No-Till Vegetable Production Using Organic Mulches

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Abstract

Conventional tillage practices and the use of polyethylene mulch has led to the loss of soil organic matter and increasing problems of erosion, water logging and soil compaction. A no-till system using permanent beds, permanent sub-surface irrigation and organic mulches grown in-situ, based on that developed by Abdul–Baki & Teasdale (1993) has been implemented as an alternative to conventional production. The system uses a tropical legume, *Centrosema pubescens* 'Cavalcade', or the C_4 grasses *Bothriochloa pertusa* 'Keppel' or 'Hatch' as cover crops over summer and fall. Cover crops are killed using glyphosate (1440g ai/Ha) and the residues left on the soil surface. Vegetable seedlings are then planted through the mulch residues and grown using conventional agronomic techniques. Following harvest, crop residues are macerated and the following cover crop direct seeded through the mulch residues. The development and implementation of this no-till system of vegetable production has resulted in significant improvements in soil aggregate stability, soil bulk density and soil biological activity, compared to polyethylene mulch and cultivation while crop yields are similar or improved.

INTRODUCTION

Vegetable crops are commonly grown in soils cultivated for structural management and weed control. Disposable drip irrigation is also often installed and removed annually, and herbicides or polyethylene mulch used to control weeds and protect fruit. While these practices produce high quality crops, they can also lead to a rapid decline in soil physical properties, and a subsequent reduction in crop yields. The yield decline appears to be related to poor soil physical conditions associated with declining organic matter levels combined with an increase in the incidence of soil-borne diseases (Adem and Tisdall, 1984; Morse, 1999). These conventional practices limit further sophistication of the production system and present problems of sustainability in the long term.

Cultivation and soil compression can be minimized by the use of permanent beds and controlled traffic (Adem and Tisdall, 1984; Lamers et al., 1986). Without additions of soil organic matter however, a permanent bed system cannot be sustained in the long term. Organic matter can be supplied in such systems by growing cover crops that are subsequently killed and left in place. This technique results in an organic residue on the soil surface that can control weeds and improve soil physical condition (Abdul-Baki et al., 1996; Abdul-Baki et al., 1997; Abdul-Baki and Teasdale, 1993; Teasdale and Abdul-Baki 1995). If the soil is left undisturbed as the cover crop residues decay, the soil space previously occupied by roots become biopores that provide useful voids through which air and water can penetrate (Stirzaker and White, 1995). Organic mulch residues left on the soil surface of uncultivated soil can improve soil moisture retention properties compared to bare cultivated soil (Schonbeck et al., 1993; Creamer et al., 1996 and Saiju et al., 2000).

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In most crops tested, the improved soil physical and biological properties found the no-till, cover crop system result in delayed but higher yields compared to growing systems involving cultivation. Yield increases have been observed in: tomatoes (Abdul-Baki and Teasdale, 1993; Abdul-Baki et al., 1996); lettuce (Stirzaker et al., 1989; Stirzaker et al., 1993); cabbage (Morse and Seward, 1986; Morse, 1993; Schonbeck et al., 1993); broccoli (Morse and Seward, 1986; Schonbeck et al., 1993); and snap beans (De Frank and Putnum, 1978). Equivalent yields to conventional tillage were observed in: broccoli (Abdul-Baki et al., 1997) and cabbage (Morse, 1993).

Some studies however (Bottenberg et al., 1999; Roberts et al., 1999) found that crops grown in mulch residues can produce lower yields than conventional production. Work undertaken by Brandenberger & Wiedenfeld (1997) showed that yield, fruit soluble solids and size of muskmelons grown on organic mulches were lower relative to a polyethylene mulch control. Wivutvongvana et al. (1991) also found lower yields under organic mulch and attributed this to a more stable diurnal soil temperature pattern under the polyethylene mulch control. Soils under organic mulches are around 3-5 ^{o}C cooler than bare soil or under polyethylene mulch (Stirzaker et al. 1989; Schonbeck et al. 1993; Stirzaker and White 1995; Creamer et al. 1996 and Borowry and Jelonkiewicz 2000).

The objective of the research was to develop a no-till, cover crop mulch system of vegetable production for the winter vegetable production areas of Australia and investigate the changes in soil bulk density, soil aggregate stability, earthworm populations, and crop yield under the no-till, cover crop mulch regime relative to conventional tillage and crop production under polyethylene mulch.

MATERIALS AND METHODS

The research was undertaken at trial sites in Bowen, North Queensland as part of a four-year study developing a permanent bed system for fresh-market tomato production using cover crop mulches.

