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Tine options for alleviating compaction in wheelings

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ABSTRACT

Repeated trafficking and harvesting operations lead to high levels of compaction in inter-row wheelings used in asparagus (*Asparagus officinalis*) production. This reduces soil porosity and infiltration resulting in water ponding on the soil surface. Even on gently sloping land this can result in runoff generation and an increased risk of soil erosion. A winged tine (WT) is currently used by a leading asparagus grower to loosen compacted inter-row wheelings. In order to test the effectiveness of this tine for alleviating compaction and implications for runoff and soil erosion control, it was evaluated alongside several other tine configurations. These were a narrow tine (NT); a narrow tine with two shallow leading tines (NSLT); a winged tine with two shallow leading tines (WSLT); and a modified para-plough (MPP). Testing was conducted under controlled conditions on a sandy loam soil in the Soil Management Facility at Cranfield University, Bedfordshire, UK. Tine performance was assessed at 3 depths (175, 250 and 300 mm) by draught force; soil disturbance (both above and below ground); specific draught for a given level of soil disturbance; surface roughness; and estimated change in soil bulk density. The effectiveness of tines for compaction alleviation and potential for mitigating runoff and soil erosion varied with depth. The most effective tines were found to be the MPP NSLT and the WSLT at 175 mm, 250 mm and 300 mm depth, respectively.

1. Introduction

Compaction, alongside soil erosion, is the costliest and most environmentally damaging consequence of conventional agriculture (FAO, 2003). Graves et al. (2015) estimated the cost of soil compaction in England and Wales at £472 million a year. This figure includes the on-site costs of the loss of nutrients and crop productivity, the increased fuel required to work compacted soils and the environmental cost of nutrient and sediment pollution, as well as enhanced greenhouse gas emissions. Compaction degrades agricultural land. In Europe alone, compaction has degraded an estimated 33 million ha of agricultural land (Oldeman et al., 1991), of which 3.9 million ha are deemed at risk in England and Wales (Graves et al., 2015).

Row crop systems are particularly prone to compaction. This is a result of regular vehicle trafficking of inter-row wheelings located between the crop rows for repeated field operations. These exist in addition to sprayer tramlines. In hand-harvested crops such as asparagus these same areas are also foot-trafficked and/or harvested using 'picking rigs' under a range of climatic conditions for a 3-month period. This can result in shallow surface compaction and soil smearing of inter-row wheelings when undertaken in very wet conditions. In addition, herbicide use to control weeds results in the surface of asparagus rows being exposed to the kinetic energy associated with raindrop impacts resulting in surface sealing and on de-hydration, capping (Romkens et al., 1986). This significantly reduces infiltration (Philip, 1998; Assouline, 2004) into the asparagus rows with runoff shed to already compacted inter-row wheelings.

Tillage can instantaneously alleviate compaction by breaking through the compacted layer and increasing soil porosity. Tine configuration and arrangement can affect the extent of compaction alleviation. Compaction alleviation is greatest when tines work well above critical working depth (Arvidsson et al., 2004). Critical depth refers to the depth at which loosening operations are limited by confining forces that prevent the upward movement of compacted soil (Spoor and Godwin, 1978). Depth of operation and thus area of soil disturbance can be increased with a decrease in tine rake angle, the addition of wings, and shallow leading tines (Godwin and Spoor, 1977; Spoor, 2006). The resulting increased porosity allows water to infiltrate into the soil reducing surface water ponding and the risk of runoff generation. The additional pore space results in an increased soil volume creating an area of loosened soil on the surface. This loosened soil can further reduce

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runoff volume by increasing surface depression storage. Tillage increases soil surface roughness which can impart friction to overland flow and increase flow tortuosity. This will reduce runoff volume (by allowing time for the runoff to infiltrate) and reduce runoff velocity and erosivity of overland flow (i.e. energy to detach and transport soil particles). This effect on runoff and erosion is demonstrated in established runoff prediction equations where the roughness of cultivated surfaces can reduce peak flow (Rational Method, Morgan, 2004) and reduce runoff sediment transport capacity (Smith et al., 2011).

In asparagus production shallow soil disturbance is currently undertaken in inter-row wheelings at 175 mm depth to alleviate compaction, whilst limiting damage to the asparagus root system, which determines crop health. Root damage risks crop diseases (*Phytophthora asparagi* and *Fusarium)* that can dramatically affect the marketable yield, as well as lead to 'asparagus decline' (Snowdon, 1991). However, current tillage practice is not addressing on-site compaction adequately, as large-scale runoff and erosion issues still persist. Furthermore an on-site penetrative resistance survey (with an Eijkelkamp Penetrologger) conducted by the authors in April 2012 demonstrated compaction beyond 175 mm, extending to 500 mm with maximum resistance around 200 mm.

