and changes in rainfall patterns (IPCC, 2001; Engelbrecht, 2005) could affect food security and agro-ecosystem sustainability significantly in the long run.

Average maize yields in the drier western half of the Highveld are particular sensitive to climate variability under present climate conditions already, with current average commercial yields being between 1000 and 3000 kg ha^{-1} (du Toit et al., 2000), depending on farming practices and the amount of rainfall during the growing season and it is hypothesised that their vulnerability will increase with climate change. This raises issues of sustainability at a regional and national level, as breakeven yields for a commercial farmer in the western Highveld of South Africa are just over 2000 kg ha^{-1} (du Toit et al., 2000).

In attempting to understand the inter-relationships between social, economic and environmental influences that are associated with sustainability, a systems approach to sustainability is therefore essential (Ikerd, 1993; Hansen and Jones, 1996). For such a systems approach a framework was adapted from von Wiren-Lehr's (2001) goal-orientated system. Hansen (1996) considers it necessary to characterise the concept of sustainability when using it to identify constraints, to identify research foci and for policy development. Incorporating Hansen's and Jones' (1996) method to characterise sustainability, the adapted sustainability framework has the following four steps:

- Goal definition (i.e. defining sustainability, spatial scales, stating required framework outputs; ensuring that the goal selected is one that is realistic to obtain);
- Sustainability modelling (i.e. selecting the simulation model and the model outputs to use as quantitative indicators of sustainability);
- Evaluation strategy (i.e. comparing quantitative measures of different strategies to managing the system); and
- Management advice (i.e. making recommendations that are predictive, with constraints to sustainability being identified).

This paper concentrates on part of the system, i.e. sustainability modelling. The objective of this assessment is to investigate agro-ecosystem sustainability in response to a range of plausible climate scenarios at the spatial scale of Quaternary Catchments in the Highveld region of South Africa. Quaternary Catchments are climatically,