Field Crops Research 210 (2017) 136–146

Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Regional, seasonal, cultivar and crop-year effects on sugarcane responses to residue mulching

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ARTICLE INFO

Keywords:
Cultivar
Ratoon
Residue mulching
Sugarcane

ABSTRACT

Inconsistent agronomic responses of sugarcane (*Saccharum* spp.) to residue mulching are due to complex interactions between soil, climatic, management and genetic factors. Information on mulch responses of diverse cultivars in contrasting environments, over multiple ratoon crops, in different cropping seasons (winter vs summer) are limited. This study aimed to quantify mulch responses in three diverse environments typical of the South African sugarcane industry and to identify factors causing such responses. Three separate factorial experiments (eight cultivars, burnt or mulched at harvest) were established in the rainfed, irrigated and temperate regions of the industry, harvested over multiple ratoon crops (up to six), with summer and winter crop starts. Mulching was significantly beneficial to cane yields in the rainfed trial (up to 20 t/ha improvement in a single crop), marginally beneficial in the irrigated trial, and unfavourable in the cooler temperate trial. The effects of cultivar and season (winter vs summer crop start) were negligible in comparison to regional and crop-year effects. Cultivar sensitivities to mulching were only evident in the temperate trial. A principal components analysis (PCA) biplot separated crops according to their responses to mulching and identified climatic factors responsible for differential responses. Water availability (as represented by a crop model derived drought index) was a primary driver of positive yield responses in the rainfed trial and the differential ratoon responses observed in the irrigated trial. Mulch responses in the irrigated trial were rainfall dependent, ranging from 0 to 20% improvements in water limiting years, to negative responses when water was not limiting. Low temperatures created by the residue layer was identified as a cause of negative yield responses observed in the temperate trial, mainly through delayed canopy development effects. Multivariate methods such as PCA are recommended to identify climatic, soil, genetic and management causes of differential mulch responses in sugarcane, either through analysis of multi-environment experiments or through meta-analysis of available literature.

1. Introduction

Sugarcane (*Saccharum* spp.) residue mulching is the physical removal of green and dead leaf material from a standing crop at harvest for use as a mulch layer over the next ratoon crop. It is generally considered as an alternative to burning the standing crop to remove this extraneous material, which facilitates manual and mechanical harvesting. Mulching is a management practice that has been widely investigated as an alternative to burning in many industries (van Antwerpen et al., 2008; Wiedenfeld, 2009; Digonzelli et al., 2011; Arceneaux and Selim, 2012; Carvalho et al., 2016). The demonstrated benefits of mulching include improved soil water conservation and crop water use (Olivier and Singels, 2012), suppression of weed growth (Carvalho et al., 2016), improved cane and sugar yields (Chapman et al., 2001; van Antwerpen et al., 2006; Digonzelli et al., 2011), and improved soil health characteristics associated with the return of organic material (Graham et al., 2001; van Antwerpen et al., 2002; Ferreira et al., 2016). Despite these known benefits of mulching, widespread uptake of this practice is limited due to practical/economic considerations, and scenario-specific negative growth responses.

In the temperate growing conditions in Louisiana, negative responses associated with excessive waterlogging (Viator et al., 2009), increased frost damage (Sandhu et al., 2013), reduction in effective season length due to early growth suppression (Viator et al., 2005; Viator and Wang, 2011), and allelopathic effects (Viator et al., 2006), are well-understood. In these cases, residue removal after harvest is a logical practice to ensure productivity of the subsequent ratoon (Viator et al., 2009). Under tropical or sub-tropical conditions, however, the responses to mulching may not be as consistent. Here, factors such as soil type (Thompson, 1966), mulch load (Torres and Villegas, 1995;

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http://dx.doi.org/10.1016/j.fcr.2017.06.001
Received 6 April 2017; Received in revised form 30 May 2017; Accepted 4 June 2017
0378-4290/

Table 1
Experimental and agro-climatic differences between the three residue retention trials.

	Irrigated Trial	Rainfed Trial	Temperate Trial
Irrigation regime	Fully irrigated (overhead sprinkler)	Fully rainfed	Fully rainfed
Cultivars tested	N25, N32, N36, N40, N41, N43, N46, N49	NCo376, N27, N29, N39, N41, N42, N45, N47	94H0049, N12, N16, N31, N37, N44, N48, N50
Harvest cycle (age at harvest)	12 months	12 months	24 months
Number of crops (and seasons) tested	Three summer crops Three winter crops	Three summer crops Three winter crops	One summer crop One winter crop
Ann. minimum temp. (°C)	15.3	16.4	11.5
Ann. maximum temp. (°C)	27.9	26.2	23.4
Mean ann. rainfall (mm)	707	857	787
Trial coordinates	27°24′0″S 31°35′0″E	28°43′0″S 31°53′0″E	29°25′0″S 30°41′0″E
Soil type	Hutton (31% clay)	Shortlands (43% clay)	Cartref (20% clay)
Trial plot dimensions (including guard rows)	6 rows, 10 m long, spaced 1.4 m apart	5 rows, 7 m long, spaced 1.2 m apart	5 rows, 8 m long, spaced 1 m apart

Carvalho et al., 2016), crop duration (Ball-Coelho et al., 1993; Viator et al., 2009), crop-start date (Digonzelli et al., 2011), seasonal rainfall (van Antwerpen et al., 2006), prevailing germination conditions (Campos et al., 2010), and cultivar (Chapman et al., 2001; Lecler et al., 2009) interact to determine the ultimate response to mulching.

