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Negative effects of lodging on irrigated sugarcane productivity—An experimental and crop modelling assessment

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ABSTRACT

Lodging lowers the productivity of sugarcane through a reduction in radiation use efficiency and stalk damage. However, there are few reports of experiments specifically designed to quantify effects of lodging in sugarcane. Efforts to model onset and progression of lodging, and the impact on crop productivity, have not been attempted. The objectives of this paper were to quantify effects of lodging on sugarcane and to develop modeling capability in terms of predicting lodging onset, progression and impact. Field experiments with irrigated ratoon crops were conducted at Pongola, South Africa. In one treatment the cane in each plot was allowed to grow through bamboo frames that prevented lodging. In the other treatment, the cane was not supported and could lodge at any stage. The degree of lodging was captured weekly by a rating that ranged from 1 to 9, where 1 = fully erect cane and 9 = completely lodged cane. At harvest estimated recoverable crystal percent (ERC %) of stalks and yield (cane and ERC) was measured for each plot. Lodging resulted in decreased ERC yields of up to 20.6%. An algorithm for simulating lodging when aboveground biomass (including rainfall and irrigation water retained on it) exceeds a variety-specific threshold, and which also considers wind speed and soil water content, was evaluated for predicting the extent and impact of lodging in the Pongola experiments, as well as for four deficit irrigation treatments of a field experiment conducted in Komatipoort, South Africa. The study showed that the onset of lodging was simulated reasonably well for various soil/crop/atmospheric conditions, while the extent of lodging at harvest was simulated very accurately for all crops. Simulated lodging was primarily driven by crop size and lodging events were triggered by rainfall that added weight to the aerial mass of the crop, and reduced the anchoring ability of the soil through saturation of the top soil. More accurate simulation of lodging, and its impacts on yield, will improve the accuracy of yield predictions by crop models, increasing their value in applications such as crop forecasting, climate change studies and exploring crop improvement and management options.

1. Introduction

Lodging can be defined as the loss of crop erectness due to either stem failure or stool tipping (Berding and Hurney, 2005). Two types of lodging occur in sugarcane namely stem lodging, in which stalks buckle and bend (and often snap), and root lodging (or stool tipping), in which root anchorage fails when they are pulled out of the soil and are sheared from the stool base. It is possible for both types of lodging to occur simultaneously within the same field. Lodging typically occurs in high-yielding crops (fresh cane mass in excess of 100 t/ha) under conditions of wet soil (poor support for roots), wet leaf canopy (altering the crop's centre of gravity) and strong wind (Singh et al., 2002).

In sugarcane lodging typically increases with increasing stalk height (Sharma and Khan, 1984). These authors found high correlations between lodging and stalk height and suggested that resistance to lodging was conferred by short sugarcane stalks. Their results showed that stalk weight and stalk thickness (diameter) at the top of the stalk aggravated lodging. Berding et al. (2005) established correlations between a number of phenotypic descriptors for erectness (stalk height, stalk diameter, stalk population density, leaves per stalk, leaf length and width) of sugarcane and showed that the strongest predictor of lodging was stalk height. These authors concluded that crop erectness could be improved by selecting clones with shorter stalks. However, it was also acknowledged that because of the strong genetic correlation between the

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traits, selecting for shorter stalks would invariably result in cane yield reductions.

Lodging is known to reduce the productivity of sugarcane through lower biomass production and a reduction in cane quality (Muchow et al., 1995; Singh et al., 2002; Berding and Hurney, 2005). These effects are caused by a reduction in radiation interception, radiation use efficiency, stalk smothering, stalk death and stalk snapping in lodged crops (Muchow et al., 1995; Singh et al., 2002; Park et al., 2005). More labour input is also required to harvest lodged cane and reduced payloads of cane delivered to the mill are common. Mechanical harvesting of lodged cane also results in infield damage to disrupted stools, which causes gaps inside the cane rows (Singh et al., 2002).

A detailed investigation by Park et al. (2005) into the so-called reduced growth phenomenon (RGP) considered the role that lodging may play in this phenomenon. Under conditions of RGP the linear relationship between cumulative intercepted radiation and biomass accumulation becomes uncoupled causing the crop not to attain its full yield potential (van Heerden et al., 2010). Park et al. (2005) cited 95% of potential yield being attained in cases where RGP did not occur compared with only 79% in crops suffering from RGP. Lodging and RGP co-occurred in 16 of the 34 cases studied by these authors. Generally, lodging occurred on average 81 days before the onset of RGP, which indicates that lodging could have been a contributing factor. However, despite lodging, RGP did not occur in nine of the 34 cases studied. This suggests that lodging does not necessarily lead to reduced growth or that it first needs to interact with other environmental factors.

