

**VG97021**

**Investigation of plastic mulch alternatives  
for intensive vegetable production**

**Jason K Olsen**

**Queensland Horticulture Institute**



*Know-how for Horticulture™*

**VG97021**

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# **FINAL REPORT**

**HRDC project number VG97021**  
**(completion date 30 June 2000)**

**Investigation of plastic mulch alternatives for intensive vegetable  
production**

Jason K. Olsen

Queensland Horticulture Institute, Department of Primary Industries



**Queensland Government**  
Department of Primary Industries

HRDC project number VG97021

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## Media summary

Disposal of used plastic mulch has become a problem to the vegetable industry due to reduced land-fill capacity and environmental protection legislation. A research program conducted by the Queensland Horticulture Institute at Bowen, Bundaberg and Gatton investigated the suitability of biodegradable mulches as viable alternatives to plastic mulch. Two systems for applying mulch to the surface of soil were investigated, including the transported mulch system (materials transported to the farm) and the killed *in-situ* mulch system (cover crop grown in beds and killed).

A large range of biodegradable transported mulch materials were tested in capsicum crops for weed suppression, soil effects, and crop response. The costs per hectare of all of the biodegradable transported materials tested were in excess of that of the plastic mulch as follows: plastic mulch (\$860) < recycled newspaper (\$1,300) < sawdust (\$1,600) < Gromulch<sup>®</sup> paper film (\$1,630) < sorghum hay (\$2,000) < Mater-Bi<sup>®</sup> biodegradable polymer (\$3,300) < hessian (\$4,000) < sugarcane trash (\$5,900) < composted mulch (\$9,300). Capsicum fruit yields were no different for plants grown in plastic, paper, or biodegradable polymer films. Provided the practical difficulties of laying the Gromulch<sup>®</sup> paper film paper film can be overcome (tearing at laying and degradation at the soil surface) or the high cost of the biodegradable polymer is reduced, these materials appear to be the best of the biodegradable transported mulch alternatives tested to plastic mulch film.

The cost of establishing a killed *in-situ* mulch is relatively low (\$300/ ha) compared with the cost of purchase and disposal of plastic mulch film (\$1,100/ ha). However, uneven growth of the vegetable seedlings, low crop yields, emergence of volunteer weeds from late-germinating seed of the cover-crop, potential build-up of soil pathogens such as root-knot nematodes, and a long establishment time (about 9-12 weeks) makes this system unattractive to most commercial growers, despite the benefits to soil health which may be arise. Future research of the killed *in-situ* mulch system needs to focus on ways of overcoming the poor soil contact of the root-ball of the vegetable seedling at planting by trialing and sourcing suitable implements. Overcoming potential nutrient tie-up problems or allelopathy should also be addressed.

## Technical summary

Australian farming enterprises grow at least 9,000 ha of small crops (including tomato, capsicum, melon, cucurbit, strawberry) per annum on soil beds covered with polyethylene mulch, however, disposal of the used mulch is coming under increasing economic, environmental, and social pressures. Work conducted in this project centred around 2 systems for applying mulch to the surface of soil in which vegetable seedlings are planted; (1) the transported mulch system whereby mulch materials are transported to the farm and laid on the surface of the soil bed prior to planting the vegetable crop, and (2) the killed *in-situ* mulch system which involves growing a cover crop in designated soil beds, applying herbicide to kill the cover crop to form an *in-situ* mulch, followed by transplanting the vegetable seedlings. Using these 2 systems, biodegradable alternatives to plastic mulch were investigated in laboratory, pot and field trials conducted at Bowen, Bundaberg, and Gatton.

A large range of biodegradable transported mulch materials were tested for weed suppression, soil effects, and crop response in capsicum (*Capsicum annuum* L.). Paper film, biodegradable polymer film, and 7.5 cm layers of sugarcane (*Saccharum* spp.) trash, sorghum (*Sorghum bicolor* [L.] Moench) hay, or waxed fibre cartons provided weed suppression equal to that of plastic mulch. However, 7.5 cm layers of composted vegetative mulch, bagasse, or sawdust, a 3 cm layer of recycled newspaper, or a fabric of hessian did not. The similar weight of marketable fruit of capsicum plants grown in the biodegradable polymer film, paper film and plastic mulch indicated that the biodegradable polymer and paper films had the agronomic potential to replace plastic mulch film. The costs per hectare of all of the biodegradable materials trialed were in excess of that of the plastic mulch as follows: plastic mulch (\$860) < recycled newspaper (\$1,300) < sawdust (\$1,600) < paper film (\$1,630) < sorghum hay (\$2,000) < biodegradable polymer (\$3,300) < hessian (\$4,000) < sugarcane trash (\$5,900) < composted mulch (\$9,300). Provided the practical difficulties of laying paper film can be overcome (tearing at laying and degradation at the soil surface) and the high cost of biodegradable polymer is reduced, these materials appear to be the best of the biodegradable alternatives tested to plastic mulch film.

Without exception, the field trials conducted with capsicum at Bowen and Bundaberg and with broccoli (*Brassica oleracea* L.) at Gatton demonstrated lower growth and yield of the vegetable crop in soil covered by killed *in-situ* mulch than in uncovered soil. For capsicum, this growth reduction in the killed *in-situ* mulch was attributed to poor weed control and to an inadequate contact of the roots of the seedlings with the tightly root-bound soil. Tolerance testing of cover crop species to root-knot nematode (*Meloidogyne javanica*) showed that the legume species *Centrosema pascuorum* Annual centrosa cv. Bundy, *Lablab purpureus* Lab lab bean cv. Highworth, and *Vigna unguiculata* Cowpea cv. Red Caloona were highly susceptible to root-knot nematode, whereas *Aeschynomene americana* American joint vetch cv. Glen, *Bothriochloa pertusa* Indian couch cv. Bowen, and *Sorghum bicolor* forage sorghum cv. Jumbo were not. The cost of establishing a killed *in-situ* mulch is relatively low (\$300/ ha) compared with the cost of purchase and disposal of plastic mulch film (\$1,100/ ha). However, uneven seedling growth, low yields, emergence of volunteer weeds from late-germinating seed of the cover-crop, potential build-up of soil pathogens, and a long establishment time (about 9 weeks) makes this system unattractive to most commercial growers, despite the benefits to soil health which may be arise. For the killed *in-situ* mulch system, future research needs to be conducted into overcoming poor soil contact of the root-ball of vegetable seedling at planting by trialing and sourcing suitable implements. Overcoming potential nutrient tie-up problems or allelopathy should also be addressed.

# 1. Introduction

Australian farming enterprises grow at least 9,000 ha of small crops (including tomato, capsicum, melon, cucurbit, strawberry) per annum on soil beds covered with polyethylene mulch. The benefits of polyethylene mulch to crop production are well documented, and include greater root growth and nutrient uptake (Wien *et al.* 1993), earlier ripening and a higher yield of fruit (Abdul-Baki *et al.* 1992), and improved fruit quality and a lower incidence of viral diseases (Singh 1992) than plants grown without mulch. However, the practice of using polyethylene mulch in the production of agricultural commodities is experiencing increasing economic, environmental, and social pressures. The problem of disposal of spent polyethylene is compounded by a key recommendation of the National Waste Minimisation and Recycling Strategy (CEPA 1992) for a 50% reduction by the year 2000 (based on the per capita amount in 1991) of the quantity of waste destined for land-fill. Some rural municipalities, which incorporate large areas of small crop production reliant on polyethylene mulch, have already taken drastic action. For example, the Bowen Shire Council of the central Queensland coast does not accept spent polyethylene mulch at the land-fill site and growers are disposing the material down a nearby disused mine shaft. Environmental Protection Legislation introduced by the governments of some Australian states will limit future disposal options. Attempts to recycle the material have been hampered by practical difficulties and high costs. At best, the price of dumping spent polyethylene mulch is expected to rise significantly in the next 3-5 years. At worst, disposal at land-fills will be completely banned and illegal dumping will attract massive fines. Therefore, the need to investigate alternatives to plastic mulch film has never been greater.

The cost of lifting, baling and disposing polyethylene mulch following cropping depends on the integrity of the polyethylene, the length of rows, soil type, distance between bed centres, and availability of suitable machinery; it typically varies from \$150-240/ ha in major vegetable production areas of Australia. A comparable cost (US\$125-175/ ha) was estimated in the US by Anderson *et al.* (1995). By saving the cost of mulch removal and disposal and by augmenting the organic matter levels in their soil, growers currently using polyethylene mulch film could benefit by using biodegradable materials which can be tilled into the soil following harvest. Examples of biodegradable materials which can be transported to the farm (transported mulches) include paper film, starch-based polymers, timber products (e.g. sawdust, bark), or other plant products (e.g. hessian, straw or sugarcane trash). Killed *in-situ* mulches (which are formed from cover crops which are killed and allowed to lay *in-situ* prior to planting the vegetable crop) may also provide a mulch cover (e.g. Abdul-Baki *et al.* 1996; Stirzaker *et al.* 1993) and obviate the need for polyethylene film.

Several studies have been conducted to assess the effects of different soil mulches on the growth and yield of vegetable crops (e.g. capsicum – Roberts and Anderson 1994, Roe *et al.* 1994; okra – Tiwari *et al.* 1998; tomato – Teasdale and Abdul-Baki 1997). Most investigations have focussed on the influence of the mulches on soil temperature, but often the effects of the mulches on crop yield are explained in terms of parameters which were not measured. For example, reduced competition from weeds (Tiwari *et al.* 1998), changes in the efficiency of water and fertiliser use by plants (Abdul-Baki *et al.* 1992), shallow planting into thick organic mulches (Roe *et al.* 1994), or poor N nutrition in organic mulches due to N immobilisation (Roberts and Anderson 1994; Roe *et al.* 1994), leaching and volatilisation (Roe *et al.* 1994) have been advanced to explain the observed effects. Whereas there are many studies published in the earlier literature of the negative impact of weeds on vegetable crops (e.g. Freisen 1979; Weaver and Tan 1983; Teasdale and Colacicco 1985), there appear

to be few studies in past or recent times which have investigated the effect of weed suppression by different mulches on subsequent yield. Furthermore, objective assessments of the presence of substances which may be toxic to root growth have been rarely made in studies of different transported mulch materials.

Studies of cover crops grown *in-situ* to provide a mulch cover have rarely investigated the effects of the cover crops on organisms which may be pathogenic to the roots of the transplanted vegetable crop. For killed *in-situ* mulches, the problems of allelopathy (Stirzaker and Bunn 1996), insufficient cover to prevent weed growth, or late germination of volunteer seeds of the cover crop (Sutton 1998), need to be addressed before any recommendation of this system can be made to growers.

The objective of this project was to find biodegradable mulches that could take the place of plastic mulch film in vegetable production. Studies were conducted to examine these alternative mulches in both the transported and killed *in-situ* mulch systems.

For the transported mulch system, field trials using capsicum as the test crop were conducted at Bowen and Bundaberg to measure the effect of various transported soil mulches on weed suppression, growth of plants, and yield and quality of fruit. A bio-assay of the possible toxicity to growth of the mulch materials used in the Bundaberg trial was conducted to gain a greater understanding of the observed effects.

For the killed *in-situ* mulch system, observation trials with many entries were conducted to identify cover crop species that may be suitable as mulches. The 6 most promising cover crop species were then studied in a factorial field experiment at Bundaberg to assess their impact on weeds and their effects on growth and yield of capsicum. Complex field trials were also conducted to sort out practical management options for using a vigorous forage sorghum cover crop as a killed *in-situ* mulch in capsicum and broccoli production systems at Bowen and Gatton, respectively. An assay of the susceptibility to root-knot nematode of the promising cover crop species used in the Bundaberg field trial was also made.

## **2. Alternatives to polyethylene mulch film – a field assessment of transported materials in capsicum at Bundaberg**

by Jason K. Olsen and Reg K. Gounder, Queensland Horticulture Institute, DPI Bundaberg Research Station.

