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Strip-tillage using rotating straight blades: Effect of cutting edge geometry on furrow parameters

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ABSTRACT

Efforts to develop strip-tillage drills for two-wheeled tractors have often used conventional bent rotary blades designed for full disturbance soil tillage which have resulted in poor furrow backfill and smeared furrows. This soil bin study examined the use of rotating straight blades with a range of cutting edge geometries for cutting a 50 mm wide strip-till furrow. Results showed that a set of rotating straight blades can only create a furrow if the blade set exerts sufficient strain onto the soil volume between the blades. The furrow formation was aided when using either inside chamfered or square edged blades. For the same thickness of blades, double-side chamfered blades, due to applying a reduced strain, resulted in an uneven furrow of shallower depth at its centre along with a coarser soil tilth, and additionally produced smeared furrow walls. For the inside chamfered and the square edged cutting edge geometries the furrow backfill was the highest with only 20–26% of loosened soil ending outside the furrow. The outside chamfered blades applied a soil strain outward from the blade set which was not able to produce a furrow and only created two smeared slots in the soil. The study recommends inside chamfered blades be used for strip-tillage, with their optimum thickness related to the targeted furrow width, in order to apply the minimum strain required for achieving a targeted loosening result.

1. Introduction

Rotary tillers powered by two-wheeled tractors (e.g. Chinese made DF 12 model from DongFeng Agricultural Machinery Group Co., Ltd.) are commonly used in many developing countries to work the land. A rotary till drill (e.g. Chinese made 2BG-6A seed drill from Danyang Liangyou Machinery Co., Ltd.) or planter can be fitted to a two-wheeled tractor which can provide soil tillage and crop seeding in the one operation. To better suit conservation agriculture systems, recent efforts (Haque et al., 2010; Hossain et al., 2009) have focussed on further developing these small scale implements for rotary strip-tillage and seeding where soil disturbance is limited only to the seed furrow. Limiting soil disturbance in strip-tillage helps reduce fuel consumption, increase work rate and improve soil health and timeliness of sowing. However, there is a scarcity of small scale implements suitable for strip-tillage which is limiting its expansion in developing countries practicing small scale farming.

In strip-till planting the rotary blades cut through crop residue and soil during furrow loosening. Relevant literature highlights that the cutting edge profile must be designed to promote soil cutting, avoid residue entangling with the blade and minimize the torque requirement (e.g. Beny and Khoo, 1970; Sakai, 1999 Sakai, 1999). Previous research has shown that the geometry of the cutting edge of a tillage tool can significantly affect soil movement and soil forces. For example, Fielke (1996) found that a greater cutting edge thickness of a sweep blade creates an increased forward and downward movement of soil accompanied by higher draught and vertically upward forces. For a concave circular disc blade, Alam (1989) reported that the penetration ability is improved when the disc is sharpened on the concave side rather than on the convex side. Hassan (1980) investigating rotating soil pulverisers summarised that a wedge shape blade (double-side chamfered) minimizes the soil cutting forces and energy requirement. Kushwaha et al. (1983) found in a shear test with 30 and 90° bevelled blades cutting wheat straw that the sharper cutting edge significantly reduced the cutting energy requirement of the straw and recommended that the interaction of the cutting edge with soil should be taken into account for an efficient cutting of crop residue.

While a sharp cutting edge on a thin blade can more easily penetrate soil, in practice, manufacturers produce tools with thicker and potentially blunter edges to achieve a longer life

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Nomenclature

α_0	Edge curve angle at the blade tip (°)
β_j	Represents the rotary speed effect
δ_k	Represents the replication effect
ε_{ijk}	Represents the NID (0, σ^2) error component
k	1/18 (constant)
μ	Is the overall (grand) mean
r, θ	Polar coordinates of the blade cutting edge profile (mm, °)
r_0	Tilling blade rotor radius (mm)
rpm	Revolution per minute
S_b	Ratio of soil breakage (%)
τ_i	Represents the cutting edge effect
$(\tau\beta)_{ij}$	Represents the interaction effect of cutting edge and rotary speed
w/w	Weight / weight basis

(Fielke, 1996). During the course of field use, the cutting edge is subjected to wear and may get blunter or sharper depending on a range of soil and tool parameters, and hence there may be a change in the intended pattern of soil movement and force characteristics over the life span of the tool.