The experimental site was established on two neighbouring fields of 1.6ha (no-till system) and 1.0ha (conventional production) respectively with 8 randomly positioned 10m long plots. The entire research site was part of a commercial tomato farming enterprise located at 19° 57'S and 148° 21'E near the town of Bowen, Queensland. Soil at the site was a light sandy clay loam of pH 7.1, 0.7% organic matter and CEC of 6.9 meq.100g^{-1}.

The soil was formed into beds and trickle irrigation tube laid 25 cm below the soil surface. Pre-plant basal fertilizer, which supplied nitrogen, phosphorus and potassium at 50; 50 and 40 kg/ha respectively, was banded and incorporated during the bed forming process. Cover crops of tropical legume *Centrosema pubescens* or tropical grass *Bothriochloa pertusa* 'Keppel' and 'Hatch' as well as *Sorghum bicolor* were direct seeded at 30, 4, 4, and 30 kg/ha respectively during summer and fall. After 8 to 10 weeks, the cover crops were killed by spraying with glyphosate at 1440 g ai/Ha, and residues left on the soil surface.

In late fall, tomato seedlings were transplanted through the mulch residues using a modified water wheel or cup planter. The balance of potassium (40 kg/ha) and nitrogen (25 kg/ha) was applied via fertigation, and crop nutrition checked using leaf analysis and comparing nutrient concentrations to published levels. The tomato crop was then trellised and managed conventionally and weeds growing through the mulch resides controlled using directed herbicide sprays, or hand weeding. Following the tomato crop harvest in spring, crop residues were broken up using a flail mulcher, base fertilisers drilled through remaining surface residues while the new cover crops were sown using a no-till seeder. No separate cultivation step was required once the beds were formed initially.

Following the establishment of a permanent bed/organic mulch system on a commercial basis, a study of soil physical characteristics was undertaken to quantify the changes in soil stability and compaction in relation to areas under conventional production.

In the comparative conventional system, soil was cultivated using rippers and discs in two directions following the previous seasons crop, sown to a forage sorghum cover crop, which was then incorporated into the soil using a disc plough and the soil left uncovered for up to six weeks prior to bed formation. Basal fertilizer which supplied nitrogen, phosphorus and potassium at approximately 80%, 100% and 100% respectively of the crop requirement was banded prior to laying polyethylene mulch and trickle irrigation tape. Processing style tomatoes (*Lycopersicon esculentum* Mill.) were transplanted through the polyethylene, trellised and grown to maturity. Following harvest the crop residues were broken up using a flail mulcher and the polyethylene mulch plus trickle irrigation tube pulled up and destroyed. Soil was then cultivated using two passes of a disc plough in two directions before being broadcast sown with a forage sorghum cover crop at a seeding rate of 15 kg/ha.

Soil samples for physical analysis and earthworm determination were taken from one site per plot (0-10cm depth). Large samples were taken at each sampling site to enable natural aggregates to remain intact and earthworms to remain active.

Soil aggregate stability was determined using a modification of the method developed by Emerson (1967) by placing air-dried aggregates approximately 1cm in diameter into in distilled water and the level of slaking observed after four hours. Four classes were devised to separate the samples: 1 = slakes & dispersive; 2 = slakes completely; 3 = slight slaking; 4= no slaking.

Soil Bulk Density was determined from soil samples taken from under polyethylene mulch, bare soil and *C. pubescens* mulch. The soil was dried at 105 ^{o}C, weighed and the volume determined by displacement after dipping in molten paraffin wax. Earthworm populations were determined by taking 1L soil samples form the top 10 cm of soil, sieving and the number of earthworms in each sample counted.

Crop yield was determined from five harvests over 14 days. Fruit was picked on colour as per commercial practice from eight 2m strips from within each treatment area. Fruit harvested was weighed and yield calculated on a per hectare basis.

RESULTS

Soil from conventional production areas using polyethylene mulch had significantly ($p<0.05$) lower aggregate stability than all other treatments. Soil aggregates taken from beneath cover crop mulches were more stable than aggregates under polyethylene mulch (Table 1) after one year under the no-till regime. Soil aggregates after three years of treatment showed similar statistical differences between the treatments.

Bulk density in permanent beds under *C. pubescens* mulch was significantly ($p<0.05$) lower than uncultivated bare soil and frequently cultivated polyethylene mulch (Fig. 1). Soil under frequent cultivation was significantly ($p<0.05$) more compacted than uncultivated bare soil.

