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Quantification of the effects of rotation breaks on soil biological properties and their impact on yield decline in sugarcane

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Sugarcane Yield Decline Joint Venture

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Abstract

Three contrasting rotation breaks (sown pasture, alternate crops and bare fallow) were established at five sites in Queensland, Australia, on land that had been under sugarcane monoculture for at least 20 years. The breaks were in place for 30–42 months at four sites and for 12 months at the fifth site. The effects of the breaks on selected soil biological properties were assessed following the removal of the breaks and before the area was re-planted with sugarcane. At the four sites with the long-term breaks, microbial biomass increased under the pasture break, declined under the bare fallow break and did not change significantly under the crop break, compared to microbial biomass under continual sugarcane. At these sites, populations of the root lesion nematode (*Pratylenchus zeae*) declined under all three breaks whereas populations of free-living nematodes increased under the pasture and crop breaks but declined under the bare fallow break. At the site with the 12 month breaks, a forage legume pasture increased microbial biomass, reduced lesion nematodes and together with the crop break increased populations of free-living nematodes. At the four sites with the long-term breaks there was an increase in the ratio of fungal:bacterial fatty acids and an increase in fatty acid 16:1ω5c (used as a biomarker for mycorrhizal fungi) under the pasture and crop breaks. Also at these sites, the soil microbial community under the pasture, crop and bare fallow breaks, respectively, showed increased, no change or diminished capacity to utilize carbon substrates compared to the soil microbial community under continual sugarcane. The yield of the sugarcane crop following all three breaks was significantly higher than the yield of the crop following continual sugarcane at each of the sites with the long-term breaks. Examination of the longevity of the effect of the rotation breaks on soil biological properties at the sites with the long-term breaks, suggested that effects on some soil organisms (e.g. lesion nematodes) maybe short-lived.

Keywords: Yield decline; Sugarcane; Rotation breaks; Pasture; Legume; Bare fallow; Microbial biomass; Fatty acids; Nematodes; Fungi; Fumigation

1. Introduction

Since the early 1970s, sugarcane in Australia has been grown largely as a monoculture, with the land re-planted to sugarcane shortly after the harvest of the final crop in a 4–5 year cycle. This system, referred to as plough-out re-plant (Garside et al., 1997) replaced a traditional system of sugarcane production where a 4–6 month fallow (either

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bare, as weeds, or a sown legume) was applied before the cycle was repeated. The practice of growing sugarcane as a monoculture has been accompanied by the more extensive use of inorganic fertilizers, insecticides and herbicides and by the introduction of mechanical harvesting with attendant use of heavy machinery to harvest and transport the sugarcane.

Whilst these changes have increased the efficiency of sugarcane production, a plateau in sugarcane yields was recorded for the 20-year period 1970–1990 (Garside et al., 1997) and is still evident today. This productivity plateau has been largely attributed to the intensification of growing sugarcane as a monoculture, which in turn has been responsible for a progressive decline in soil health. In glasshouse studies, substantial increases in sugarcane growth (often $>100\%$) can be achieved when soil that has been under long-term sugarcane monoculture is fumigated with methyl bromide (Croft et al., 1984; Magarey, 1994, 1996), leading to recognition that the practice of growing sugarcane as a monoculture is associated with a soil-based production constraint now referred to as yield decline. Yield decline has been defined as ‘the loss of productive capacity of sugarcane soils under long-term monoculture’ (Garside et al., 1997).

While the causes of yield decline are complex, current evidence suggests that a combination of factors associated with the current sugarcane management system (e.g. growth of sugarcane as a monoculture, frequent aggressive tillage operations between crop cycles, heavy harvesting machinery) have resulted in sugarcane soils becoming physically, chemically and biologically degraded and thus conducive to the growth and survival of soil organisms detrimental to the growth of sugarcane (Magarey, 1996; Garside et al., 1997; Pankhurst et al., 2003). Several soil organisms associated with yield decline have been identified, including pathogenic fungi (e.g. *Pachymetra chaunorhiza*, *Pythium arrhenomanes*) (Magarey, 1994, 1996), and root-infecting nematodes (e.g. *Pratylenchus zeae*—lesion nematode, *Meloidogyne javanica*—root knot nematode) (Stirling et al., 1996, 1999).

In 1993, a multidisciplinary research program known as the Sugar Yield Decline Joint Venture (SYDJV) was established to investigate the cause and develop solutions to yield decline in the Australian sugar industry. The SYDJV developed a farming systems approach to the problem with a major focus on the re-introduction of a rotation break into the current sugarcane farming system. Rotation breaks are used universally in agriculture to break disease cycles and to improve general soil fertility. To this end the SYDJV established a series of rotation experiments at five sites across the sugar industry, incorporating three contrasting breaks. The breaks were a sown pasture, alternate cropping (usually involving a grain legume), and a bare fallow. These breaks were selected with the aim of inducing contrasting differences in soil properties and thus different impacts on soil factors associated with yield decline.

The objective of the research reported in this paper was to examine the effects of the three contrasting rotation breaks on a range of soil biological properties including the lesion nematode. It was predicted that the different breaks would have contrasting effects on the soil biology which would be reflected in the yield of the following sugarcane crop.

2. Materials and methods

2.1. Rotation experiments

The rotation experiments were established at five sites located between latitudes 17°S and 25°S along the eastern seaboard of Queensland, Australia. Each site was located within a major sugarcane-growing region of Queensland and each site had grown sugarcane with minimum fallow for at least 20 years. The soil and climatic details of each of the sites are summarized in Table 1. At each site, the sugarcane

Table 1
Site characteristics and details of the rotation experiments

	Tully	Ingham	Burdekin	Mackay	Bundaberg
Location	Feluga	Lannercost	Brandon	Walkerston	Clayton
Latitude/longitude	17°52′S/145°57′E	18°36′S/146°03′E	19°33′S/147°19′E	21°10′S/149°03′E	24°50′S/153°30′E
Annual rainfall (mm)	4074	2020	945	1684	1100
Soil classification	Yellow Kandosol	Chromosol	Melanic Tenosol	Red Chromosol	Yellow Chromosol
Plot size	24×30 m	16.6×25 m	12×38 m	15.6×25 m	10.5×30 m
Date breaks established	December 1993	December 1994	November 1994	December 1994	October 1995
Length of break (months)	42	30	42	30	12
Sequence of crops	S,P,M,S,P,F,S	P,F,S,F,P	P,S,S,F,P,F,S	P,F,S,F,P	P,NB
Date breaks removed	July 1997	July 1997	July 1998	July 1997	August 1996
Date plots re-planted to sugarcane	October 1997	September 1997	August 1998	August 1997	October 1996
Irrigation	Nil	Nil	Full	Supplementary	Full

Soil classification was after Isbell (1996). The crops used in the alternate crop break were S, soybean; P, peanut; M, maize; NB, navy bean, F, fallow.