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Liquid fertilizer application to ratoon cane using a soil punching method

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ABSTRACT

Sugarcane is a semi-perennial crop that is cultivated for five or six harvest cycles before replanting. Following annual mechanized harvest, nitrogen (N) fertilizer is commonly applied during the ratoon cane sprouting phase through furrows along the side of plant rows (subsurface application) or banded on the surface. With subsurface application, mechanical operations are hampered by the trash coverage that remains after harvest; furthermore, opening furrows can partially damage roots. However, with soil surface application, nutrient uptake efficiency is decreased as a result of microbial immobilization and losses through ammonia volatilization and runoff. Thus, to achieve subsurface application for ratoon cane with minimal mobilization of the system (soil, straw and roots), this work aimed to (i) develop and evaluate a mechanical prototype that enables a soil punching process in ratoon cane and (ii) evaluate the cane yield using the soil punching method for liquid N fertilizer injection compared to liquid N fertilizer applied alongside of plant rows on the surface and subsurface (through furrows). To evaluate the punching mechanism, we performed a kinematic simulation (puncher tip displacement and injection time interval), tests in a soil bin and ratoon cane field. Based on prototype operations, the average distance between applications was 300 mm, with an average depth up to 90 mm, which was similar to the design requirements. Regarding results of liquid N fertilization methods in a ratoon cane field, we found that the incorporation treatments (soil punching and subsurface application through furrows) achieved slightly better cane yield (98–96 Mg ha^{-1}) when compared to the surface application (91 Mg ha^{-1}) and control treatment (75 Mg ha^{-1}). In general, the soil punching was considered as a promising alternative method for supplying liquid fertilizer at the subsurface using low-energy power (approximately 745 W) with minimal environmental impact.

1. Introduction

Sugarcane is the most promising source for ethanol and sugar production. Currently, Brazil is the largest sugarcane producer, with 688 million Mg cultivated on 9.8 million hectares (IBGE, 2015). Recently, the harvesting model of burning (to facilitate mechanical or manual harvest) has been replaced by mechanical green cane harvesting due to several environmental advantages, such as soil moisture maintenance, nutrient recycling, weed reduction (Marchi et al., 2005), legal issues (GESP, 2007) and lower labour intensive. However, fertilizer incorporation into the soil is hampered by the significant amount of trash coverage (mainly, dry leaves and tops) left on the soil surface after harvest (Cantarella et al., 2008; Vieira-Megda et al., 2015). In São Paulo (the largest cane-producing state in Brazil), studies performed after cane harvest have reported trash amounts ranging from 10 up to 20 Mg ha^{-1} (Fortes et al., 2012; Vitti et al., 2007a)

During sprouting and growth, which occurs after the annual cane harvest, nitrogen (N) is required in greater amount. In general, N is the most difficult nutrient to manage in sugarcane fertilization because of interactions with soil organic matter (SOM) and potential losses in the soil-plant system (Cantarella and Rossetto, 2010; Franco et al., 2010; Thorburn et al., 2011). In Brazil, the most

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common methods for N fertilization in ratoon cane utilize granular sources applied along the side of plant rows through furrows (subsurface application) or banded on the surface. However, N fertilizer applied on the surface without incorporation may increase N loss due to ammonia (NH_3) volatilization (Rodrigues and Kiehl, 1986; Cabezas et al., 2000; Prasertsak et al., 2002), especially when urea, uran, aqua ammonia or anhydrous ammonia is used (losses can be up to ~40%, Costa et al., 2003). This process is mainly caused by an enzyme present in the sugarcane straw (urease activity). The fertilizer incorporation into the subsurface can reduce volatilization (especially when urea is used), though fertilizer incorporation by means of furrows may have low efficiency and high costs (Mariano et al., 2012).

In general, surface application has advantages such as effective capacity for the field operation (hectares per hour); however, losses to the environment are more likely, contributing to less effective fertilizer uptake by the crop. On the other hand, site-specific management and incorporation of fertilizer into the subsurface can contribute to reducing the environmental impact, and supplying fertilizer near the roots to facilitate uptake. Within this context, liquid fertilizer injection into the subsurface represents an alternative strategy due to some favourable advantages for site-specific management, such as better control of application uniformity and the required dose, lower nutrient segregation (Boaretto et al., 1991; Korndörfer et al., 1995; Pio et al., 2008).

Liquid injection can be achieved by means of a punching process through the straw layer and soil subsurface using a probe, with minimal mobilization (soil and straw) without damage to the ratoon cane roots. Some mechanical equipment with a similar approach for liquid fertilizer injection can be found in Baker et al. (1989), Womac and Tompkins (1990), Chen (2002), Johann et al. (2006), Nyord et al. (2008), Lang et al. (2011), Liu et al. (2011), Wang et al. (2011) and Niemoeller et al. (2011). However, such equipment was developed to assist liquid fertilizer injection by considering the intrinsic characteristics of the crops in those studies (maize and rice).

