Harvesting subterranean clover seed with peanut technology

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Abstract
Harvesting subterranean clover seed is technically challenging and is reliant on suction harvesters developed in the early 1960s. Current challenges with the cost, difficulty and environmental impacts of seed harvesting threaten the future of the seed production industry. To overcome these challenges, we are investigating the use of peanut harvesting technology to harvest subterranean clover seed. A two-row peanut digger was tested on two subterranean clover seed crops to evaluate its applicability and efficacy. Preliminary tests show this approach has the potential to harvest subterranean clover seed and address some of the negative impacts of the current system. Future work should evaluate machinery modifications, plant agronomy, seed physiology and commercial viability.

Keywords
Subclover, peanut digger, seed production, suction harvesting, Horwood Bagshaw Clover Harvester

Introduction
Subterranean clover (*Trifolium subterraneum* L.) is Australia's most widely sown annual pasture legume and forms an important part of Australia's farming systems (Nichols et al., 2012, Peoples and Baldock, 2001, Smith, 2000). However, harvesting subterranean clover (subclover) seed has inherent challenges due the plant's unusual seed setting mechanism. Subclover buries its seed, which increases the complexity of seed harvesting compared to aerial-seeded crops. Many seed harvesting approaches and technologies have been developed to meet this challenge, but there remain significant issues associated with subclover seed harvesting (Moss et al., 2021b).

Suction machinery is primarily used to harvest subclover seed today. However this process is slow, labour intensive and can negatively impact the soil, leading to erosion; these issues have resulted in a decline in the number of seed producers (Hassall and Associates, 2001, Loi et al., 2005, Moss et al., 2021a). Furthermore, the industry is dominated by a single harvester, the Horwood Bagshaw Clover Harvester, which has not been manufactured since the early 1990s and yet is still used by nearly all seed producers (Moss et al., 2021a). Suction technology and associated soil preparation were identified by Moss et al. (2021a) as the root cause of the primary issues affecting the seed production industry and advocate for new harvest methods to be researched.

We have identified peanut harvesting machinery as an applicable technology for potential use in the subclover seed industry. Peanuts are a below ground legume seed harvested in a two-step process. A "digger" first cuts the taproot, lifts the plant and inverts it into a row for drying before a "combine" collects and threshes the dried, inverted row (Bader and Sumner, 2009). If this technology can be adapted for subclover harvesting it will provide a faster, simpler and less destructive harvesting approach with existing machinery supported by a large commercial industry. In this paper we discuss preliminary investigations into this approach from one season and two sites of data.

Methods
Trial
A hydraulically powered, two-row peanut digger produced by Kelley Manufacturing (KMC) was tested and evaluated at two sites: The University of Western Australia Field Station (UFS), in Shenton

Park (-31.95, 115.80), Western Australia (WA) and at a commercial seed producer's property at Capel, WA.

At UFS, three cultivars of subclover were sown at 20 kg/ha on 22 May 2020: cv. Dalkeith (ssp. *subterraneum*), cv. Monti (ssp. *yanninicum*) and cv. Mawson (ssp. *brachycalycinum*). The cv. Mawson and cv. Monti were coated with commercial seed supplied by Barenbrug Seeds, while the cv. Dalkeith seed was scarified and inoculated with *Rhizobium leguminosarum* bv. *trifolii* strain WSM1325. These were grown on an irrigated sand dressed with loam. Super-potash 3:1 (180 kg/ha) was applied at sowing and re-applied in mid-September. Irrigation was applied when needed to prevent moisture stress and ceased on November 15. Other inputs and conditions were intended to represent a commercial seed crop. Peanut digger tests were conducted in November 2020.

At Capel tests were conducted in a rainfed commercial seed production paddock of subclover cv. Trikkala (ssp. *yanninicum*) on a fine textured, sandy soil. This was sown in April 2020 and had well-developed swards. Tests took place in this environment throughout December 2020.