Studies on mulching are mostly scenario-specific, focusing on specific industry conditions. A key consideration often overlooked (or assumed) in literature is the nature of the harvesting system employed. The crop dynamics associated with a mechanically harvested mulched field are indeed different to those of a manually-harvested mulched field. Differences in mulch consistency (effects on water infiltration and germination), compaction effects, potential stool damage, and mulch load are likely to cause differential responses to mulching. Yet, a large majority of research in this area has focused on mechanical systems, with assumptions of applicability to manual systems in general. In South Africa, mulching is employed within a manual harvesting system as a large portion of the crop is planted on steep terrain (> 20% slope) where mechanised harvesting is not possible (Meyer 2005). Additionally, longer ratoon cycles thought to be associated with local varietal characteristics (generally between 7 to 10 crops harvested from single plantings) in South Africa suggest differing crop dynamics (particularly stalk population dynamics) that could impact differently on mulch responses.

The South African sugar industry may be separated into three distinct geographical regions. The coastal rainfed region is characterised by moderate to low potential soil and climatic features in a topographically diverse landscape. The irrigated northern region is characterised by less diverse topography and soils, lower rainfall and higher temperatures. The high altitude midlands (temperate) region is characterised by cooler temperatures (frosts are common in low-lying valleys), with fairly uniform soils. Here sugarcane is usually harvested at 24 months of age, in comparison to the 12–18, and 12 month harvesting usually practiced in the coastal rainfed, and irrigated regions, respectively. Some climatic and agronomic differences between the regions are described in Nxumalo (2015).

The practice of residue mulching is not common in South Africa, with an estimated 10% of the industry employing the system. Reasons for the lack of uptake of mulching as a routine practice include increased costs and reduction in harvest efficiency of labour, perceived increased transport costs (more leaf residue left on stalk compared with burning), and increased risks of unplanned fires. These logistical and practical reasons are also complemented by agronomic reasoning. Many growers have reported negative growth (not necessarily yield) responses to mulching in some regions with winter crop starts. Additionally, growers have reported negative responses to mulching of newer released cultivars, citing this as a reason for non-adoption of these cultivars. There is also uncertainty around the consistency of mulch responses over many ratoon crops in each of the regions. This study was undertaken to clarify the agronomic responses to mulching under different growing conditions typically encountered in the industry. The primary objective of the study was to quantify mulch responses of commercial cultivars in different regions of the industry when grown over multiple ratoon crops, and in different cropping seasons (winter vs. summer). A secondary objective was to identify factors influencing regional, seasonal, and crop-year (ratoon) dependent mulch responses.

2. Materials and methods

2.1. Experimental details

Three field experiments were established on regional research farms of the South African Sugarcane Research Institute (SASRI), on the east coast of South Africa in 2008. The sites represented the three major production regions of the industry, and will henceforth be referred to as the rainfed (coastal rainfed region), irrigated (irrigated northern region), and the temperate (cooler midlands region) trials. Each trial consisted of eight commercial cultivars (different cultivar sets tested in each trial – aimed at commercial relevance) that were either burnt or mulched at harvest. The mulched treatment entailed retention of a full residue blanket (brown and green leaf material), while the burn treatment entailed burning and physical removal of all residue i.e. a bare soil surface. All harvesting, residue spreading, and/or residue removal was done manually. Trials consisted of four replications, arranged as strip plots, with residue treatment (burn vs. mulch) as whole plots and cultivar as sub-plots. Plot dimensions varied between trials (Table 1), with outer guard rows of plots excluded from evaluation in all cases.

In all trials, data collection began on the first ratoon crop i.e. after application of the residue mulch. For the rainfed and irrigated trials, the first, second, and third ratoon crops were ratooned (harvested) in October at ages of approximately 12 months each. These crops will be referred to as “summer crops”, as they effectively ratooned (emerged) through summer. The fourth ratoon crop was grown for a period of eight months and then “cut back” in June to bring the trial into a winter crop start. Hence, the subsequent fifth, sixth and seventh ratoon crops from these trials, which were harvested annually in June, will be referred to as “winter crops” as they effectively ratooned through winter. For the temperate trial, the first ratoon crop that started in summer grew for a period of 24 months (summer crop). The second ratoon was “cut back” at eight months to bring the trial into a winter cycle. The subsequent third ratoon then ratooned (emerged) through winter and was harvested at 24 months of age (winter crop) (Table 1). This arrangement allowed for the assessment of responses to mulching with both summer and winter crop starts. The implications of the confounding ratoon effect (i.e. younger ratoons had summer crop starts while older ratoons had winter crop starts) on the interpretation of the