### **2.1 Summary**

Materials used as mulches may be either transported to the farm then laid on the soil surface or grown *in situ*. To assess biodegradable alternatives to non-degradable polyethylene film, the response of capsicum cv. Target grown in soil beds covered with hessian (burlap), hardwood sawdust, sugarcane trash, paper film, black biodegradable polymer film, white polyethylene film, or left uncovered was investigated in a field trial during the autumn/winter growing season in subtropical Australia. Use of a split-plot design (mulch whole plots with weeded or unweeded subplots) permitted both weed growth and the effect of weed competition on fruit yield to be measured. The presence of substances within the materials that were possibly detrimental to plant growth was assessed in a separate experiment. The weight of marketable fruit was highest for capsicum plants grown in the weeded subplots of biodegradable polymer and polyethylene, although the yields from these subplots were not different from those for plants grown in the weeded subplots of the paper and sawdust or the unweeded subplots of the biodegradable polymer and paper. The reduction in weight of marketable capsicum fruit from weed competition was ranked for the various mulch treatments as follows: paper < biodegradable polymer < cane trash < polyethylene < hessian < sawdust < bare soil. More hours at optimum soil temperature for root growth (18.9-30°C) prior to canopy closure probably accounted for the variation in marketable yield of the capsicum crop. Results from the mulch toxicity experiment indicated that the mulch materials were unlikely to contain phytotoxic substances. Provided the practical difficulties of laying paper film can be overcome and the high cost of biodegradable polymer is reduced, these materials appear to be the best of the biodegradable alternatives tested to polyethylene film.

### **2.2 Introduction**

This study was conducted to measure the effect of various transported soil mulches on the growth of plants and on the yield and quality of fruit of a capsicum crop grown during a typical autumn/ winter season in subtropical Australia. Assessments of the impact of weed suppression on yield, and of the possible toxicity of mulch materials to growth, were conducted to gain a greater understanding of the observed effects.

### **2.3 Materials and methods**

#### ***Mulch toxicity experiment***

The possible inhibiting effect of the mulches on seed germination and seedling growth was tested using the method described by Hunter *et al.* (1998), which recommended the use of sorghum (*Sorghum bicolor* [L.] Moench cv. Jumbo) as the test plant species. It was not considered prudent to alter the methodology of Hunter *et al.* (1998) by replacing sorghum with capsicum as the test species. Indeed, capsicum seeds were germinated and the seedlings were grown in trays under nursery conditions, well away from the soil beds covered with the various mulch materials. Samples weighing approximately 1 kg each of the polyethylene,

paper, biodegradable polymer, hessian, sugarcane trash, and sawdust mulches were ground through a 1-mm mesh in a stainless steel mill. Each ground material was then combined thoroughly in the ratio of 1:1 by volume with a peat/ perlite mix. A potting mix of peat/perlite alone was used as a control. A 200 mL volume of each potting mix, nutrient solution, a lime/ dolomite slurry and an amount of deionised water required to wet each potting mix to a free-drained state were placed and thoroughly mixed in 500 mL polypropylene containers. Twenty sorghum seeds were sown at a depth of 5 mm into the potting mix in each container. The containers were sealed with polypropylene lids and placed in a growth cabinet (12 h day/night cycle) from 26-29 March 1999; a temperature probe in the growth cabinet recorded a mean air temperature of 24.0°C (range 23.1-25.4°C). Seedlings and seeds which had not germinated were carefully recovered after the 3-day growth cycle and were washed in deionised water and blotted dry with a paper towel. Each seedling was stretched out on graph paper and the distance from the seed to the tip of the extended leaf and from the seed to the tip of the root system were recorded. Following these measurements, shoots were cut immediately above the seed and weighed. The 7 potting mixes were replicated in 6 blocks.

### **Field trial**

A field trial was conducted on a soil, variously classified as a Tropeptic Eutruxox (USDA 1975) and a Haplic Mesotrophic Red Ferrosol (Isbell 1996), to assess the effects of transported mulches on the growth response of capsicum cv. Target plants at Bundaberg Research Station (24°51'S, 152°24'E), Queensland, Australia. Analysis of the surface 15 cm of the soil showed it to have the following chemical characteristics: pH 6.5 (1:5 soil:water); electrical conductivity 0.4 dS/m (1:5 soil:water); organic carbon 1.1% ( $K_2Cr_2O_7 + H_2SO_4$ );  $NO_3-N$  3.5 mg/kg (1:5 soil:water); available P 165 mg/kg (1:100 soil:0.5M  $NaHCO_3$ ); exchangeable K 0.62 cmol(+)/kg (1:20 soil:1M  $NH_4Cl$ , pH 7.0); and effective cation exchange capacity 9.97 cmol(+)/kg.

On 31 March 1999, raised soil beds (1.5 m between centres) were formed into 9 rows of length 45 m, running in a N-S direction. Fertilisers were incorporated into the soil beds to supply the following elements (kg/ ha): 56 N, 116 P, 92 K, 195 S, 226 Ca, and 14 Mg. Polyethylene trickle irrigation tubing (wall thickness 200  $\mu$ m, internal diameter 16 mm, emitter spacing 300 mm) was laid along the centre of each bed at a depth of 3 cm below the soil surface. For the centre 7 rows, plots of length 10.5 m were left uncovered (bare soil) or were covered with one of the following mulch treatments: 25- $\mu$ m white on black polyethylene film with the white side facing up (25 g/m<sup>2</sup>; Beaver Plastics, Melbourne), 300- $\mu$ m recycled brown paper film (100 g/m<sup>2</sup>; Gromulch<sup>®</sup>, St. Regis Paper Company Ltd, Maidenhead, UK), 25- $\mu$ m starch-based biodegradable black polymer film (30 g/m<sup>2</sup>; Mater-Bi<sup>®</sup>, Novamont S.p.A., Novara, Italy; Bastioli 1998), hessian (200g/m<sup>2</sup>; Pope Packaging, Brisbane), a 7.5 cm layer of sugarcane trash (1.5 kg/m<sup>2</sup>), or a 3 cm layer of hardwood sawdust (10.3 kg/m<sup>2</sup>). With the exception of polyethylene film, the transported mulch materials were laid by hand. The outside rows were covered with white on black polyethylene mulch film (white side facing up) and were used as guard rows.

The 6-week-old capsicum (*Capsicum annuum* L. cv. Target) seedlings were transplanted into the field on 8 April 1999 into 50-plant plots arranged in a randomised blocks layout with 4 blocks. For each of the 28 whole plots, one-half (subplot) was randomly selected for regular weeding (weeded subplot) whereas the other subplot remained unweeded (unweeded subplot). For each subplot, the 25 capsicum seedlings were transplanted in a diamond

configuration in double rows 30 cm apart with 40 cm between plants in each row, resulting in a population of 33,333 plants/ ha. Three plants at the northern end (2 on the W side and one on the E side of the double rows) and the 2 plants at the southern end were designated as buffer plants, resulting in 20 datum plants per subplot. In the ensuing text, the position of a particular datum plant will be identified using the assumption that datum plants are counted from the S end of the subplot. Therefore, the nomenclature E5 refers to the 5<sup>th</sup> datum plant in the E row of a particular subplot, counting from the S end of that subplot.

The following elements (kg/ha) were administered through the trickle irrigation tubing between transplanting and the final harvest: 150 N, 29 P, 55 K, 99 Ca, 0.06 Zn, 0.17 B, and 0.03 Mo. A total of 15 fertigation were made, usually on a weekly basis, to provide 10 kg N/ ha per fertigation. The first fertigation was with urea the day following transplanting, but thereafter, a commercial blend of soluble fertiliser (CO<sub>3</sub>, Grow Force Australia Ltd) and Ca(NO<sub>3</sub>)<sub>2</sub> were applied alternately. Prior to fruit set (average fruit diameter 20 mm) on 2 June 1999, a total of 90 kg N/ ha had been applied by fertigation.

For each weeded subplot, tensiometer tubes were inserted to a depth of 20 cm within the row between E3 and E4. Tensiometer suction was measured at 5, 11, 19, 26, 34, 39, 46, and 53 DAT, prior to the first irrigation cycle for a given week. Irrigation water was applied up to 3 times per week to maintain the tensiometer suction of soil under the polyethylene mulch at approximately 10-30 kPa.

Two datum plants (E8 and W2) were selected in each weeded subplot for measurement of plant height (distance from the cotyledonary node to the terminal bud). The same 2 plants were measured 7, 11, 19, 26, 34, 39, 47, and 54 DAT.

For the period 21-27 April 1999, a temperature probe installed at depth 5cm under white polyethylene mulch at the N end of the unweeded subplot of block 3 recorded minimum diurnal values between 6:00 and 7:30 a.m. and maximum diurnal values between 2 and 2:30 p.m.. Within these specified times, temperature data at depth 5cm were recorded at 20, 27, 32, 40, 47, and 54 DAT at 2 fixed positions for each weeded subplot; viz. within rows at positions equidistant between E1 and E2, or between W8 and W9.

For the period 30 April – 7 May 1999, a temperature probe was installed at a depth of 5 cm in the weeded subplot of the bare soil, polyethylene, paper, and biopolymer treatments of Blocks 2 and 3; each probe was placed within the row and equidistant between E9 and E10 and recorded the soil temperature at intervals of 30 min.

The weeded subplots were hand-weeded at 35, 48, and 74 DAT. On each occasion, the weeds (primarily *Amaranthus viridis* L., *Eleusine indica* (L.) Gaertn., *Portulaca oleracea* L., *Solanum nigrum* L., and *Sonchus oleraceus* L.) were washed in tap water to remove adhering soil, placed in labelled paper bags, dried in a forced-draught oven at 65°C, and weighed. Measurements from each weeding were added to give the total weight of weeds removed.

The youngest mature leaf blade plus petiole (YML) was sampled from every plant within each weeded subplot at 42 and 55 DAT, corresponding to first anthesis and fruit set, respectively. Leaves were sampled between 7 and 10 a.m., placed and sealed in labelled plastic bags, and stored in an insulated box with cooling blocks until transportation to the laboratory where samples were held at 4°C before preparation. Petioles were excised, sliced into 5-mm pieces to promote sap expression, and crushed in a stainless steel garlic crusher

(pore size 1-2 mm). Sap was collected, immediately frozen, then stored before analysis. Nitrate in diluted sap (1:19 sap:deionised water) was determined by rapid colorimetric analysis (Merckoquant test strips analysed with a Nitracheck nitrate meter) calibrated to a regression curve using known nitrate standards (0, 25, 50, 100, 200, and 400 mg NO<sub>3</sub>/L made from KNO<sub>3</sub>). The excised blades of leaves sampled from the weeded subplots of the bare soil treatment (blocks 1 and 3 at 42 DAT; blocks 2 and 4 at 55 DAT) were immersed and gently agitated in a 1:40 solution of surfactant:tap water; the surfactant (Extran 300<sup>®</sup>) did not contain P. The samples were removed from this solution after 1 min and then immersed and gently agitated in clean tap water for approximately 20 s, followed by several rinses with deionised water. Washed samples were placed separately in labelled paper bags which were placed in a forced draught oven at 65°C until dry. The oven-dried leaf blades were ground through a 1-mm mesh in a stainless steel mill. Samples were dried again at 85°C for 48 h before chemical analysis. Total N was determined using Kjeldahl digestion followed by automated colorimetry (O'Neill and Webb 1970), whereas P, K, S, Ca, Mg, Na, Cu, Zn, Mn, Fe, B, and Al were measured using HNO<sub>3</sub> digestion and inductively coupled plasma emission spectrometry (Zarcinas *et al.* 1987).