There were significantly ($p<0.05$) more earthworms under *C. pubescens* and *B. pertusa* mulch than in uncultivated bare topsoil or under polyethylene mulch (Fig. 2). No earthworms were found in any sample under polyethylene mulch. There was also a high level of microbial activity as determined by fluorescein dye acetate under organic mulches compared to soil under polyethylene mulch (data not shown).

The yield of tomatoes after 5 harvests were not significantly different ($p>0.05$) for conventional and no-till production (Fig. 3).

DISCUSSION

The use of a continuous system of no-till vegetable production over three consecutive seasons of tomato crops has lead to a significant reduction in bulk density (Fig. 1) and improvements in soil aggregate stability (Table 1) and earthworm population (Fig. 2).

The changes in soil tillage under the permanent bed system have lead to significant improvements in soil physical and biological properties.

A permanent bed system has a number of benefits to farms growing vegetable crops on raised beds in horticultural production areas throughout Australia. The permanent bed system reduces the time spent in cultivation and laying polyethylene mulch before the crop; and lifting and disposal of polyethylene mulch, and cultivation after the crop. The system also has permanent trickle irrigation installed, negating the need for annual installation and removal of trickle irrigation tube following the crop.

The frequent disruption of soil structure in conventional tillage has led to a degradation of soil physical properties as shown by the lower aggregate stability (Table 1) and high level of compaction (Fig. 1) observed under the conventional treatments.

In contrast, the combination of reduced tillage and the retention of cover crop residues as organic mulch resulted in soil that has a higher aggregate stability and lower bulk density than under conventional tillage (Table 1, Fig. 1). The soil under the minimum tillage regime reflects the benefits of organic matter additions as demonstrated by the significant increases in worm populations (Fig. 2). This increase in organic activity may have led to soil aggregates binding together through secretion of organic compounds and the physical actions of the cover crop root system (Stirzaker et al. 1989). Leaving the cover crop to breakdown in-situ and minimising tillage maintains this structure over the long-term.

The difference between the production systems has practical implications for reducing erosion and runoff during crop production and during the cover crop stage. In the permanent bed system, the soil is not left bare for extended periods therefore reducing the erosion risk present in the conventional system. The soil structural improvements evident under the permanent bed system further reduce surface runoff and erosion risk during both crop production and cover crop stages by improving infiltration and reducing surface sealing and crusting. The higher level of aggregate stability in the permanent bed system also prevents any exposed soil from erosion during rainfall events.

The system of production described in this paper shows that vegetable crops such as tomatoes (and others, data not shown) can be grown successfully without reducing production for up to 4 years using cover crop residues without the need for cultivation.

The remainder of this discussion section outlines the main guidelines developed to assist growers in implementing this system on a commercial vegetable farm, and as outlined in Fig. 4 can be divided into seven stages:

1. Commencing the cycle
2. Sowing the cover crop
3. Managing the cover crop
4. Killing the cover crop
5. Establishing the commercial crop
6. Commercial crop growth
7. Sowing the next cover crop

Step 1: Commencing the Cycle

Base fertiliser must be applied at this stage, as it is the only point in the cycle when the soil surface is readily accessible allowing easier application of solid fertilisers. Soluble fertilisers can be applied just prior to the commercial crop through trickle irrigation or applied as a side dressing and watered in using overhead irrigation.

Step 2: Sowing the Cover Crop

Ideal cover crops for the summer period in the dry tropics are the Indian Bluegrass varieties ‘Hatch’ and ‘Keppel’ and a tropical legume *Centrosema pubescens* cv. ‘Cavalcade’. These cover crops form dense and stable mulches, however they are slow to establish and are poor competitors to weeds in the early stages of growth.

Step 3: Managing the Cover Crop

Typically it is best for efficiency that cover crops are maintained with minimal inputs of water, fertilisers and chemicals. However, as the quality of the mulch produced by the cover crop is vital to commercial crop productivity, some management is required to ensure maximum biomass is produced.

Step 4: Killing the Cover Crop

Cover crops must be killed to enable the commercial crop to establish successfully. The tropical grasses and legumes grown in commercial trials in Bowen were successfully killed using glyphosate at maximum label rates using an air assisted spray boom to ensure full coverage and penetration.

Step 5: Transplanting the Crop

Following the cover crop it is recommended that another soil test be taken to determine levels of nutrients remaining in the soil following the cover crop stage. This soil test can then be used to determine what rates of fertiliser may need to be applied through trickle irrigation before the commercial crop is established. Transplanting seedlings through organic mulches has required adaptation of existing technology to ensure a good and consistent establishment of the commercial crop.

