SHORT COMMUNICATION

CLIMATE CHANGE AND YIELD DECLINE: AN ANALYSIS OF ACTUAL AND SIMULATED YIELD DATA FROM THE BT1 FIELD EXPERIMENT

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Abstract

This communication briefly investigates the existence of long-term trends in yield as a result of soil degradation, technology improvement and climate change in the BT1 field experiment at Mount Edgecombe. It attempts to quantify the impacts of these factors by comparing simulated with actual yields from the last 50 years. The implications of these findings for future research focus and agricultural practice are discussed.

Keywords: yield decline, climate, harvest age, crop model, sustainability, soil degradation

Introduction

Efforts in agricultural research and practice are often re-directed following the acceptance of beliefs based on trends in production or production factors. For example, it is widely accepted that sugarcane monoculture, cane burning and inorganic fertilization cause soil degradation and consequent yield decline in the long term (Garside *et al.*, 2001; Meyer and van Antwerpen, 2001). This has led to the renewed focus on sustainable agronomic practices. Other notions that could influence resource allocation and management focus are ratoon yield decline, productivity improvement due to improved technology and climate change. These beliefs are difficult to validate because of the highly variable nature of dryland sugarcane production. Several decades of continuous observations would be required. Excellent data from the long term BT1 field experiment (van Antwerpen *et al.*, 2001) at Mount Edgecombe (29°42'S, 31°2'E, 96masl) provide such an opportunity. Comparing actual data from the experiment with simulated data from a reliable crop model will aid the interpretation of data by providing a consistent benchmark of agro-climatic yield potential.

This communication briefly investigates whether data from the BT1 experiment support the following hypotheses:

- Yields decline due to a degradation of the productive capacity of soil caused by unsustainable agronomic practices
- Yields increase because of improved technology
- Yields are affected significantly by climate change.

Method

Yield in a given year is determined by various factors. The long-term mean environmental potential (climate and soil) provides the underlying basis, while seasonal climate causes deviations around this mean. Other factors may cause systematic divergence of yields from the long-term mean, these include:

- long-term climate change
- technological improvement (improved cultivars and agronomic practices)
- soil degradation
- harvest age reduction.

It is necessary to quantify the effects of long-term climate change, inter-seasonal climate variation and declining harvest age, to distinguish these from the effects of technology improvement and soil degradation. The approach was to compare actual cane yields from the period 1954-2004 with simulated yields emanating from various weather input scenarios. These scenarios were:

- The base line weather data set that supposedly includes inter- and intra-seasonal variation, as well as climate change trends due to global and local climate change.
- A weather data set corrected for the local climate change by removing trends in wind.
- A weather data set that was corrected for local climate change, and also for global climate change, by removing trends in temperature and vapour pressure.

Climate trends were removed by fitting a linear regression on annual averages of a given variable versus year. Daily data were then adjusted accordingly with 1954 as the base year. Data available for the period 1941 to 1953 were not included in the analysis as the weather data were either incomplete or unreliable. After each adjustment, evaporative demand was recalculated according to the Penman-Monteith method.

The aforementioned three input sets were used to simulate yields with the Canegro model (Singels and Bezuidenhout, 2002) for the actual crop cycles used in the experiment. Soil characteristics of Arcadia soil form, Rydelvale series, were used as model input (rooting depth 120 cm, available water capacity 187 mm).

The effect of declining harvest age (from approximately 23 months in the 1950s to 12 months in the 1990s) was removed by annualising yields to a common crop cycle of 365 days. Simulated yields were then compared with yields recorded for the ‘burnt with tops spread, fertilised’ treatment.

Results

Climate trends

Significant long-term trends were identified for several weather variables. There has been a large, highly significant decline in wind speed (-1.9 km/d per year, R^2=0.728), presumably due to the growth of trees around the weather station site. Temperatures have increased significantly, especially minimum temperatures (+0.015ºC per year, R^2=0.306). This confirms the large body of evidence for global warming and is similar in magnitude to findings by Nayamuth (2005).

Mean vapour pressure deficit (MPVD) did not change significantly. Taking into account the fundamental relationship between temperature and MPVD this implies that mean vapour pressure has increased over this period.

Although there was no significant trend in rainfall, the data strongly suggest an increase in variability. There was no significant trend in solar radiation.

Yield trends

Correcting for the long-term trend in wind data caused simulated yields to decline relative to those from unadjusted data, due to an increase in evapotranspiration. This culminated in calculated yields over the last decade that would be on average 9 t/ha/an lower. Removing temperature and vapour pressure trends caused a further decline in yield, culminating in yields over the last decade that are on average 14 t/ha/an lower than for unadjusted data, and 5 t/ha/an lower than for wind corrected data.

This implies a yield increase of 8% over the last 50 years resulting from climate change (temperature increase of 0.75°C). This is ascribed to increased rate of canopy development, improved radiation interception and increased partitioning of assimilate to stalks (instead of leaves and roots). The impact on evapotranspiration and water stress seems minor. This contradicts the results of Nayamuth (2005), who used the APSIM sugar model to predict a 32% decrease in sucrose yield as a result of a 2°C rise in temperature. The conclusion is that climate change caused a small increase in actual yields.