The following pesticides were sprayed over the capsicum crop at standard rates: *Bacillus thuringiensis* and methomyl for lepidopterous insects; methamidophos for lepidopterous insects, green peach aphid [*Myzus persicae* (Sulzer)], and 2-spotted mite (*Tetranychus urticae* Koch); Cu(OH)<sub>2</sub> for bacterial spot (*Xanthomonas campestris* pv *vesicatoria*). Weeds in the inter-rows between soil beds were controlled by applications of paraquat at the standard rate.

Capsicum fruit were harvested from the 20 datum plants grown in each of the 56 subplots at 113, 124, and 138 DAT, then graded and weighed. Coloured fruit were harvested and considered marketable at >100 g in weight and if free from blemishes and deformation. Yield measurements from each harvest were added to give total yield values.

Following the final harvest, soil cores (43 mm diameter, depth 20 cm) were taken from 10 positions within the weeded subplots at 147-148 DAT (viz. within rows at 7.5 cm either side of the stems of plants E2, E5, E8, W4, and W7). The soil in each core was separated into 4 depths (0-5, 5-10, 10-15, 15-20 cm) and soil at each depth was bulked together for a particular subplot. Roots within each sample were washed free of soil, and placed in labelled paper bags which were placed in a forced draught oven at 65°C until dry. The dry roots from each sample were weighed, then placed evenly on acetate sheets and scanned to an electronic file using a Hewlett Packard ScanJet 4c. Root lengths were determined by computerised image analysis (Sci-Scan Image Analysis System, Delta T, UK).

Whereas no allowance was made for the effects of mulch types on modifying the water and nutritional status of the soil, variation among the treatments was minimised by the application of a luxury amount of water and nutrients. This 'nil intervention' approach was considered appropriate methodology to compare mulch treatments. Another approach, not used in the present study, is that of 'full intervention' in which growth of the capsicum crop would be optimised by modifying all inputs to suit the peculiarities of the particular treatment. That methodology was considered more appropriate for comparison of the systems necessary to manage the optimal growth of the capsicum crop grown in a particular mulch treatment than for the comparison of mulch treatments on capsicum growth.

### **Statistical analysis**

Analysis of variance was used to test the effects of treatments in both the mulch toxicity experiment and the field trial. Treatment means were compared using the protected l.s.d. procedure operating at  $P=0.05$ .

## 2.4 Results

### *Mulch toxicity experiment*

When used as a potting mix in combination with peat/ perlite, the finely-ground mulch materials had no effect on the germination of sorghum seeds after 3 days (Table 1). The length of roots of the sorghum plants was greatest ( $P<0.05$ ) in the potting mix containing sawdust and least ( $P<0.05$ ) in the potting mix with polyethylene (Table 1). Both the length and the fresh weight of shoots of the sorghum plants grown in the sawdust and control potting mixes were greater ( $P<0.05$ ) than those measured in any other treatment (Table 1).

**Table 1. Seed germination and seedling growth of sorghum grown for 3 days in potting mixes made from the various mulch materials used in the field trial**

Each mulch material was ground through a 1-mm mesh in a stainless steel mill and combined thoroughly in the ratio of 1:1 with a peat/ perlite mix

Methodology for the test is described in Hunter et al. (1998)

Means within columns followed by the same letter are not significantly different at  $P=0.05$  (F-test for treatments). The effect of mulches on seed germination was not significant

Potting mix	Germination (%)	Shoot length (cm)	Root length (cm)	Fresh weight of shoots (mg/ shoot)
Control	99.2	3.52b	5.32d	25.3b
Sugarcane trash	99.2	2.84a	4.79c	18.2a
Degradable polymer	99.2	2.97a	5.01cd	18.3a
Hessian	100.0	2.72a	4.97c	19.8a
Paper	99.2	2.91a	4.47b	20.3a
Polyethylene	97.5	2.95a	4.09a	21.1a
Sawdust	99.2	3.59b	5.83e	25.3b
l.s.d. ( $P=0.05$ )	2.3	0.45	0.32	3.7

### *Field trial*

The mean daily air temperature and irradiance and the total rainfall for each month spanning the duration of the field trial (from sowing on 8 April to final harvest on 24 August 1999) compared favourably with the Bureau of Meteorology 30-year average for these parameters (Fig. 1).

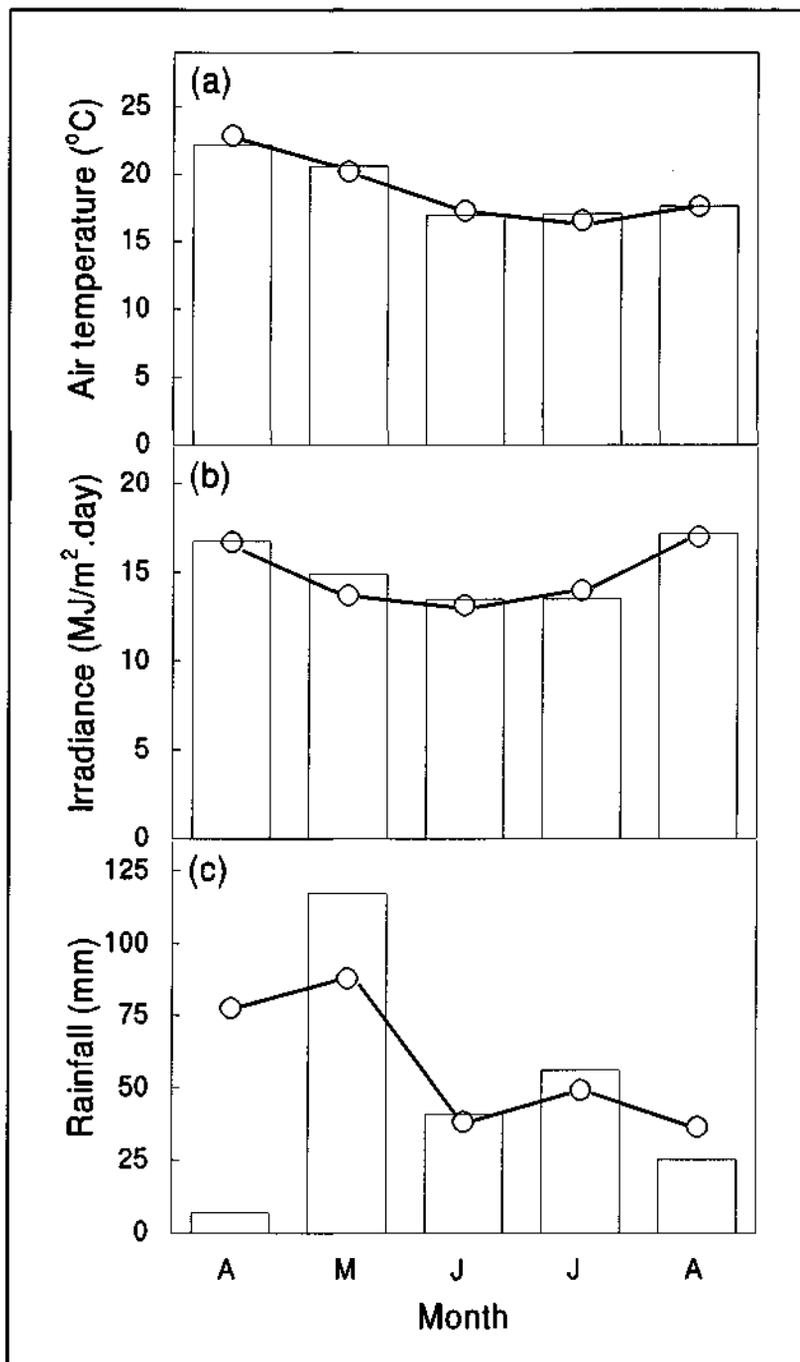


Fig. 1. The mean daily (a) air temperature and (b) irradiance and (c) the total rainfall for each month spanning the duration of the field trial in 1999. The open bars are the actual values encountered whereas the curves are the Bureau of Meteorology 30-year-averages (from 1970 to 1999, inclusive).

The plant height data revealed that for all mulch treatments, capsicum plants had a sigmoidal growth response curve. However, no difference in the height of capsicum plants grown in the 7 mulch treatments was detected at any measuring time.

Tensiometer suction did not differ in the weeded subplots of the mulch treatments for 7 of the 8 measuring times. At 26 DAT, however, the highest suction occurred in the bare soil treatment (13.0 kPa), although this value did not differ from those measured in soil covered by paper, hessian, or black biodegradable polymer (11.8, 11.5, or 11.5, respectively).

The total dry weight of weeds removed from the weeded subplots was higher ( $P < 0.05$ ) for bare soil (57.8 kg/ha) and hessian (47.4 kg/ha) than for the other treatments. The dry weight of weeds removed from the sugarcane trash (21.9 kg/ha), sawdust (12.7 kg/ha), paper (8.5 kg/ha), polyethylene (6.9 kg/ha), and biodegradable polymer (4.5 kg/ha) treatments did not differ. The polyethylene, biodegradable polymer and paper mulches were sufficiently opaque to restrict the growth of weeds to the plant hole in which each capsicum seedling was transplanted. Conversely, the hessian, sugarcane trash, and sawdust mulches allowed light through to the soil surface, and weed growth occurred over the entire surface of the raised plant bed. Weeds grew under the hessian material without penetrating it, making their removal from the weeded subplots difficult and incomplete.

Petiole sap nitrate concentrations of plants growing in the weeded subplots did not differ among the mulch treatments at 42 DAT (first anthesis), whereas at 55 DAT (fruit set), concentrations for the sawdust and bare soil treatments (4,440 and 4,630 mg/L, respectively) were lower ( $P < 0.05$ ) than those for the other treatments, except for paper. However, the concentrations of nitrate in the petiole sap of plants grown in the sawdust and bare soil treatments at 55 DAT were well above the concentration range at fruit set (520-1220 mg/L) associated with 95 and 100% of maximum marketable fruit yield for capsicum plants grown in the autumn/ winter season at Bundaberg (Olsen and Lyons 1994).

The concentrations of all measured elements in the blades of leaves sampled at 42 and 55 DAT from the weeded subplots of the bare soil treatment were either within or above the normal range suggested by Weir and Cresswell (1993) for the youngest mature blade plus petiole of a capsicum crop at the early fruiting stage.

Closure of the leaf canopy for each double row of capsicum plants occurred at approximately fruit set (55 DAT). Soil temperatures were measured in the weeded subplots up to canopy closure, but not after, since the effect of shading from the plants would have confounded the effect of the various mulches on the temperature of the soil. On an individual day (23 DAT) with high solar irradiation (19.7 MJ/m<sup>2</sup>.day), minimum soil temperatures occurred between 6:00 and 6:30 a.m. and maximum values were recorded between 2:00 and 2:30 p.m. in the weeded subplots of the bare soil, biodegradable polymer, paper and polyethylene whole plots in Blocks 2 and 3 (Fig. 2). These times agreed favourably with the time periods selected for measurement of minimum (6:00-7:30 a.m.) and maximum (2:00-2:30 p.m.) soil temperatures in the weeded subplots of all the mulch treatments at 20, 27, 32, 40, 47, and 54 DAT.

At all 6 measuring times, the maximum soil temperature was greater ( $P < 0.05$ ) under the black biodegradable polymer than under the other mulch treatments (Fig. 3a). Except at 54 DAT, the maximum soil temperature under the sugarcane trash mulch was lower ( $P < 0.05$ ) than under the other mulch treatments.

Minimum soil temperatures at 5 cm depth were lower ( $P < 0.05$ ) in the bare soil treatment than in the other treatments at 27, 40, and 47 DAT (Fig. 3b), although the minimum temperatures under the bare soil plots did not differ from those under the paper mulch plots at the other measuring times. Minimum soil temperatures measured under the sawdust mulch at 27 DAT

and under the sugarcane trash mulch at 47 DAT were higher ( $P<0.05$ ) than the temperature minima recorded under the other mulch treatments.

