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Decline in the growth of a sugarcane crop with age under high input conditions

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Abstract

In Australian sugarcane crops, growth in terms of radiation use efficiency (RUE) can appear to slow down well before final crops are harvested, despite conditions that are considered favourable for growth. In order to assess the extent and cause of this reduced growth phenomenon (RGP), 14 experiments conducted in Australia were examined. From these experiments, 34 treatments were selected where nutrients and water were likely to be non-limiting and consequently the yields obtained were likely to be limited only by temperature and radiation.

Radiation use efficiency is defined as the measured amount of net biomass accumulated above ground per unit radiation intercepted. Accumulated biomass may have been lost through loss of stalks. In almost half of the treatments RUE significantly declined between approximately 223 and 665 days after crop start. The high incidence of RGP found in the analyses (a) challenges the previously held assumption that a constant value of RUE can be used to adequately describe biomass accumulation in sugarcane as a function of cumulative radiation interception and (b) suggests that relatively low growth rates during the later phases of the cropping season are frequently experienced throughout the Australian sugar industry. Reduced growth phenomenon resulted in actual biomass at final harvest being on average 21% less than potential yield, compared with 5% in crops that did not display a slowdown in growth.

Mean maximum RUE in the plant crop was greater than in ratoon crops, at 1.37 and 1.19 g MJ^{-1}, respectively. As there was no effect of location, cultivar, crop duration, ratoon crop class or fumigation treatment on RUE for the periods either before or after the onset of reduced growth, it would appear that the value of RUE is predominantly influenced by crop class. Despite the differences in RUE between the two crop classes, RGP occurred at a similar frequency in both plant and ratoon crops.

In order to gain a greater mechanistic understanding of the factors likely to be associated with the onset of the RGP, the relative time of lodging, specific leaf nitrogen (SLN), number of stalks and seasonal temperature were all considered individually. Whilst declining SLN and increasing stalk loss were associated with reductions in growth during the later

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periods of crop growth, it is likely that lodging also contributed to the widespread slowdown in biomass accumulation, whereas photosynthetic stress, as a result of extreme temperatures, did not play a substantive role in reducing growth.

Keywords: Radiation use efficiency; Extinction coefficient; Radiation interception; Reduced growth phenomenon; Specific leaf N; Lodging

1. Introduction

Increases in crop yield may be achieved either through an increase in resource input, or the more efficient use of present resources. However, once water and nutrients are supplied in sufficient quantities, the solar radiation receipt and its conversion to biomass will ultimately determine the productive potential of an environment. The efficiency of crop growth, when supplied with sufficient water and nutrient resources, can therefore be expressed as the relationship between biomass accumulation and the amount of solar radiation intercepted and assimilated into dry matter. Drawing upon this approach, radiation use efficiency (RUE) expresses the photosynthetic efficiency of a crop as the ratio of net above-ground crop biomass to intercepted radiation (Monteith, 1977). Whilst this calculation provides an actual value of RUE, RUE may also be expressed in terms of potential values using measures of gross primary production that may or may not include under-ground plant biomass.

Used as a measure of agricultural productivity, RUE enables the quantification of maximum productive capacity, or benchmark yield, of an environment to be assessed. This enables theoretical productivity to be compared against attainable yields (those taking into account losses due to water and nutrient limitations and climate variability), and actual yields (those taking into account all yield-reducing factors, including pests and pathogens, Rabbinge, 1993). Such comparisons provide a clear indication of the production losses and inefficiencies of a system, an estimate of the amount of input resources required to produce a specified crop output and identify the foci for future efforts to increase productive capacity.

A comprehensive review of RUE values across a number of crop species conducted by Sinclair and Muchow (1999) shows that the value of RUE varies with species. Although there are some important exceptions, there is a general trend for crops utilising the C_4 photosynthetic pathway, such as maize and sugarcane, to display the highest maximum values of RUE at approximately 1.65 and 2.0 g MJ^{-1} intercepted solar radiation, respectively. C_3 crops, including wheat, barley and rice, generally display comparatively lower values of maximum RUE, at approximately 1.46, 1.3 and 1.39 g MJ^{-1} intercepted solar radiation, respectively.

Radiation use efficiency is a measure of photosynthesis and is therefore dependent on canopy photosynthetic rate, which itself is related to nitrogen content per unit leaf area (referred to as specific leaf nitrogen, SLN) (Sinclair and Horie, 1989; Gimenez et al., 1994; Hammer and Wright, 1994). Leaf photosynthesis and RUE are not responsive to SLN at high levels. With decreasing SLN however, the rate of leaf photosynthesis becomes increasingly depressed and RUE values show a high degree of sensitivity to further changes in SLN once levels fall below saturation. Although no studies on the relationship between SLN and photosynthesis have been undertaken on sugarcane to date, a threshold of 1.2 g m^{-2} has been identified in maize as limiting RUE (Sinclair and Horie, 1989). Despite sufficient levels of N fertilizer, SLN is known to decrease during approximately the second half of sugarcane growth (Haslam and Allison, 1985; Wood et al., 1996). This is particularly prevalent during the reproductive stage in some determinate crops, when the mobilisation of N away from leaves to harvestable organs results in a reduction in RUE (Gimenez et al., 1994; Muchow and Sinclair, 1994). Drought (Muchow, 1985) and decreases in mean air temperature (Andrade et al., 1992) are also notable factors found to induce photosynthetic stress.

Lodging is a contributory factor in the decline in the rate of biomass accumulation in the later stages of sugarcane growth, either directly through disturbance to the crop canopy, smothering and/or the subsequent death of stalks (Muchow et al., 1994b; Singh et al., 2002). Reductions in growth have also been attributed