Peanut digger machinery evaluation

The performance of the peanut digger was evaluated against different plant maturities and machine configurations. No physical modifications were made beside standard configuration adjustments of: blade angle, blade spacing, conveyor angle, gauge wheel height and three point linkage lengths. The machinery was initially set up in line with recommendations from peanut harvesting literature and adjusted iteratively as tested on subclover. The primary parameters and performance criteria are summarised in Table 1 and were qualitatively assessed. Plant senescence was scored on a 5 point scale from completely green and lush (5) to completely senesced (1). Harvesting success at varied levels of senescence was assessed by testing at progressing dates in the harvest season.

Table 1. Criteria for initial plant assessment, machine configuration and performance used to evaluate peanut digger tests.

Performance criteria	Root cutting effectiveness
	Plant lifting effectiveness
	Inverted row quality
	Soil retention in plant
	Seed loss
Plant condition	Senescence rating
	Biomass
Machine configuration parameters	Cutting depth
	Ground speed
	Conveyor speed

Results and discussion

Performance evaluation

The peanut digger was able to successfully cut, lift and invert subclover plants when operating in the optimal set up and conditions, particularly at UFS (Figure 1). However, at the commercial site issues were experienced with high soil retention and difficulty in maintaining appropriate cutting depth. Here the plant sward had formed a dense root structure that retained high amounts of soil in the inverted row. Further investigation is required to address sand retention and other issues. However, the results of this preliminary study were sufficiently promising (demonstrated the ability to pick up and invert rows without significant seed loss) to indicate that a peanut digger approach to harvesting subclover seed should be researched further.

Plant conditions
Plant conditions significantly impacted machinery performance with plants needing to have some strength to facilitate lifting from the soil whilst retaining burrs. Therefore, timing, weather and agronomy will be key factors to the success of this approach for subclover seed harvesting. More above-ground plant biomass increased the likelihood of material becoming tangled around the cutting blades or conveyor. These tests indicate that as long as there is a high level of plant interconnectivity, then above ground biomass can be reduced, which is already standard practice for suction subclover seed harvesting (Moss et al., 2021a).

As plants senesced, machinery performance deteriorated due to break up of plants, burr drop and reduced inverted row quality. Strength of stems and peduncles was the key factor in rows being effectively picked up and inverted. Senescence of leaves and petioles did not negatively affect performance. Subclover harvesting approaches with this equipment will therefore need to be undertaken prior to complete plant senescence. This contrasts current suction subclover harvest practices, but is similar to swathing other crops such as canola (Vera et al., 2007).

Figure 1. Subclover (cv. Monti ssp. *yanninicum*) row being cut and inverted by a peanut digger. Stems and peduncles are still green and allowed plant to form well connected row with high proportion of seed retained.

Machine configuration
Machine configuration had a significant impact on harvest quality and performance. Ground speeds of 3 to 4 km/h produced best results against the performance criteria under the conditions tested – compared to 4.5 to 8 km/h typically used in peanut harvesting (Bader and Sumner, 2009). It is expected that ground speeds could be increased to match peanut harvesting once the system has been tuned correctly. Conveyor speeds equal to or slower than ground speed produced best results, corresponding to the setup used for peanuts in heavy biomass conditions (Kirk et al., 2018).

Cutting depth was a critical parameter for ensuring effective root cutting, reduced soil retention and reduced seed loss. Optimal depth was immediately below the buried burr, which varied depending on soil conditions and cultivar, but was typically below 30 mm. This is shallower than peanut harvesting (which can cut as deep as 100 mm), due to shallower seed burial in subclover. The shallower cutting depth resulted in challenges maintaining depth control. More accurate depth control methods will likely be required in future research.

The two digging blades were set up so that there was minimal gap in the centre. This was necessary as subclover is grown in swards, whereas peanuts are grown in rows. This meant the blades were required to cut across their full width and flexing of the blade negatively affected cutting depth. Blade rigidity will need to be increased in future subclover testing and this may suggest a connected blade arrangement.

Conclusion

Peanut harvesting technology shows promise as an approach for subclover seed harvesting. Machinery modifications will be needed to address plant character differences between subclover and peanuts. Harvest timing and methods to harvest the inverted subclover row will need to be further studied as well as the agronomic and commercial implications of harvesting subclover seed earlier in the season. However, the results of this preliminary study merit further investigation into these areas.

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