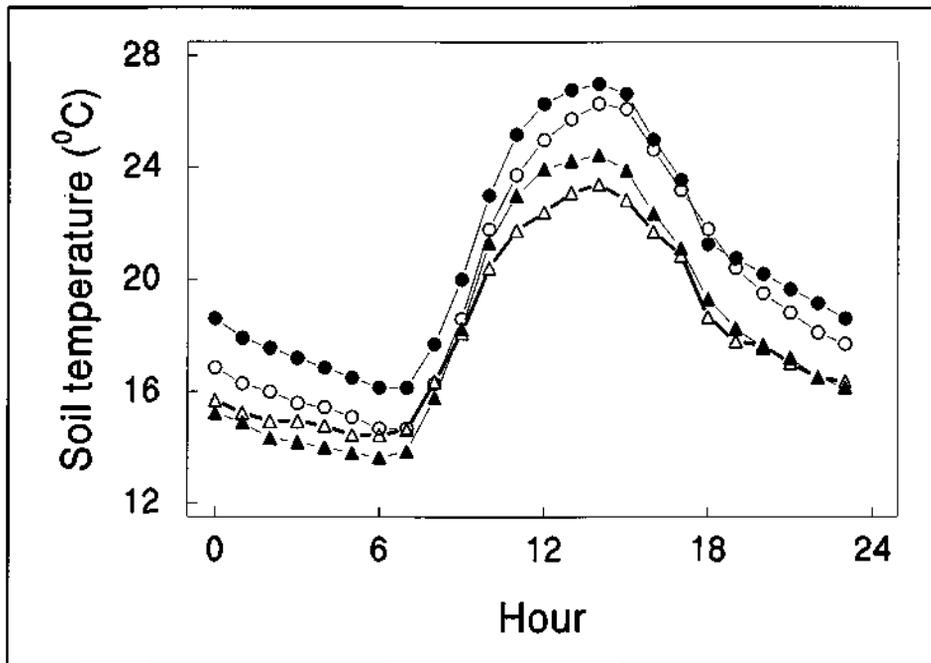


Fig. 2. Soil temperatures at 5 cm depth within the E row of capsicum plants grown in the weeded subplots of the bare soil (▲), biodegradable polymer (●), paper (Δ), and polyethylene (○) treatments during 1 May 1999 (23 DAT). Values are means at each hour (E standard time) for Blocks 2 and 3. Total radiation received on this day was 19.7 MJ/m<sup>2</sup>.day, maximum air temperature was 26.3°C, minimum air temperature was 11.2°C, and no precipitation occurred.

The weights of all fresh fruit harvested from capsicum plants grown in the weeded subplots of the polyethylene mulch and in the weeded and unweeded subplots of the biodegradable polymer were high and did not differ (Fig. 4a). The fresh weight of all fruit was least ( $P<0.05$ ) for plants grown in the unweeded subplots of the bare soil whole-plots. A similar response was observed for the weight of marketable fruit, since the highest marketable yields were harvested from plants grown in the biodegradable polymer treatment (both weeded and unweeded subplots) and from the weeded subplots of the polyethylene treatment (Fig. 4b). The weight of unmarketable fruit harvested from plants in the weeded subplots of the polyethylene treatment and from the unweeded subplots of the bare soil treatment were higher ( $P<0.05$ ) and lower ( $P<0.05$ ), respectively, than that from plants in the other treatments (Fig. 4c). The average fresh weight of individual marketable fruit was highest for plants grown in the weeded subplots of the sawdust treatment, but this value did not differ from that of plants grown in the unweeded subplots of the same treatment or the weeded subplots of the sugarcane trash, hessian and bare soil treatments (Fig. 4d).

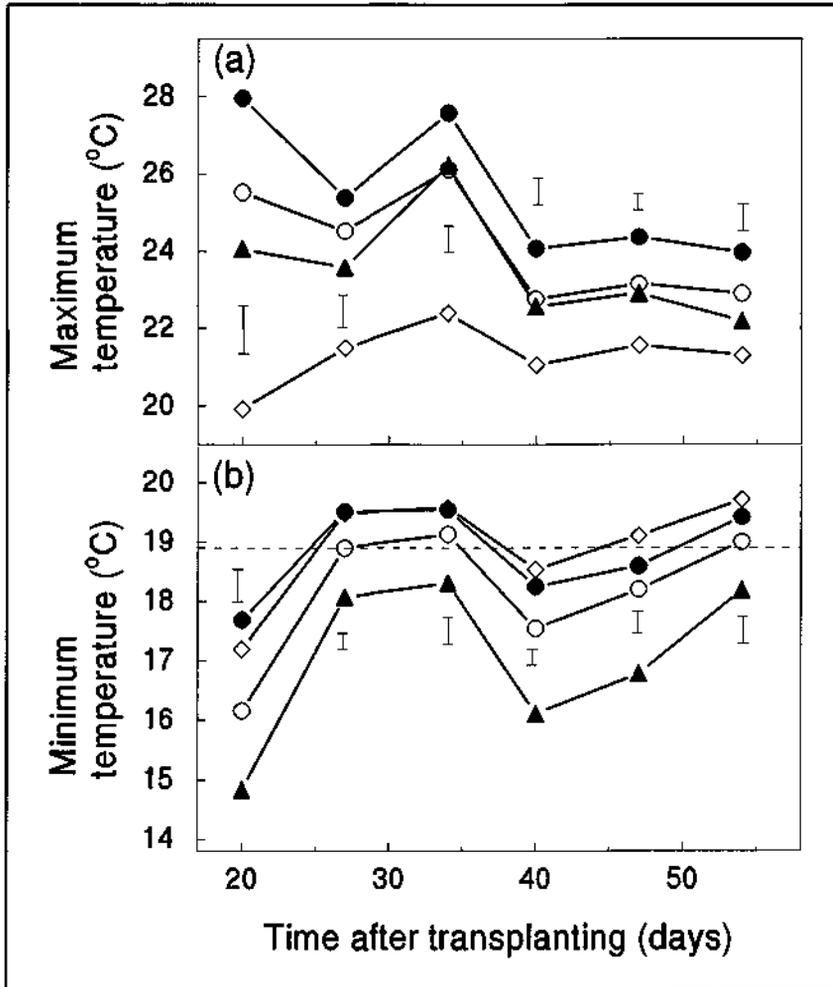


Fig. 3. Mean (a) maximum and (b) minimum soil temperatures at 5 cm depth within the E and W rows of capsicum plants grown in the weeded subplots of the bare soil (▲), biodegradable polymer (●), polyethylene (○), and sugarcane trash (◇) treatments at various times after transplanting the capsicum seedlings. The ANOVA F-test for treatments was significant ( $P < 0.05$ ) at each measuring time. Vertical bars, representing the l.s.d. at  $P = 0.05$ , are for the comparison of means at each measuring time. In (b), the critical temperature ( $18.9^{\circ}\text{C}$ ) below which the growth of roots and tops of capsicum plants is restricted (Wilcox and Pfeiffer 1990) is represented by a dashed horizontal line.

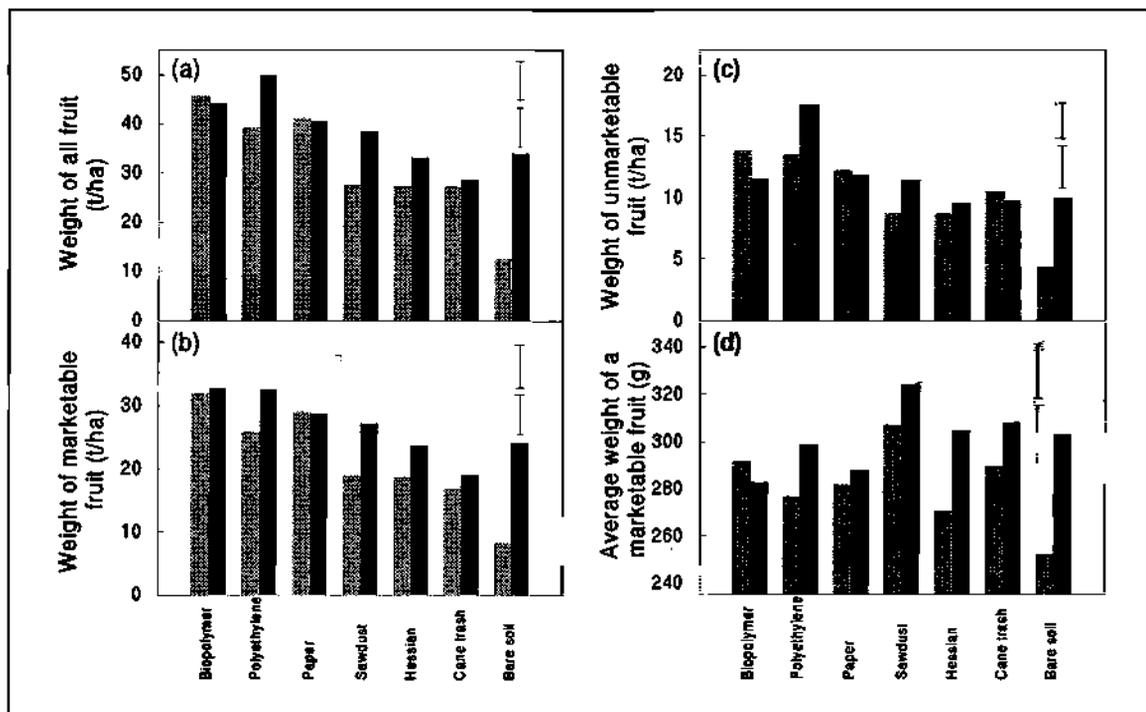


Fig. 4. Effect of mulch type on the fresh weight of (a) all fruit, (b) marketable fruit, and (c) unmarketable fruit, and on (d) average fresh weight of individual marketable fruit of capsicum plants grown in the unweeded (hatched bars) or weeded (filled bars) subplots. The vertical lines, representing the l.s.d. at  $P=0.05$ , are for the comparison of means which are either within a particular mulch treatment (top line) or for any other mulch x weeding combination (bottom line).

At 147-8 DAT, capsicum root length density at a horizontal distance of 7.5 cm from the base of the stems was maximal at the 0-5 cm depth interval (19.2 mm/cm<sup>3</sup>), and progressively decreased with sampling depth (18.0, 11.2, and 10.3 mm/cm<sup>3</sup> for the 5-10, 10-15, and 15-20 cm depths, respectively). These means were the average of all 7 mulch treatments, since the root length density values of the capsicum plants grown under the different mulches did not differ at  $P=0.05$ .

For each weeded subplot, regression analysis revealed a positive relationship ( $r^2=0.37$ ) between the mean soil temperature (recorded at a depth of 5 cm on 20, 27, 32, 40, 47, and 54 DAT) and the total weight of marketable fruit harvested (Fig. 5).

For soil temperatures which were recorded for 4 of the 7 mulch treatments from 1-6 May 1999 at intervals of 30 min, regression analysis revealed that the weight of marketable fruit and the average time per day that the soil temperature was  $\geq 18.9^\circ\text{C}$  (a critical temperature, identified by Wilcox and Pfeiffer 1990, below which the growth of roots and tops of capsicum plants is restricted) were moderately correlated ( $r^2=0.55$ ) (Fig. 6). Therefore, 55% of the variation in marketable yield was explained by the effect of these mulches on soil temperature.



Based on the methodology used in the present study, the actual weight of the biodegradable polymer, paper, hessian, sugarcane trash, and sawdust used on a per area basis was 1.2, 4, 8, 50, and 344-times greater, respectively, than that of polyethylene (Table 2). The purchase cost of polyethylene per ha was also less than that of the other mulches, although due to its inability to degrade, polyethylene was the only entry to have a cost of disposal (Table 2). A measure of the cost efficiency for a particular mulch was obtained from division of the average weight of marketable fruit harvested from the weeded and unweeded subplots (kg/ha) by the total purchase and disposal costs (\$/ha). The low cost of and the relatively high yield of plants grown with the polyethylene film made it the most cost-effective mulch, with paper mulch the next most cost-effective. The low cost efficiency of the biodegradable polymer resulted from its high purchase cost, whereas the low values for hessian and sugarcane trash were attributed to both high purchase costs and low fruit yields (Table 2). No effort was made to include the intangible benefits to soil fertility and structure by using high input organic materials such as sawdust or cane trash.