Step 6: Growing the Crop

Crop growth following transplant follows a similar pattern to conventional agronomy, with careful management of nutrition, weed emergence, and irrigation. Crop nutrition should be monitored using leaf tests. Following harvest crop residues are slashed or mulched, the main priority at this point is to destroy crop residues whilst avoiding disturbance to the mulch residues.

Step 7: Sowing the Next Cover Crop

Cover crops are sown using no-till or minimum-till methods such as direct drill or light surface cultivation.

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Tables

Table 1. The aggregate stability of the top 10cm of soil at completion of vegetable crop harvest as affected by one season and three seasons of various mulch treatments. Four classes indicate the level of stability: 1 = slakes & dispersive; 2 = slakes completely; 3 = slight slaking; 4= no slaking. Letters following values indicate homogenous groups at p>0.05.

Mulch type	Aggregate Stability Class	
	1 Season	3 Seasons
Bare soil	4.0[a]	4.0[a]
Sorghum bicolor mulch	3.5[ab]	3.9[a]
Bothrichloa pertusa mulch	3.0[b]	4.0[a]
Centrosema pubescens mulch	2.8[b]	3.0[b]
Polyethylene mulch	1.3[c]	2.3[c]
	p>0.05	p>0.05

Figures

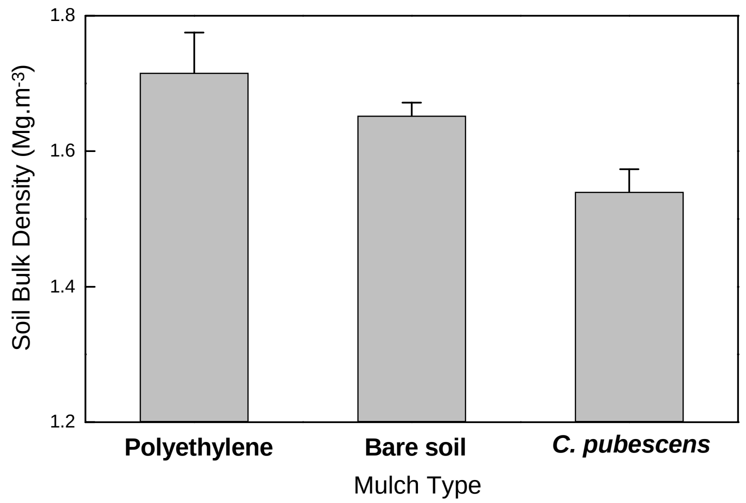

Fig 1. The dry bulk density of the top 10cm of soil at completion of tomato crop harvest as affected by one season of various mulch treatments. Plants were grown using polyethylene mulch and frequent cultivation; permanent beds, through Centrosema pubescens mulch residue; and no-till without mulch (bare soil). Vertical bars indicate standard errors.

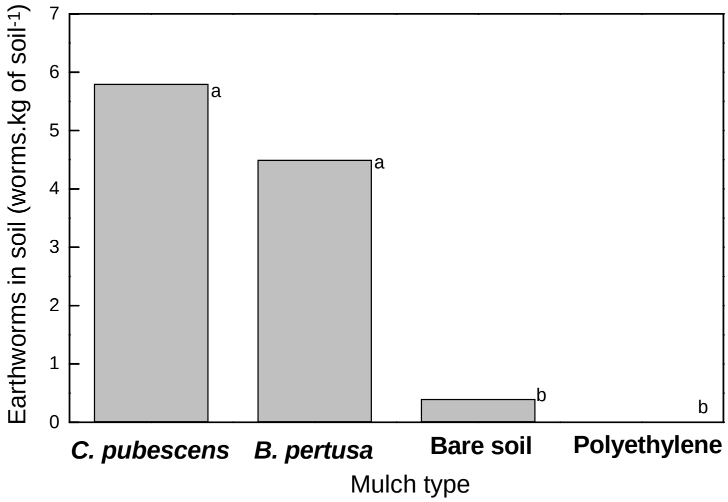

Fig. 2. The number of earthworms per kg of soil in the top 10cm of soil at completion of tomato crop harvest as affected by one season of various mulch treatments. Plants were grown using polyethylene mulch and frequent cultivation; permanent beds, through Centrosema pubescens or Bothriocola pertusa mulch residue; and no-till without mulch (bare soil). Letters following values indicate homogenous groups at p>0.05.

