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An assessment of sustainable maize production under different management and climate scenarios for smallholder agro-ecosystems in KwaZulu-Natal, South Africa

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Abstract

The need to improve smallholder rainfed maize production in a sustainable manner is important in South Africa, as maize is a staple food to the rural indigenous population. Smallholder maize production is often characterised by low yields, which are often significantly lower than the potential for the land. However, sustainable maize production is not only a question of yields, but also of protection of the environmental resource base, social welfare, and the livelihoods of farmers as well as adjacent rural and urban communities. Sustainability for the smallholder farmer raises questions of household food security, farmer and community well-being as well as agro-ecosystem integrity.

Sustainability was assessed at the smallholder agro-ecosystem scale using a goal-orientated sustainability framework. The use of the physically based CERES-Maize crop model within the sustainability framework meant that agro-ecosystem responses to different management options (e.g. tillage systems and fertiliser application) and climate change scenarios could be quantified. The agro-ecosystem that has been simulated is at Potshini village, which is about 10 km from Bergville in the western-central region of KwaZulu-Natal province, South Africa. The agro-ecosystem was simulated for different management strategies for a range of plausible future climate scenarios for South Africa. The future climate scenarios of '$2 \times CO_2$' and '$2 \times CO_2 + 10\%$rain' had the biggest positive effect on mean grain yield. These scenarios had increases of over 1000 kg/ha with inorganic fertiliser and ~200 kg/ha with manure. The largest negative effects on yield are with the '+2 °C' scenario. The biggest increase in losses of organic nitrogen were with the '$2 \times CO_2 + 2$ °C' scenario where losses increased by up to 5%.

Keywords: Sustainability; Agro-ecosystem; Smallholder; Food security; Climate change

1. Sustainable smallholder agro-ecosystems

The population in sub-Saharan Africa is predicted to increase to over one billion by 2025 (Inocencio et al., 2003). In order to meet the food requirements of the increased population and achieve food security by 2015, agricultural production would need to increase by 6% per annum (Inocencio et al., 2003). These advances will need to be made with the added problem of predicted climate change. Climate change will potentially affect the lives of people in many ways, particularly in Africa where many poor smallholders depend on agriculture for their livelihood and where there are few alternatives of earning a living (Jones and Thornton, 2003).

The need to improve smallholder rainfed maize production in a sustainable manner is important in South Africa as maize is a staple food. Smallholder maize production is often characterised by low yields, which are often significantly lower than the potential for the land. Sustainable maize production is not only a question of achieving reasonable yields, but of government policy on agriculture, protection of the environmental resource base, social welfare, and the livelihoods of farmers and adjacent rural and urban communities. Sustainability for the small-scale farmer raises questions of equity, economic viability of

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their operations and household food security. It is valuable to investigate sustainability at the field scale using both field data and model simulations for an improved understanding of food security at the household level. At the household level it is crucial for the farmer to minimise the fluctuations in household income over time, as well as to maintain or increase a particular wealth level and nutritional status (Thornton and Wilkens, 1998). The small-scale farmer is more susceptible than commercial farmers to climate variability and its impact on yields.

The use of a systems approach is deemed essential in assessing agro-ecosystem sustainability and in understanding the inter-relationships between social, economic and environmental influences that are associated with sustainability (Ikerd, 1993; Hansen and Jones, 1996). In this assessment the following working definition of sustainability, based on the work of Chambers (1997), is used: 'Sustainability is applying long-term perspectives, in regard to human well-being and ecological integrity, to policies and actions'. The definition of sustainability selected is central to the determination of types of agro-ecosystem functions used to assess sustainability. In regard to this paper, long term is considered to be two generations, or 40–50 years. This length of time is useful as rainfall in South Africa has been identified by previous research (Tyson, 1986) as having 18–22 year 'cycles'. The climate data set used included 49 years of data which ensured that the period to test sustainability covered at least two of these cycles. A goal-orientated framework was adapted from von Wiren-Lehr's (2001) goal-orientated system. This framework has been devised to answer the following questions: How can an actual agro-ecosystem be identified as being sustainable or not? What facets of a system make it sustainable? Are there research and operational implications associated with climate change? Incorporating Hansen and Jones' (1996) scheme to characterise sustainability, the adapted sustainability framework has the following four steps:

- Goal definition (define sustainability, spatial scales, state required framework outputs; ensure that the goal selected is one that is realistic to obtain).
- Sustainability modelling (select the simulation model and the model outputs to use as quantitative indicators of sustainability).
- Evaluation strategy (compare quantitative measures of different strategies to managing the system).

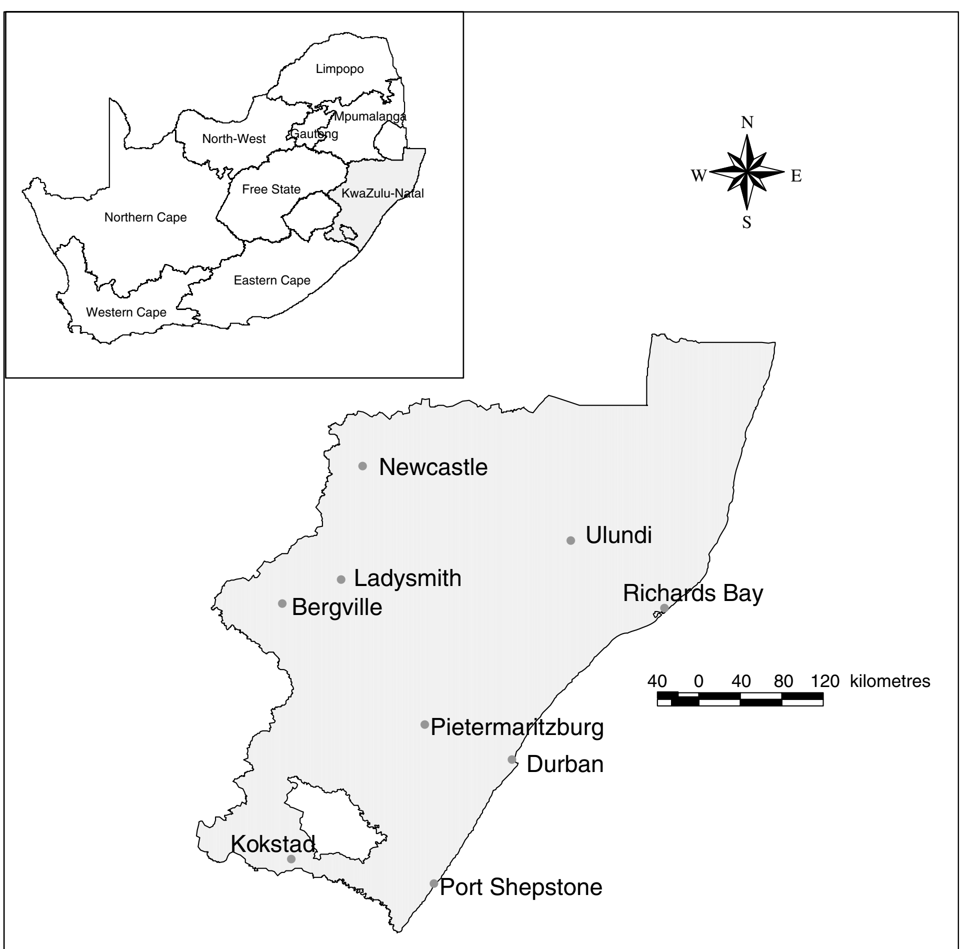

Fig. 1. Location of Bergville in KwaZulu-Natal, South Africa.