**Table 2. Weight, cost and cost efficiency of the various mulches**

Calculations based on 1.5 m bed centres and 1.2 m-wide rolls of polyethylene, biodegradable polymer, hessian, and paper mulches (which need to be secured by having their edges tucked under the soil) or 1.0 m-wide applications of sawdust and sugarcane trash

The purchase costs were derived from the manufacturers' quotes for the materials used in the field trial. The cost efficiency of each mulch was calculated as the average weight of marketable fruit harvested from the weeded and unweeded subplots divided by the sum of the purchase and disposal costs. For each mulch, the cost of transport to the farm or the cost of laying were not included in the cost efficiency calculation

Mulch	Weight (t/ha)	Purchase cost (\$/ ha)	Disposal costs (\$/ ha)	Weight marketable fruit (t/ ha)	Cost efficiency (kg/ \$)
Polyethylene	0.20	860	240	29.1	26.5
Biodegradable polymer	0.24	3,330	0	32.3	9.7
Paper	0.80	1,630	0	28.9	17.7
Hessian	1.6	4,000	0	21.1	5.3
Sugarcane trash	10.0	5,900	0	17.8	3.0
Sawdust	68.7	1,600	0	23.0	14.4

## 2.5 Discussion

The finding that the length and fresh weight of shoots of the sorghum seedlings were greater in the control and sawdust-based media than in potting mixes containing the other mulch materials may indicate the presence of phytotoxic substances in the sugarcane trash, degradable polymer, hessian, paper, or polyethylene mulches. Conversely, the lack of an effect of the ground mulches in potting mixes on the germination of sorghum seeds suggested that these materials were unlikely to contain substances toxic to plant growth. A more

detailed study, as conducted by Stirzaker and Bunn (1996), would need to be undertaken to completely eliminate the possibility that phytotoxins from the mulch materials could impair the growth of the capsicum seedlings. Indeed, adsorption by peat may have reduced the harmful effects of phytotoxins in the assay, although the 2:1 ratio by volume of mulch material:peat would probably have limited the confounding effect of adsorption. Furthermore, the short duration of the study may not have been sufficient to assess fully the phytotoxic effects of the mulch materials, including their impact on microbial activity in the soil and the subsequent effect on plant growth. The superior root and shoot growth of sorghum plants in the potting mix containing sawdust showed the beneficial effects of this material in potting media. The high use of hardwood sawdust in growing media by the nursery industry in Australia until recent times (Sharman 1993) is testimony to this assertion, although the industry has recently discontinued wide-spread use of this material due to N and P draw-down effects (K. G. Bodman, pers. comm.). Lower root lengths of sorghum plants grown in the polyethylene-based mix than in mixes based on the other mulches may have reflected the poor properties of ground polyethylene for root growth, rather than the presence of chemicals toxic to plants.

The relatively high minimum temperatures under the sawdust and sugarcane trash mulches can be attributed to the insulation effect of these thick organic mulches in reducing the night-time loss of long-wave radiation from the underlying soil. The greater storage of heat under the black biodegradable polymer than under the other treatments during the day could account, in part, for its comparatively high minimum soil temperature; a similar conclusion was made by Teasdale and Abdul-Baki (1995) for soil beds covered with black polyethylene. The low minimum soil temperatures in the bare soil and paper mulch treatments may be attributed to their high rates of evaporation. This view is supported by the tensiometer data at 26 DAT, which showed that the values measured in the bare soil and paper mulch treatments were ranked first and second, respectively. Owing to the latent heat of vaporisation, these treatments would be expected to have a lower store of solar energy as heat than would the other treatments with lower evaporative losses. Indeed, evaporation of moisture from bare soil has been shown to account for a significant loss of energy (Bristow 1988). Evidence which supports the hypothesis that high evaporative losses may have occurred from the bare soil and paper mulch treatments was demonstrated in a 55-day laboratory experiment conducted by Anderson *et al.* (1995); water loss from soil within 100 mL beakers which were covered with paper mulch or not covered was 23- or 38-times greater than that from soil within beakers covered with black polyethylene.

Ham *et al.* (1993) explained high soil temperatures at a depth of 10 cm under black polyethylene by its high short-wave absorptance and conductance of absorbed radiation to the soil. The same process may explain the higher soil temperatures under the black biodegradable polymer than under the other mulch treatments. The low maximum soil temperature under the sugarcane trash may be explained by the significant amount of air space within the 7.5 cm layer of this mulch. The low thermal conductivity of air (Marshall and Holmes 1979) would preclude the conductance of a large amount of absorbed heat from the mulch to the soil. A similar conclusion was made by Kumar and Srivastava (1997), who attributed lower average weekly soil temperatures at 10 cm depth under sugarcane trash than under black polyethylene or control treatments to poor conductivity of radiant heat by the organic mulch.

Because the root length density data revealed that the highest proportion of roots was located in the uppermost 10 cm of soil, the temperatures which were taken at the 5 cm depth would

have been representative of the values encountered by the majority of roots growing in the soil beds. Soil temperatures  $<18.9^{\circ}\text{C}$  were found by Wilcox and Pfeiffer (1990) to restrict the growth of roots and tops of capsicum cv. California Wonder, and a root zone temperature of  $30^{\circ}\text{C}$  corresponded with maximum fruit weight of cv. Bell Boy in glasshouse experiments conducted by Gosselin and Trudel (1986). Therefore, the soil temperatures encountered in the present study were probably sub-optimal for maximum fruit yields and were apparently limiting to the growth of roots for some of the time in most mulch treatments (Fig. 2). The positive relationship between marketable yield and the mean soil temperature on selected days prior to canopy closure (Fig. 5) crudely indicated this point. The cluster of means for sugarcane trash in Fig. 5 which corresponded with a low weight of marketable fruit and a low mean temperature suggest that a major limitation to the high yield of capsicum plants grown in this mulch were soil temperatures which were either sub-optimal or only marginally above the critical value for growth. The positive relationship between marketable yield and the average time per day that the soil temperature in each treatment was equal to or greater than the critical value for growth (Fig. 6) further confirmed that a significant component of the variation in marketable yield of the capsicum crop was attributed to the soil temperature under the mulch.

Despite the variation in yield, however, the height of plants grown in the weeded subplots of the various mulch treatments did not vary up to 54 DAT. The absence of any difference in the height of the capsicum plants may have reflected the rapid growth pattern of plants in combination with a regime of declining of air temperature (Fig. 1), and also the fact that the height of plants had increased by 37% prior to the first measurement of soil temperature. Furthermore, height of plants may be a less sensitive indicator of biomass and subsequent weight of fruit than other plant parameters such as total dry weight or leaf area.

Since tensiometer suction prior to the first irrigation cycle for a given week did not differ among the mulch treatments in 7 of 8 measuring times, it is unlikely that the mulch treatments changed the status of the soil water supply enough to significantly affect yield. The fact that irrigation water was applied regularly to maintain relatively low tensiometer suction probably contributed to this outcome. A contrasting result was reported by Kumar and Srivastava (1997) for a tomato crop grown during the winter/ spring season in Pantnagar, India. Those authors found that soil moisture at a depth of 15 cm was higher ( $P<0.05$ ) for beds covered with black polyethylene mulch film than for beds covered with sugarcane trash, which, in turn, had a higher ( $P<0.05$ ) soil moisture than that of soil without a mulch cover. However, the contrasting results between those of the present study and those of Kumar and Srivastava (1997) is explained easily, since the latter authors employed only 3 irrigation cycles throughout the life of the crop and measured soil moisture 15 days after each irrigation.

Any effect of the mulches on the nutritional status of the crop was considered to be unimportant, since petiole sap nitrate concentrations did not vary among mulch treatments at first anthesis. Although differences in petiole sap nitrate concentrations did occur at fruit set, the lowest values were well above the concentration range which corresponds with 95-100% maximum marketable fruit yield (Olsen and Lyons 1994). The concentrations of a range of elements within the dried blade of YMLs sampled from the weeded subplot of the low-yielding bare soil treatment were either within or above the normal range suggested by Weir and Cresswell (1993), further suggesting that nutrient supply was non-limiting to optimal crop growth.

Inclusion of the weeded and unweeded subplots for each whole plot in the design of the field trial enabled both the dry weight of weeds which grew through each mulch, as well as the effects of this weed competition on crop yield, to be quantified. The weight of marketable capsicum fruit produced in the weeded and unweeded subplots of the biodegradable polymer, paper, sugarcane trash and hessian mulch treatments did not differ, although probably for different reasons. Apart from the holes in which the capsicum seedlings were transplanted, weed control by the biodegradable polymer and paper films was total, resulting in similar yields for the weeded and unweeded subplots. Conversely, weed control under the hessian mulch was poor, since light transmission through the material was high. Removal of weeds from the weeded subplots was hampered by the fact that they did not penetrate the hessian. Therefore, the relatively low yield of fruit from capsicum plants grown in both the weeded and unweeded subplots of the hessian mulch treatment was probably a result of intense weed competition. The low weight of marketable fruit produced by capsicum plants grown in both the weeded and unweeded subplots of the sugarcane trash was probably a reflection of the sub-optimal soil temperatures under this mulch for high fruit yield.

The higher ( $P < 0.05$ ) weight of marketable fruit of capsicum plants grown in the weeded than in the unweeded subplots of the bare soil, sawdust and polyethylene treatments can be explained simply by competition from weeds in the unweeded subplots. The higher ( $P < 0.05$ ) dry weight of weeds pulled from the weeded subplots of the bare soil treatment than from the weeded subplots of any other treatment, except hessian, supports this theory. Weed growth was relatively unabated by the presence of the sawdust mulch, and, despite the relatively low dry weight of weeds removed from the weeded subplots, weed competition with the capsicum crop in the unweeded subplots was intense. Although the polyethylene film provided an excellent barrier to weed growth, disproportionately higher growth of and competition from weeds in the plant holes of the unweeded subplots in Blocks 1 and 3 resulted in a lower ( $P < 0.05$ ) mean weight of marketable fruit in the unweeded subplots than in the weeded subplots of this mulch treatment.

The similar weight of marketable fruit for the weeded subplots of polyethylene and the weeded and unweeded subplots of both the biodegradable polymer and paper indicated that these biodegradable mulches have the agronomic potential to replace polyethylene. The similar yield of marketable fruit harvested from capsicum plants grown with paper and polyethylene mulches in the present study concurs with the findings of Anderson *et al.* (1995) for tomato in Massachusetts and those of Hochmuth and Hochmuth (1994) for capsicum in Florida.

The greater weight of marketable fruit harvested from capsicum plants grown in the polyethylene than in the sugarcane trash in the present study is consistent with the greater ( $P < 0.05$ ) dry weight of shoots and fresh weight of roots of tomato plants grown with polyethylene film than with sugarcane trash during the winter/ spring season in Pantnagar, India (Kumar and Srivastava 1998). Other studies have also shown greater yields of vegetable crops grown with polyethylene than with organic mulch (e.g. Roe *et al.* 1994 – capsicum; Tiwari *et al.* 1998 – okra). Therefore, organic materials which are transported to the farm and laid on the soil surface appear to offer limited potential to replace polyethylene film, although their long-term benefits to soil fertility and structure should not be discounted.

The high cost efficiency value determined for the polyethylene mulch was expected, given the extensive use of this product by Australian farming enterprises. While the cost of disposal remains low (Table 2), widespread use of polyethylene mulch is likely to continue.