In recent years, studies aimed at improving ratoon cane fertilization have mainly focused on evaluations of N fertilizer rates (Vitti et al., 2007a; Cantarella et al., 2008; Franco et al., 2010, 2011; Mariano et al., 2012; Otto et al., 2014) and N sources (Costa et al., 2003; Vitti et al., 2007b; Cantarella et al., 2008; Nascimento et al., 2013; Vieira-Megda et al., 2015). In contrast, studies about N fertilizer application methods are less common (Prasertsak et al., 2002; Vitti et al., 2007b), even though decisions about the application method are crucial to fertilizer uptake efficiency. Fertilization improvements can be reasoned with with regard to reducing loss to the environment in combination with greater uptake. Thus, application method can contribute to site-specific management when combined with other techniques, such as variable rate application, timing (application during the appropriate plant growth stage, i.e., when the fertilizer is most crucial) and splitting application (more applications throughout the crop cycle).

Liquid fertilizer application at the subsurface by means of minimal mobilization (soil, straw layer, roots) can be an alternative to supply fertilizer near the cane roots, contributing to loss reductions and fertilizer uptake increases. In an effort to achieve subsurface application with minimal mobilization, this work aimed to (i) develop and evaluate a mechanical prototype that enables a soil punching process in ratoon cane and (ii) evaluate the cane yield using the soil punching method for liquid N fertilizer injection compared to liquid N fertilizer applied alongside of plant rows on the surface and subsurface (through furrows).

2. Material and methods

2.1. Working principle

For prototype design, the requirements were subsurface application without tillage, through vertical soil punching (100 mm deep) with equidistant points of application (300 mm apart). The major components of the proposed mechanical system for vertical soil punching included a rotating drum cam, carriage, spline shaft, and slider-crank mechanism with a puncher (Fig. 1). The rotating drum cam was designed to drive the carriage along alternative movements in a longitudinal direction at the same forward speed. The slider-crank mechanism, which drives the punching mechanism for soil penetration was assembled on the carriage. The traction wheels were used to provide mechanical power, with synchronism conducted by a power transmission (sprockets, gears and spline shaft). Essentially, the working principle consists of punching mechanism synchronism related to the forward speed.

During soil punching, the longitudinal movement of the carriage cancels out the relative velocity opposing the forward speed, and the slider-crank drives the puncher tip vertically into the soil. In summary, the main kinematic characteristics for a punching cycle are as follows: (i) zero linear displacement during vertical soil punching; (ii) twofold linear velocity when the puncher tip is driven above the ground to the next soil punch. The period of cycle (T [s]) was determined according to the distance between equidistant soil punching points (s [m]) relative to the forward speed ($\dot{x}$ [m s^{-1}]), enabling calculation of the mechanism's angular velocity ($\dot{\omega}$ [rad s^{-1}]). To assist in the design, construction and comprehension of the soil punching mechanism, we performed a kinematic analysis by means of the Newton-Euler method. The characteristics verified in this analysis were the displacement of puncher tip and the injection time. For this, we carried out the simulation analysis using Matlab R2010a (The Mathworks, Inc. Natick, MA). Following construction and evaluations, we registered the product (Patent BR 102013018213 – Magalhães and Silva, 2013).

2.2. Evaluation methodology

2.2.1. Mechanical process of soil punching

First tests were conducted in a soil bin, where soil is free of organic material and stones, providing homogeneous soil conditions. This soil was originated from an arable Oxisol soil layer located in southern Brazil. According to the USDA textural triangle,

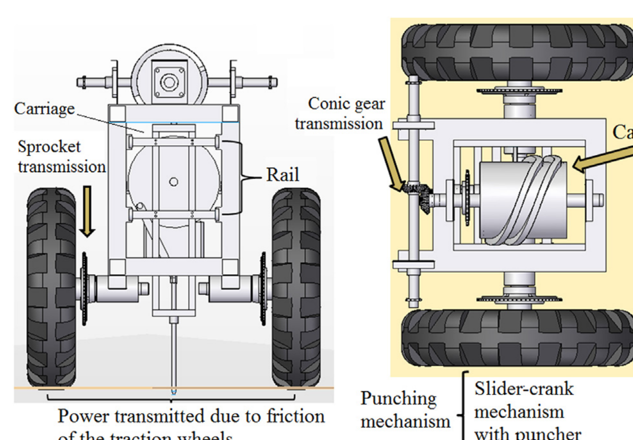

Fig. 1. Layout of the soil punching prototype. The machine was powered by traction wheels with the power transmitted using sprockets, gears and spline shaft.