There are very few reports of field trials specifically designed to quantify the effects of lodging on sugarcane productivity, mainly due to the practical difficulties in conducting these type of studies. Hurney and Berding (2000) showed, from paired-within-plot comparisons of erect and lodged (physically pushed over by hand) stalks, that lodging reduced sugar content by 1.2 units, or 9%. Lodging also caused stalk death and deterioration that resulted in cane yield increase to terminate or even decline (by up to 8%) before harvest. However, lodging close to harvest had no seriously deleterious effects on yields. In experiments conducted in Australia, sugarcane crops were physically prevented from lodging by means of bamboo scaffolding (Singh et al., 2002). These experiments revealed that prevention of lodging resulted in 11–15% and 15–35% higher cane and sugar yields, respectively.

Attempts to model the onset of lodging in sugarcane crops and the impact of lodging on crop productivity are few. The APSIM-sugar model (Keating et al., 1999) simulates yield reduction due to lodging through a user-specified stalk death rate and reduction in radiation use efficiency. The onset of lodging is also user-specified. The approach is therefore to force model simulation with observed data rather than representing cause/effect relationships. Inman-Bamber et al. (2004) formulated lodging rules in a simulation study with the APSIM model based on various combinations of dry biomass, rainfall and antecedent soil water content thresholds.

The DSSAT-Canegro v4.5 (Singels et al., 2008) and Canesim (Singels, 2007) models have an algorithm for simulating the occurrence of lodging events and their impact on crop processes. Simulated lodging occurs when aboveground biomass (fresh mass plus the estimated mass of rainfall and irrigation water retained on it) exceeds a given threshold. The threshold is variety-specific and also depends on wind speed and water content of the top soil. Lodging is simulated as an incremental process and the extent of lodging at each event is proportional to the magnitude of threshold exceedance. Lodging reduces interception of radiation and radiation use efficiency. Although the work by Singh et al. (2002) shows that different mechanisms contribute to lodging-induced yield reductions, the primary drivers of yield in the crop models are radiation interception and its efficiency of conversion to biomass. This lodging algorithm has not been tested and values of the various parameters (fresh aboveground biomass threshold, wind speed and soil water parameters) were based on anecdotal information. There is therefore a great need to evaluate and possibly refine the lodging algorithm to produce more accurate estimates of the extent of lodging and its impact on crop growth and yield for different varieties under different environmental conditions. A reliable model can be used for calculating lodging risks for different variety-environment-management situations, thereby assisting in the designing of management practices and breeding strategies to minimise lodging impacts.

The objectives of this paper were firstly to quantify the effects of lodging on sugarcane productivity under irrigated conditions, and secondly, to use the experimental evidence acquired from the field experiments to evaluate an existing model for predicting the onset and progression of lodging and its impacts on crop productivity.

2. Materials and methods

Two field experiments were conducted over consecutive seasons at the South African Sugarcane Research Institute's research farm at Pongola (27°24′S, 31°35′E, 308 masl). In the first field experiment lodging was studied in a crop on a May-harvest cycle (autumn). In the second field experiment the following year, lodging was studied in a crop on a December-harvest cycle (summer). These contrasting harvest cycles were selected to best capture most of the climatic conditions that mature crops experience in this production region.

Lodging was also carefully monitored in a field experiment conducted at the South African Sugarcane Research Institute's research farm near Komatipoort (25°37′S, 31°52′E, 187 masl). In this experiment, which was designed to study water stress effects (Rossler, 2014), four different deficit irrigation treatments were applied, leading to different patterns of growth and onset/severity of lodging. The data collected in this experiment were considered useful for model testing.

2.1. Trial details

2.1.1. Field experiment 1 (Pongola–Autumn harvest cycle)

A field trial was planted to variety N25 (chosen because of its high propensity for lodging) on 11 September 2008. At planting 300 kg/ha superphosphate and 250 kg/ha urea was applied in the furrow followed by a second application of 250/kg ha urea four months later. The plant crop was slashed-back on 31 March 2009 to establish an autumn-harvest crop cycle. The 1st ratoon was fertilised with 480 kg/ha urea applied as two equal split applications two months apart. Fertiliser was applied according to maximum crop requirements (in order to maximise biomass yields which would favour the occurrence of lodging) determined from soil samples taken before planting/slash-back and leaf samples taken from the young crop at an age of 3–4 months. The crop was initially irrigated by overhead sprinklers to bring the water in the soil profile to field capacity. Thereafter water was applied by surface drip irrigation to maintain soil moisture content in the top 60 cm of the soil profile between 75 and 95% of field capacity. Soil moisture content was monitored by means of Decagon 10HS soil moisture probes inserted into undisturbed soil at 15 cm and 45 cm depths at each of five positions within the field.

The experiment was a completely randomised design (CRD) with six replications per treatment. Each treatment plot comprised five cane rows 9 m long spaced 1.4 m apart. Plots were separated from each other on all sides by 2 m corridors of bare soil to ensure that lodging later on in the mature crop in one plot would cause the least possible impact on cane growing in adjacent plots. The trial