The relatively high cost efficiency of paper mulch film indicated that this material has the potential to replace polyethylene in farming systems. However, one disadvantage of paper film is its greater weight than that of polyethylene film (Table 2), which increases the costs of field application (Anderson *et al.* 1995). Other practical difficulties in using paper mulch were highlighted by Hochmuth and Hochmuth (1994) and include the need to modify mulch applicators to reduce tearing at laying, the tearing of the mulch at planting, and the rapid breakdown of buried paper with the associated problem of holding the paper mulch on the beds. The last issue raised by Hochmuth and Hochmuth (1994) was not a problem in the present study for either the paper mulch or the biodegradable polymer. Nevertheless, re-use of these mulches for a second crop, as can be the practice for polyethylene mulch in the Bowen and Bundaberg districts, would not be feasible since significant degradation of the buried component of these materials had occurred by final harvest. Use of the same film of polyethylene for 2 crops would halve the costs of purchase and disposal for each crop, and thereby reduce significantly the cost efficiency value of this material.

The poor supply and generally high cost of biodegradable polymers in Australia is currently a major limitation to their acceptance by commercial vegetable growers. Due to the dearth of available material at the time of this study, the Mater-Bi<sup>®</sup> mulch was imported directly from Italy. However, it was the high cost of this material, not transport costs, which resulted in its low cost efficiency value (Table 2), since the cost of importation was not included in the efficiency calculation. Although technologies for the formulation of low-cost starch-based polymers are currently under examination (e.g. Anon. 1999; Cooperative Research Centre for International Food Manufacture and Packaging Science – Drs P. Halley and G. Christie), production of these materials as mulch film for large-scale farming enterprises may still not become a commercial reality for several years.

Due to low cost efficiency values, the lack of suitable laying machinery, and an inability to suppress weed growth, the hessian, sugarcane trash and sawdust mulches are unlikely to be viable alternatives for polyethylene in large-scale commercial enterprises. However, with the likelihood of increased availability and lower prices in the future, paper and biodegradable polymer films are the best options for the replacement of polyethylene film. The increasing cost of disposal for polyethylene in the future will only hasten the replacement of this material with alternatives.

### **3. A field assessment of biodegradable transported mulch materials in capsicum at Bowen**

by Ross M. Wright, Queensland Horticulture Institute, DPI Centre for Dry Tropics, Bowen Research Station.

#### **3.1 Summary**

A late season trial was conducted at Bowen Research Station in 1997 to compare a range of biodegradable transported mulch materials with standard plastic mulch using capsicum as the test crop. The biodegradable mulch treatments included (1) recycled waxed fibre cartons coarsely shredded, (2) recycled newspaper finely shredded, milled and compressed, (3) composted vegetative mulch, (4) bagasse - sugarcane remnant material following milling, and (5) forage sorghum hay. Marketable fruit yields and size of individual fruit did not differ for fruit harvested from the weeded half of the plots, whereas if the unweeded half of each plot was harvested, strong competition from weeds in the recycled newspaper, composted mulch and bagasse treatments would almost certainly have reduced marketable fruit yield in those plots. A major obstacle to the adoption by farmers of alternatives to plastic mulch relates to the cost and logistics of transporting and applying these materials to large areas of land. With the exception of the recycled newspaper treatment, no development of equipment for applying these alternatives has been undertaken. Additionally, the material cost of the alternatives alone may rule them out. The biodegradability of the waxed fibre carton is also doubtful due to the paraffin wax coating over the fibreboard. A number of options exist for replacement of plastic mulch with degradable materials which would perform a similar task to that of plastic. However, it appears unlikely at this stage that an economically viable alternative mulch produced off-farm could compete with plastic mulch. Whereas there may be additional longer term benefits from the practice of the addition of large amounts of organic matter, the additional costs and logistics of doing so are obstacles which would be difficult to overcome.

#### **3.2 Introduction**

Disposal of mulch and trickle irrigation tubing at the end of the crop cycle has become an increasing problem in modern vegetable cropping. This is certainly the case in the Bowen area, where growers have either burnt plastic (polyethylene) mulch at the end of the season, or disposed of plastic at the town refuse tip. Neither of these methods have been satisfactory, with burning causing problems with pollution of nearby urban areas and dumping causing significant problems with land-fill space occupied.

The increased use of this production system has certainly been justified on economic grounds. Expansion of the vegetable industry during the late 1970's and 1980's paralleled the increasing use of trickle irrigation in this industry. DPI trials in the early 1970's indicated the superior water use efficiency of trickle irrigation and plastic mulch, with water savings up to 80% compared with flood irrigation. Later experiments in the 1980's also showed the superior effects of plastic mulch compared with herbicides for weed control, when used in conjunction with trickle irrigation, with yield increases of 20% - 50%.

These advantages have led to the situation today where some 4000 ha of vegetables in the Bowen district are grown under plastic mulch and trickle irrigation. However, the stage has been reached where pressure on local authorities to reduce land-fill areas has prompted an examination of alternative mulching systems. Preliminary investigations in the Bowen area have assessed several alternatives to plastic mulch in tomato crops. Mulched vegetative material from the local tip in various stages of decomposition, recycled newspaper in finely shredded form and forage sorghum hay have been tested in both small plots and larger scale trials on grower properties. These alternatives have shown reasonable promise in comparative trials with plastic mulch. While they have not provided equivalent performance to plastic mulch, they have given sufficient encouragement to undertake further development and assessment of those alternatives previously tested and additional available candidates.

### 3.3 Materials and methods

A late season trial was conducted at Bowen H.R.S. in 1997 to compare a range of alternative mulch treatments with a standard plastic mulch used commercially in the district. The test crop was capsicum. The mulch treatments tested were as follows:-

1. Recycled waxed fibre cartons coarsely shredded.
2. Recycled newspaper finely shredded, milled and compressed.
3. Composted vegetative mulch.
4. Bagasse - sugar-cane remnant material following milling.
5. Forage sorghum hay.
6. Plastic mulch.

The mulch treatments were set out on 4-8-1997 on pre-formed beds which had received standard fertilizer and soil insect treatments. Treatments waxed fibre carton, composted mulch, bagasse, and sorghum hay were laid out by hand as no mechanised method of placement had been devised locally. They were placed at a depth of approximately 7.5cm as observations on previous tests had indicated this to be a satisfactory depth for weed control. The recycled newspaper mulch was laid by machinery produced in Bowen by an engineering tradesman who had pioneered this system in conjunction with local growers. The depth of material laid with this treatment was approximately 3.0cm. The plastic mulch treatment was laid out with standard machinery used commercially by the industry.

Capsicum seedlings grown using the *speedling* method were transplanted on 11-8-1997. The plastic mulch treatment was planted using a standard water-wheel planter whereas all other treatments were planted by hand. The nature of the materials and the depth of the materials used did not allow for conventional machine planting. Plants were set out in double rows 40cm apart with plants 40cm apart in the row. The experimental block was irrigated following planting and replanting of seedlings which had failed to establish was carried out on 18-8-1997. Shallow tensiometers were installed in one replicate at 15cm depth 2 weeks after field planting following an irrigation. Irrigations were carried out when 8am tensiometer readings on any treatment reached 40kpa during the vegetative stage and 25kpa during the fruit set and fruit filling stages. Soil temperatures were measured with a probe thermometer twice weekly at 8am and 2pm at a depth of 5cm under the soil, through to harvest stage.

Treatment plots were 15m long. Half the length of each plot was kept weed-free, both within the plot and in the inter-row area, throughout the life of the crop. Soluble fertilizer side

dressings were applied through the irrigation system at regular intervals as required. Canopy heights for each weed-free plot were measured on 10-10-1997. Ratings for weed incidence in the unweeded sections of plots were made just prior to first harvest on 23-10-1997. Only the weed-free sections of plots were harvested, a 4.8m datum area containing 12 plants being used. Harvesting commenced on 24-10-1997 with an additional 2 harvests being carried out on 3-11-1997 and 12-11-1997. Fruit were graded into marketable and unmarketable following each harvest, counted and weighed.

### 3.4 Results and discussion

Loss of seedlings in the first week following planting was random and not a result of any treatment differences. Few visual differences were evident between treatments for the first 2-3 weeks. Following this period, the recycled newspaper treatment visually lagged behind the other treatments in terms of plant size, the difference being consistent in each replicate. This effect had been observed in a previous experiment where tomatoes were the test crop. Whereas it is possible that nitrogen draw-down may play a part in this effect, it seems unlikely given the fact that the treatment resides on the soil surface and quite liberal side-dressings of nitrogenous fertilizers were applied to the crop in addition to a basal dressing. The difference persisted through to harvest, Table 3 demonstrating this effect at 2 weeks prior to harvest. Plants grown in the recycled newspaper treatment had a lower canopy height ( $P<0.05$ ) than plants grown in all other treatments, with the exception of the standard plastic mulch. Although a similar trend was evident with the plastic mulch, the difference was not significant.

**Table 3. Crop canopy height at 2 weeks before fruit harvest**

Treatment	Canopy height (cm)
Waxed fibre carton	58.6
Recycled newspaper	48.7
Composted mulch	57.8
Bagasse	56.5
Sorghum hay	59.5
Plastic mulch	53.8
l.s.d. ( $P=0.05$ )	5.7

Water loss as indicated by tensiometer readings was most rapid in recycled newspaper, sorghum hay, and plastic mulch and slowest in bagasse. The composted mulch also lost moisture more rapidly than bagasse, but appeared to be less consistent in rate of loss than recycled newspaper, sorghum hay, and plastic mulch. Minimum soil temperatures measured at 8am were quite stable throughout the period of the experiment with no difference between treatments. At the start of the experiment the 8am temperature range was 21-22°C in all treatments, while at harvest the range increased slightly to 23-24°C. Maximum temperatures measured at 2pm showed greater variation between treatments, the plastic mulch plots consistently measuring 3 to 6°C higher than all other treatments. At the start of the experiment, the 2pm temperatures in the plastic mulch plots ranged from 26-30°C whereas all other treatments fell within the range of 23-26°C. This difference was less marked by harvest time when the crop canopy had closed over causing shading of the various mulches.

Nevertheless, 2pm temperatures in the plastic mulch plots ranged from 26-28°C whereas all other treatments generally ranged from 24-26°C.

Within the unweeded plots, the weed population was very high in the inter-rows and extending up to the edges of the formed beds, with little to no difference between treatments. However, within the formed bed there were marked differences between the plastic mulch treatment and all other treatments, with the plastic mulch plots almost weed-free. The waxed fibre carton and sorghum hay treatments also provided quite satisfactory control whereas the remaining treatments provided only moderate to fair control ( Table 4 ).

**Table 4. Weed control ratings within the formed bed of the various mulch treatments.**

Treatment	Weed control rating
Waxed fibre cartons	4.0
Recycled newspaper	6.2
Composted mulch	6.0
Bagasse	5.5
Sorghum hay	4.0
Plastic mulch	1.8

Weed control rating scale

- 1 - Completely weed free
- 2 - Very good control
- 3 - Good control
- 4 - Sufficient in practice
- 5 - Medium control
- 6 - Fair control
- 7 - Poor control
- 8 - Very poor control
- 9- No effect

The relatively thin layer of recycled newspaper mulch probably explains the poor weed control from this treatment, whereas the composted mulch treatment itself no doubt carried viable weed seeds despite having been composted. The major weed species dominating all treatments was giant pigweed (*Trianthema portulacastrum*). Other major weed species present through all treatments were barnyard grass (*Echinochloa colonum*), blackberry nightshade (*Solanum nigrum*), wild hops (*Nicandra physalodes*) and volunteer tomatoes. Species confined to the composted mulch plots were green amaranth (*Amaranthus viridis*) and bullhead (*Tribulus terrestris*). Couch grass (*Cynodon dactylon*) was also present in the composted mulch and bagasse plots.