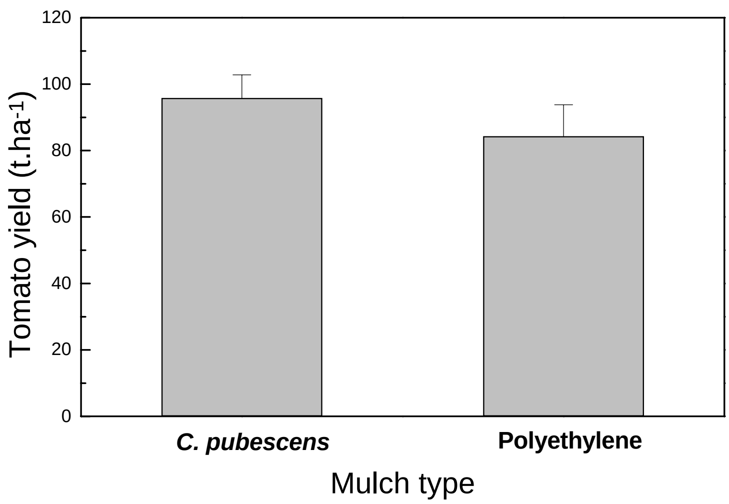

Fig. 3. The yield of processing style trellised tomatoes harvested 5 times. Plants were grown using polyethylene mulch and frequent cultivation or permanent beds, through Centrosema pubescens mulch residue. Vertical bars indicate standard errors.

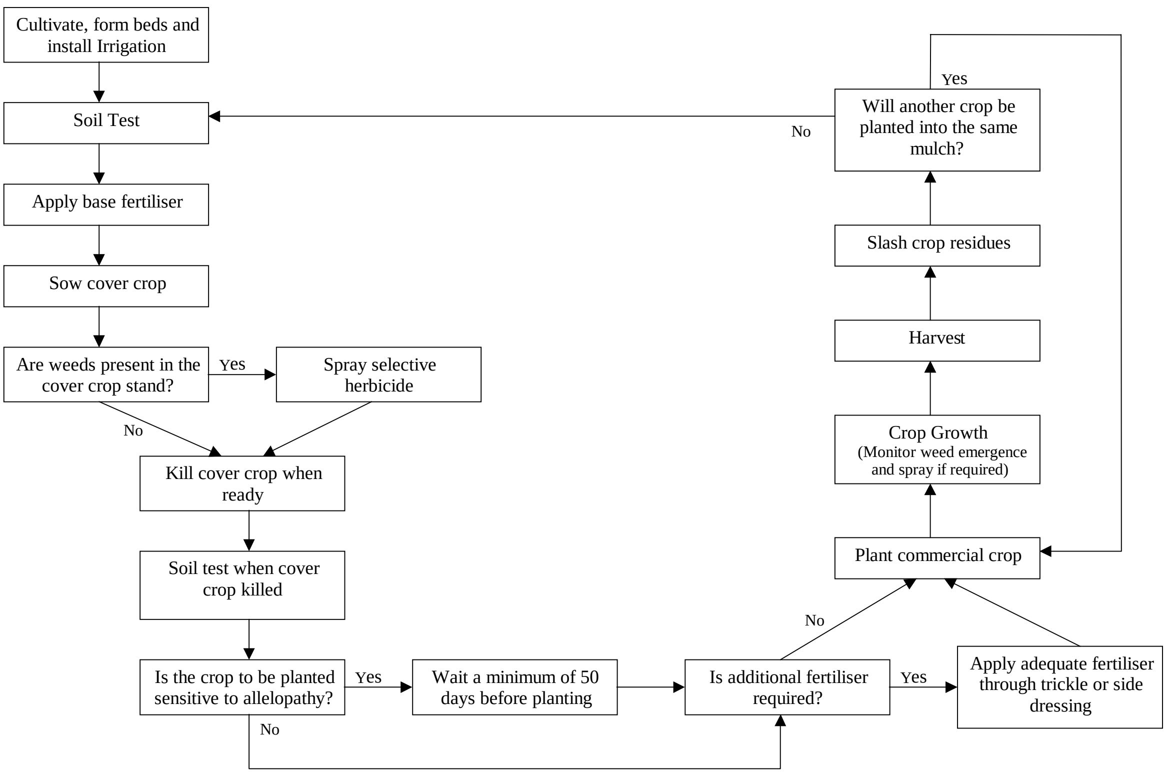

Fig. 4. A Chart of operations for implementation of a no-till permanent bed vegetable production system using in-situ grown cover crop residues.