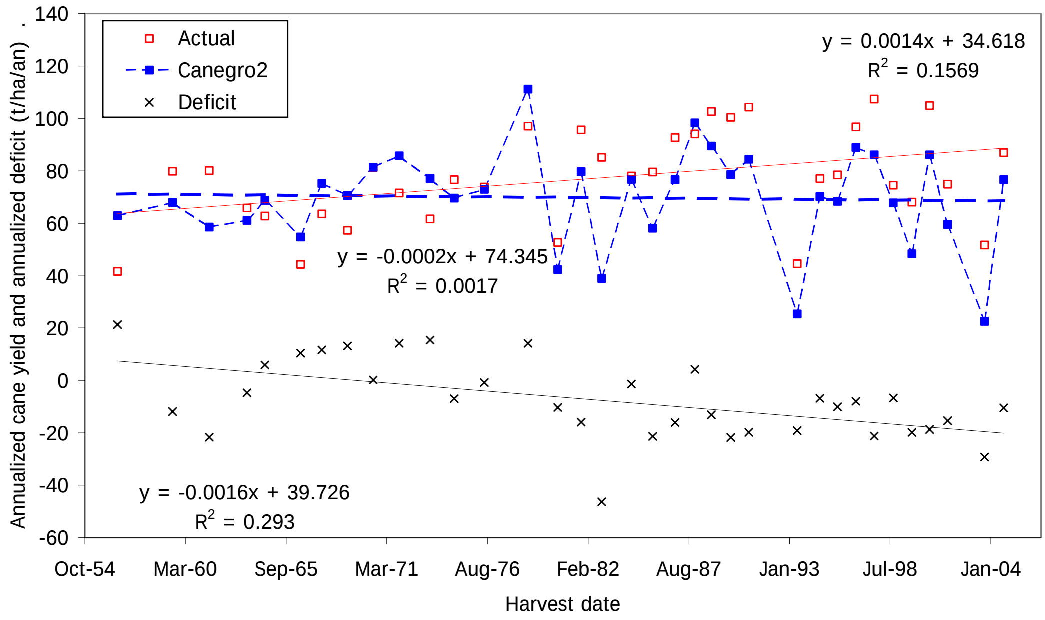

Figure 1. Annualised actual and simulated yields for the wind corrected weather dataset. The difference between simulated and actual yields (deficit) is also shown. The linear regression for each series is given.

Figure 1 compares actual yields with simulated yield for wind corrected weather data. This series of simulated yields is the best representation of actual yields because the long-term trend in wind is believed to apply only to the weather station and not to the experimental site. There is no significant trend in either of the two series. The model tended to underestimate yields especially in the latter part of the record. Apart from a few outliers, the model mimics inter-seasonal variation in yield reasonably well.

The difference between simulated and actual yields (known as yield deficit) is an indication of the impact from factors other than inter-seasonal climate variation and harvest age, such as soil degradation or technological improvement. There is a significant decline in the yield deficit (Figure 1), culminating in an average deficit of -15.5 t/ha/an in the last decade. Actual yields have therefore increased relative to environmental potential. This exceeds the estimated climate change impact of 5 t/ha/an, leaving a net positive impact of 10.5 t/ha resulting from soil degradation and technology improvement. The only technology that changed was the introduction of new cultivars (Co301, NCo376, N16, N27) and a reduction of harvest age. In terms of cane yield, the performance of N27 and N16 is not much better than that of NCo376 ([1]personal communication). It is therefore deduced that yields have increased mainly due to an increased growth efficiency (t cane/ha/month) of crops harvested at a young age and that this is not accounted for in simulations.

[1] Kerry Redshaw, Senior Agronomist (Varieties), South African Sugarcane Research Institute, P/Bag X02, Mount Edgecombe, 4300, South Africa.

Thus, there seems to be very little evidence of yield decline resulting from soil degradation, notwithstanding typical symptoms. Organic matter (and microbial mass and acitivity), pH, Ca and Mg content of the soil have all declined over time (van Antwerpen *et al.*, 2001), but current levels are still considered to be within the acceptable range.

There was no significant correlation (R^2=.0048) between yield deficit and ratoon stage. Hence, there is no evidence of ratoon decline in this experiment. It should be noted that the cane in is this experiment is harvested by hand and that no heavy machinery is used.

Conclusions

There is little evidence of loss of soil productive capacity over a 50-year period on the BT1 experiment despite the continuous practice of monoculture, cane burning and inorganic fertilization and in the presence of soil degradation symptoms. On the contrary, there is evidence of an increase in productivity as a result of reduced harvest age (10 t/ha/an) and climate change (5 t/ha/an).

It must be emphasised that these findings are relevant only to soils with similar characteristics (fertile, well buffered and no heavy machinery). However, the case study demonstrates that symptoms of soil degradation and the presence of practices that are deemed unsustainable do not necessarily require immediate intervention. Soil status should be benchmarked against quantitative thresholds that are linked with cane productivity. Decisions to intervene should be based on this information.

The study also demonstrated the importance of good yield and weather records as well as the usefulness of simulation modelling to assist yield decline investigations.

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