Visual observations suggested that the recycled newspaper treatment might perform the worst of all treatments in terms of yield, due to the shorter plant stature produced from this treatment. However, this was not the case with the only trends indicating lowest yields for the waxed fibre carton treatment and highest for the plastic mulch treatment. Despite this trend, analysis of variance did not reveal any statistical differences between any of the treatments for total yield, marketable yield, fruit number or mean fruit size for any of the categories measured (total, marketable or reject). Marketable fruit yields and size of individual fruit are displayed in Table 5.

**Table 5. Fruit yield data from the capsicum plants grown in the various mulch treatments.**

<b>Treatment</b>	<b>Marketable fruit weight (kg)</b>	<b>Marketable fruit number</b>	<b>Marketable fruit size (g)</b>
Waxed fibre carton	13.77	64.5	214
Recycled newspaper	15.80	77.0	205
Composted mulch	15.59	70.2	221
Bagasse	15.68	71.7	219
Sorghum hay	15.58	73.5	211
Plastic mulch	16.84	72.0	235
l.s.d. (P=0.05)	3.74	12.6	32

The performance of the various mulches in terms of crop production gives some encouragement for their further development, although only the weed-free sections of plots were harvested. If the unweeded sections of plots were harvested, strong competition from weeds in the recycled newspaper, composted mulch, and bagasse treatments would almost certainly have reduced marketable fruit yield in those plots. A major obstacle to the adoption by farmers of alternatives to plastic mulch relates to the cost and logistics of transporting and applying these materials to large areas of land. With the exception of the recycled newspaper treatment, no development of equipment for applying these alternatives has been undertaken. Additionally, the material cost of the alternatives alone may rule them out. Estimates of material costs of some of these options on a linear meter of row are as follows:-

Recycled newspaper -	\$0.18 - 0.20
Composted mulch -	\$1.40 - 1.80
Sorghum hay -	\$0.30
Plastic mulch -	\$0.13

Whereas no costs are available for the waxed fibre carton and bagasse treatments, transport and application costs are likely to rule them out. The biodegradability of the waxed fibre carton is also doubtful due to the paraffin wax coating over the fibreboard.

### **3.5 Conclusions**

A number of options exist for replacement of plastic mulch with degradable materials which would perform a similar task to that of plastic. However, it appears unlikely at this stage that an economically viable alternative mulch produced off-farm could compete with plastic mulch. Whereas there may be additional longer term benefits from the practice of the addition of large amounts of organic matter, the additional costs and logistics of doing so are obstacles which would be difficult to overcome.

## 4. Alternatives to polyethylene mulch film – field assessments of killed *in-situ* mulches in capsicum at Bundaberg

by Jason K. Olsen and Reg K. Gounder, Queensland Horticulture Institute, DPI Bundaberg Research Station.

### 4.1 Summary

A preliminary observation trial, a factorial field trial, and a nematode susceptibility test were conducted at Bundaberg Research Station to assess the suitability of killed *in-situ* mulches as alternatives to polyethylene mulch film for capsicum production.

The preliminary trial showed that considerable variation in production of dry matter of tops existed for the cover crop species grown. Sudan grass and Indian couch produced the greatest weight of dry matter of tops among the grasses and lablab bean was the most vigorous legume. Small outbreaks of 2-spotted mite occurred in some legume species.

For the main factorial field trial, the performance of a capsicum crop grown in the autumn season of 1999 was measured in soil beds which were either bare or covered with a killed *in-situ* mulch from one of 4 legume (American joint vetch *Aeschynomene americana* cv. Glen; Annual centrosema *Centrosema pascuorum* cv. Bundy; Lab lab bean *Lablab purpureus* cv. Highworth; Cow pea *Vigna unguiculata* cv. Red caloona) or 2 grass (Indian couch *Bothriochloa pertusa* cv. Bowen; Jumbo sorghum *Sorghum bicolor* cv. Jumbo) species. The cover crops were grown for 6 weeks in the soil beds which were fitted with trickle irrigation tubing and fertilised with basal fertiliser. At 3.5 weeks prior to transplanting the capsicum seedlings, the cover crops were sprayed with glyphosate and allowed to lodge on the soil beds to form a killed *in-situ* mulch. Use of a split-plot design (mulch whole plots with weeded or unweeded subplots) permitted both weed growth and the effect of weed competition on fruit yield to be measured. The results showed that the low fruit yields of capsicum plants grown in all the killed *in-situ* mulches would be a major impediment to the adoption of this system by commercial growers. The low yields were the result of poor weed control by the mulches and difficulties encountered at planting the capsicum seedlings through the mulch cover and into the root-bound soil below. The time required to establish the cover crop (about 9 weeks) is an added constraint to adoption. For the killed mulch system to be more effective, machinery would need to be sourced which will loosen soil around the transplanted seedling to improve soil contact, whilst ensuring adequate mulch cover remains on the soil surface around the seedling. The inadequacy of the vigorous cover crops used in this study to arrest weed growth as killed *in-situ* mulches suggests that weed control would be an ongoing problem for growers adopting this system.

Apart from the American joint vetch which showed no galling or egg masses, the legume crop species were highly susceptible to root-knot nematode (*Meloidogyne javanica*) infection and reproduction. Of these, centro was the most susceptible to root-knot nematode. In the

absence of soil-applied nematocides or fumigants, a killed *in-situ* mulch formed by centro would dramatically increase the population of root-knot nematodes in the soil. Use of a heavy clay soil would probably reduce the rapidity with which nematodes would increase under this cover crop. The tolerance of the grass species to root-knot nematode was also highlighted by this experiment, with no galls or egg masses measured for the Indian couch or Jumbo sorghum plants. Use of either of these crop species as a killed *in-situ* mulch would limit an increase in the population of root-knot nematode in the soil.

## 4.2 Introduction

Previous work has shown that cover crops which are grown *in situ* prior to planting a vegetable crop may provide a mulch cover (e.g. Abdul-Baki *et al.* 1996; Stirzaker *et al.* 1993) and obviate the need for polyethylene film. Use of a killed *in-situ* mulch as a replacement for plastic mulch would also protect the soil from erosion, moderate soil temperatures, suppress weeds (Sutton 1998), as well as increase organic carbon levels in the soil. However, there appear to be few, if any studies, which definitively show that yields of transplanted vegetable crops with poorly developed root systems such as capsicum grown in killed *in-situ* mulches can match, or even approach, those of plants grown in the plastic mulch system. Indeed, production of sufficient mulch material from killed *in-situ* cover crops to suppress weed growth is an issue (Sutton 1998), as is allelopathy from the mulch (Stirzaker and Bunn 1996). Furthermore, rarely is consideration given to the effects of a killed *in-situ* mulch on root pathogens such as nematodes.

Therefore, the following studies were conducted to address these issues. An initial study was made to firstly assess the vigour and suitability of a wide range of cover crop species which may be useful as killed *in-situ* mulches. The most promising cover crop species were then studied in a factorial field experiment to assess their impact on weeds and their effects on growth and yield of capsicum. A third study was conducted to assess the susceptibility of the cover crop species to root-knot nematode.

## 4.3 Materials and methods

### *Preliminary investigation of cover crops*

A preliminary investigation was conducted to assess the vigour and suitability of a broad range of cover crop species as killed *in-situ* mulches. Fifteen 15 legume species and 6 grass species (Table 6) were each sown at 200 g seed/ 10 m length of row on 30 October 1997 in raised beds fitted with trickle irrigation tubing and supplied with basal fertiliser. The plants were irrigated according to tensiometer suction and fertilised with urea on 3 occasions. After 10 weeks (on 9 January 1998), tops were cut from within randomly placed quadrats (1 m<sup>2</sup>), dried and weighed.

**Table 6. Cover crop species assessed for their suitability as killed *in-situ* mulches in observation trials conducted at Bundaberg Research Station**

Scientific name	Common name	Cultivar(s)
Legumes		
<i>Aeschynomene americana</i>	American joint vetch	Glen and Lee
<i>Aeschynomene villosa</i>	Hairy joint vetch	Kretschmer and Reid
<i>Arachis pintoii</i>	Amarillo pinto peanut	Amarillo
<i>Cassia rotundifolia</i>	Round leaf cassia	Wynn cassia
<i>Centrosema pascuorum</i>	Annual centrosa	Bundy and Cavalcade
<i>Clitoria ternatea</i>	Butterfly pea	Millgara
<i>Lablab purpureus</i>	Lab lab bean	Highworth
<i>Leucaena leucocephala</i>	Leucaena	Cunningham
<i>Lotononis bainesii</i>	Lotononis	Miles
<i>Lotus uliginosus</i>	Greater lotus	Maku
<i>Macroptilium atropurpureum</i>	Siratro	Aztec atro
<i>Stylosanthes hamata</i>	Caribbean stylo	Varano
<i>Trifolium repens</i>	White clover	Haifa
<i>Trifolium subterraneum</i>	Subterranean clover	Claire
<i>Vigna luteola</i>	Dalrymple vigna	Dalrymple
Grasses		
<i>Avena sativa</i>	Oats	
<i>Cynodon dactylon</i>	Green couch	
<i>Bothriochloa pertusa</i>	Indian couch	Bowen
<i>Digitaria milanjiana</i>	Strickland grass	Sirajan
<i>Echinochloa utilis</i>	Japanese millet	White panicum
<i>Sorghum sudanense</i>	Sudan grass (sudax)	Sudan

#### ***Factorial field assessment of killed in-situ mulches***

From the information obtained in the preliminary investigation and further information from pasture expert Dr Bruce Cook (DPI Gympie), the following cover crop species were selected for more detailed study: *Aeschynomene americana* American joint vetch cv. Glen, *Bothriochloa pertusa* Indian couch cv. Bowen, *Centrosema pascuorum* Annual centrosa cv. Bundy, *Lablab purpureus* Lab lab bean cv. Highworth, *Vigna unguiculata* Cowpea cv. Red Caloona, and *Sorghum bicolor* Forage sorghum cv. Jumbo.

A field trial was conducted on a soil, variously classified as a Tropeptic Eustrustox (USDA 1975) and a Haplic Mesotrophic Red Ferrosol (Isbell 1996), to assess the effects of killed *in-situ* mulches derived from the 6 cover crop species listed above on the growth response of capsicum cv. Target plants at Bundaberg Research Station (24°51'S, 152°24'E), Queensland, Australia. Analysis of the surface 15 cm of the soil (sampled 8 January 1999) showed it to have the following chemical characteristics: pH 6.6 (1:5 soil:water); electrical conductivity 0.05 dS/m (1:5 soil:water); organic carbon 1.1% ( $K_2Cr_2O_7 + H_2SO_4$ );  $NO_3-N$  4.1 mg/kg (1:5 soil:water); available P 185 mg/kg (1:100 soil:0.5M  $NaHCO_3$ ); exchangeable K 0.69

cmol(+)/kg (1:20 soil:1M NH<sub>4</sub>Cl, pH 7.0); and effective cation exchange capacity 10.65 cmol(+)/kg.

On 18 January 1999, raised soil beds (1.5 m between centres) were formed into 9 rows of length 45 m, running in a N-S direction. Fertilisers were incorporated into the soil beds to supply the following elements (kg/ ha): 56 N, 116 P, 92 K, 195 S, 226 Ca, and 14 Mg. Polyethylene trickle irrigation tubing (wall thickness 200 µm, internal diameter 16 mm, emitter spacing 300 mm) was laid along the centre of each bed at a depth of 3 cm below the soil surface. For the centre 7 rows, plots of length 10.5 m were left unsown and uncovered (bare soil) or were sown on 19 January 1999 at a rate of 200 g seed with one of the 6 crop species given above. The outside rows were covered with white on black polyethylene mulch film (white side facing up) and were used as guard rows.