Rotary tiller blades have been found to smear the soil during furrow cutting with strip-till drills (Asl, 2006; Johansen et al., 2012; Hossain et al., 2009). Smearing is defined as a thin layer of soil compaction induced under high sliding pressure against a tool surface, in which the soil structure is destroyed and the porosity is significantly reduced. A smeared layer impedes gas and water movement as well as affects root penetration upon drying. This effect may confine the seedling roots to the seed furrow, increasing risks of seedling mortality in both dry and wet conditions (Iqbal et al., 1998). The process of smearing also increases the power requirement (Hendrick and Gill, 1974) and represents significant inefficiencies in the furrow cutting operation.

This paper follows on from the work of Matin et al. (2014) and Matin et al. (2015) which studied the effects of rotary blade geometry and operating speed on the soil cutting and throwing process and torque and energy requirements in strip-tillage. Their study found that conventional bent C-blades (having a sidelong and a lengthwise section) used for strip-tillage produced a fine soil tilth, but achieved a poor furrow backfill (mass proportion of the original soil retained in the furrow after tillage), measured at 41% at 500 rpm due to the soil carrying and throwing action of the blades. They showed that the backfill improved to 74% at 500 rpm when using straight C-blades (no sidelong section and having a 1.5 mm thick double-side chamfered cutting edge sharpened at 8°) which also produced a comparable fine soil tilth and significantly reduced the specific energy requirement. Hence, they recommended the straight blade as the preferred blade geometry for strip-tillage. However, straight blades can have different cutting edge profiles with limited information on the most efficient cutting edge geometry for use in small scale rotary strip-tillage operations. Therefore, this paper reports on an investigation of straight blades by examining the interaction of their cutting edge geometry with soil, in a strip-tillage context. It examines and quantifies the effect of four cutting edge geometries for blades of the same thickness (namely: double-side chamfered, inside only chamfered, outside only chamfered and square edged) on the process of soil cutting and throwing, and on various seedbed furrow parameters. Torque and energy data were also acquired and will be reported separately. Overall, the study aimed at recommending an optimum blade cutting edge design for rotary cutting of a strip-tilled furrow.

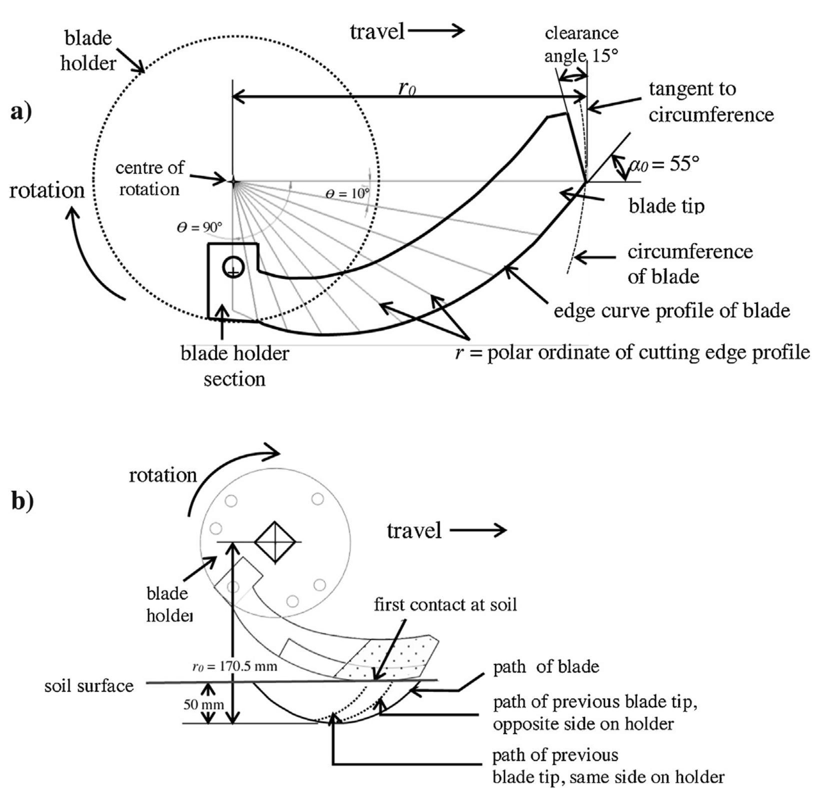

Fig. 1. Straight blade design for efficient soil cutting as per as per Sakai, 1999: (a) illustration of cutting edge profile and clearance angle, (b) soil-blade initial point of contact starting the soil cutting process (example blade paths shown for 250 rpm and v = 0.67 m s^{-1}).