On-site erosion and runoff control can be achieved through a combination of shallow soil disturbance using a winged tine (WT) and application of surface mulch. This outcome has been observed on fully replicated and instrumented runoff erosion plots set up in asparagus inter-row wheelings situated in Herefordshire, UK (Niziolomski et al., 2014). Whilst different surface mulch options have already been investigated (Niziolomski et al., 2014), the efficiency of the current shallow soil disturbance practice has not. This study aims to address this knowledge gap. This in turn can aid the prevention of onsite soil degradation from compaction, contribute to improving the water quality of the local catchment and have wider implications of reversing and preventing soil degradation from compaction in row crops. In order to achieve this, a novel soil bin experiment was set up to evaluate the effect of tine configuration on alleviating soil compaction through above and below ground soil disturbance whilst considering implications for runoff and soil erosion control.

2. Material and methods

Five tine configurations were selected for testing (Table 1, Fig. 1) based upon their suitability for alleviating compaction in wheelings. With the exception of the winged tine (WT), all configurations were designed and built for this experiment. These were a narrow tine (NT); the currently adopted winged tine (WT); a narrow with two shallow leading tines (NSLT); a winged tine with two shallow leading tines (WSLT); and a modified para-plough (MPP).

2.1. Soil testing

Testing was undertaken at the Cranfield University Soil Management Facility, Bedfordshire, UK. A soil bin (20 × 1.7 × 0.7 m) filled with a sterile, light sandy loam soil (64% sand, 18% clay and 18% silt), was prepared in 50 mm layers to the planned depth of cultivation. Each layer was wetted to an approximate moisture content of 8.2% and subsequently rolled 13 times using a 700 kg roller to create compaction of approximately 1.6 g cm^{-3}. This bulk density and soil type closely reflected the field condition, i.e. a sandy loam soil (69% sand, 15% clay and 16% silt) with a bulk density of 1.7 g cm^{-3}. Once prepared, each tine configuration was mounted in turn onto the soil bin processor and tested.

Testing was carried out in triplicate at depths of 175, 250 and 300 mm below the ground surface. These were selected to simulate the current depth of operation and depths that would address the observed deeper onsite compaction. This was conducted in two phases; the first phase tested each tine at 175 mm depth, and the second phase at 250 and 300 mm depth. All testing was completed on one tine before moving onto the next. The order in which the tines were selected for testing was randomised. During the second phase, the depth of cultivation for each tine was randomised between 250 and 300 mm. Two tine runs were conducted along the length of each soil bin preparation giving an approximate plot size of 1.7 × 6.0 m (±0.3 m). Tines were pulled through at 2.1 km h^{-1}. For each soil bin preparation, soil bulk density samples were taken in triplicate down the centre of the soil bin at 0–5 cm depth prior to tine testing in order to ensure consistency.

2.2. Variables and data collection

Tine performance was assessed using seven indicators: draught force (D); soil disturbance (both above (D_{AG}) and below ground (D_{BG})); specific draught for a given level of soil disturbance (SD_D); surface roughness (both in-line (SR_I) and perpendicular (SR_P) to the direction of cultivation); and bulk density reduction. These were selected to assess implement dynamics and quantify the extent of compaction alleviation and soil properties beneficial to increasing infiltration.

Draught force was measured using a calibrated Extended Octagonal Ring Transducer (EORT), through a series of strain gauges on the tine mounting point (Godwin, 1975). These measurements were recorded using data logging software (Data Acquisition System Laboratory Ver. 8.00.04). The draught force measurements made it possible to infer tractor power requirements and fuel costs for each tillage system; with higher draught force associated with a greater power requirement and higher fuel cost.

In order to assess the efficiency of each tine in relation to compaction and potential runoff/erosion control, the traditional specific draught calculation was adapted to include both above and below ground disturbance. The resulting equation was:

Table 1
Technical properties of the tested tine configurations.

Description	Code	Geometry	Configuration
Winged tine	WT	Rake angle; 45°, wing inclination; 30°.	Single tine, in-line.
Narrow tine	NT	Rake angle; 45°	Single tine, in-line.
Modified para-plough	MPP	Tine and rake angle; 45°.	Two tines, in parallel.
Winged tine with two shallow leading tines	WSLT	Rake angle; 45°, wing inclination; 30°.	Two leading shallow tines spaced 220 mm apart, 350 mm ahead of main tine.
Narrow tine with two shallow leading tines.	NSLT	Rake angle; 45°.	Two leading shallow tines spaced 220 mm apart, 350 mm ahead of main tine.