Urea was applied through the trickle irrigation tubing at a rate of 10 kg N/ha on 6 occasions (9,15, 22 February and 1, 8 March 1999) to ensure the cover crops were not limited by N. The plants were inspected for insect and disease damage on 3 March 1999, and on 8 March 1999, tops were cut at ground level using 1 m<sup>2</sup> quadrats, placed in a drying barn at 75 °C until dry, then weighed. The weighed plant tops were then returned to their respective plots in the field. The cover crop species were sprayed with glyphosate on 15 March 1999 and allowed to lodge on the soil beds to form a killed *in-situ* mulch.

The 6-week-old capsicum seedlings were transplanted into the field on 8 April 1999 into 50-plant plots arranged in a randomised blocks layout with 4 blocks. For each of the 28 whole plots, one-half (subplot) was randomly selected for regular weeding (weeded subplot) whereas the other subplot remained unweeded (unweeded subplot). For each subplot, the 25 capsicum seedlings were transplanted in a diamond configuration in double rows 30 cm apart with 40 cm between plants in each row, resulting in a population of 33,333 plants/ ha. Use of a split-plot design (mulch whole plots with weeded or unweeded subplots) permitted both weed growth and the effect of weed competition on fruit yield to be measured.

Irrigation, fertigation and pesticide applications were the same as those described in the transported mulch assessment conducted in Bundaberg (Section 2.3), since both trials were adjacent to each other and were run concurrently. Similarly, measurement of tensiometer suction, sap nitrate concentration, foliar nutrient concentrations, plant height, weed growth, soil temperature, and fruit yield was made using the same procedure as described previously in that section.

Depth and percent cover of the mulches on the surface of the soil were measured at 2 fixed points in the weeded subplots at 6, 11, 20, 27, 34, 40, 47, 54, 60, and 68 days after transplanting (DAT) the capsicum seedlings. Percent cover was measured by laying a grid (25 x 25 cm<sup>2</sup> squares) flat on the mulch surface and counting the number of squares in which cover was equal to or greater than 50%. This value was then multiplied by 4 to give percent cover.

Penetrometer measurements for the upper 5 cm of soil surface were taken from 2 positions in each weeded subplot at 20 DAT, 24 hours after irrigation was applied to the soil.

On 25 August 1999 (the day after final harvest), the root systems of 5 randomly picked plants grown in the weeded subplots were exhumed, washed clean of soil, dried in a forced draught oven at 65°C until dry, then weighed.

Whereas no allowance was made for the effects of mulch types on modifying the water and nutritional status of the soil, variation among the treatments was minimised by the application of a luxury amount of water and nutrients. This 'nil intervention' approach was considered appropriate methodology to compare mulch treatments. Another approach, not used in the present study, is that of 'full intervention' in which growth of the capsicum crop would be optimised by modifying all inputs to suit the peculiarities of the particular treatment. That methodology was considered more appropriate for comparison of the systems necessary to manage the optimal growth of the capsicum crop grown in a particular mulch treatment than for the comparison of mulch treatments on capsicum growth.

Analysis of variance was used to test the effects of treatments in the in detailed factorial assessment of killed *in-situ* mulches. Treatment means were compared using the protected l.s.d. procedure operating at  $P=0.05$ .

#### ***Assessment of nematode susceptibility of the cover crop species***

Seeds of each of the 6 cover crop species studied in the factorial field experiment and tomato cv. Tiny Tim were sown on 1 September 1999 into 15 cm pots containing sterilised medium grade sand. Plants were thinned to 5 per pot after 2 weeks. Four weeks later, each pot was inoculated with 10,000 eggs of the root-knot nematode *Meloidogyne javanica*, which had previously been multiplied on tomato plants and were extracted with sodium hypochlorite. A complete randomised design with 5 replications was used giving a total of 35 pots (7 crop species x 5 replicates).

At 7 weeks after inoculating with root-knot nematode, roots of plants from each pot were washed, checked for the presence of egg masses using a dissecting microscope at x30 magnification, and rated for galling caused by root-knot nematode using the following scale: 0 = no galls; 1 = 1-25%; 2 = 26-50%; 3 = 51-75%; 4 = 76-99%; 5 = 100% of roots galled.

## **4.4 Results and discussion**

### ***Preliminary investigation of cover crops***

The vigour of the cover crop species grown at Bundaberg Research Station for 10 weeks (from 30 October 1997 to 9 January 1998) varied considerably (Fig. 7), with Sudan grass and Indian couch having the greatest production of dry matter of tops among the grasses and lab lab bean being the most vigorous legume. The poor germination of lotononis and greater lotus severely reduced their dry weights. Dalrymple vigna suffered from the disease sclerotinia soon after germination but then recovered. Small outbreaks of 2-spotted mite occurred in some legume species.

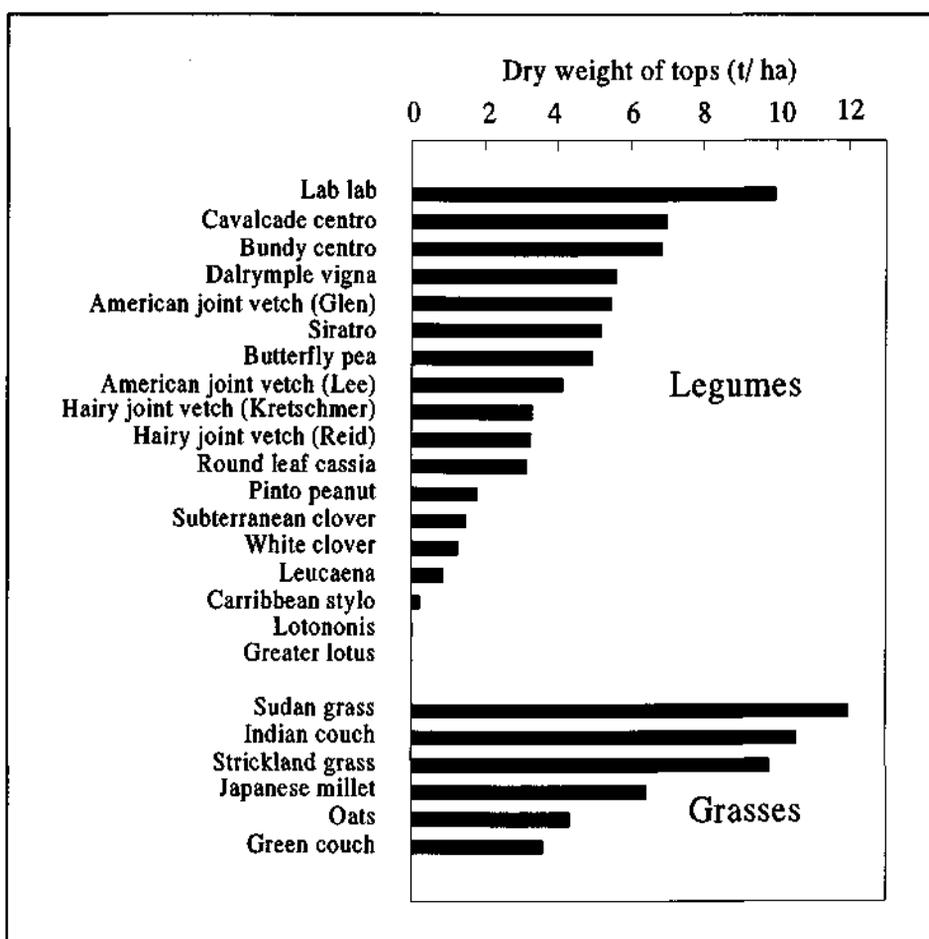


Fig. 7. The dry weight of tops of crop species which could be potentially used as killed *in-situ* mulches for capsicum production.

### **Factorial field assessment of killed *in-situ* mulches**

Inspection of the cover crop species on 3 March 1999 revealed silver-leaf white-fly (*Bemisia tabaci* Strain B) on the centro, cowpea, and lablab plants, although no significant damage was visible. Bean fly (*Ophiomyia phaseoli* Tryon), Lepidopterous larvae and thrips were also prevalent on the cowpea, and the bean fly caused lodging of some plants. The cowpea was also infected by rust (*Puccinia* sp.) and *Cercospora* sp., which caused the older leaves to turn yellow and abort. Necrotic spots on the vetch, Indian couch, and sorghum were caused by *Alternaria* sp., *Helminthosporium* sp., and *Helminthosporium* sp., respectively. The high incidence of insects and fungal pathogens on the cowpea suggests that this cover crop species would need to be sprayed with pesticides to yield to its potential. Such practices would probably not be acceptable in a killed *in-situ* mulch production system.

The dry weight of the tops of the cover crop species cut prior to glyphosate application revealed large variation among the cover crop species (Fig. 8), with sorghum producing a greater weight ( $P < 0.05$ ) than the other crop species. The dry weights of tops of lablab and cowpea were greater than those of the other legumes and the Indian couch.

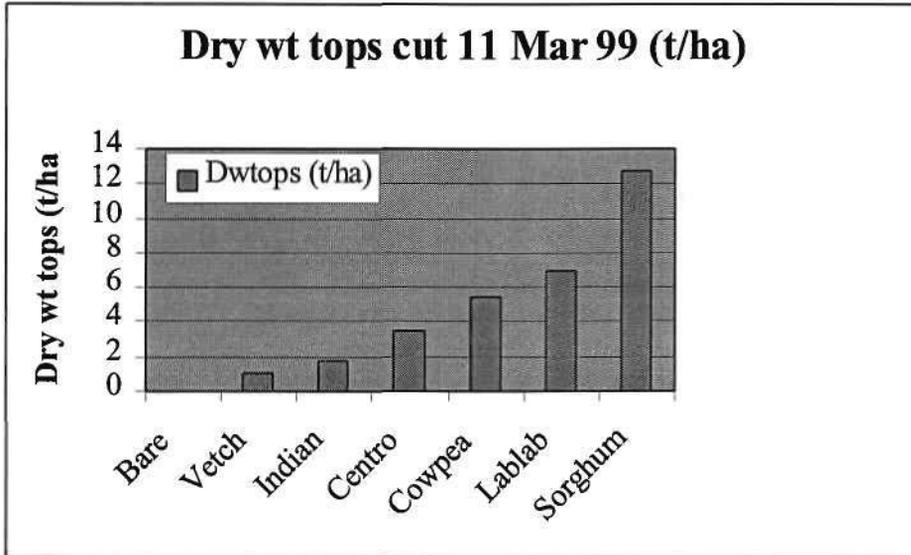


Fig. 8. Dry weight of tops of the cover crop species grown as killed *in-situ* mulches in the factorial field assessment. The F-test for mulch treatments was significant at  $P=0.05$  (l.s.d. = 1.73).

The capsicum seedlings were transplanted at 24 days after spraying the cover crops with glyphosate. By this time, the cover crops had lodged onto the soil surface and did not require rolling. Despite the beds being irrigated 48 hours before planting to make penetration of the soil easier than if the soil was dry, a water-wheel planter could not be used because the density of roots from the cover crops did not allow a proper plant hole to be formed. Therefore, all capsicum seedlings were transplanted by hand, ensuring that an adequate plant hole was formed and seedlings were bedded in after planting. Difficulty was encountered in transplanting the capsicum seedlings through the killed *in-situ* mulch cover, particularly the sorghum which formed the thickest cover.

At 14 DAT, it became clear that the growth of the capsicum seedlings was slower than that of seedlings taken from the same batch and planted on the same day in an adjacent trial investigating transported mulches on newly-formed beds (described in Section 2). Exhumation of the root balls of several seedlings revealed that poor soil contact was made with the root system of the vegetable seedling at the time of planting. Penetrometer measurements from the weeded subplots at 20 DAT revealed that less force was required to penetrate the upper 5 cm of soil in the bare soil ( $0.8 \text{ kg/cm}^2$ ), vetch ( $1.3 \text{ kg/cm}^2$ ) and centro ( $1.4 \text{ kg/cm}^2$ ) treatments than soil in the other treatments. However, the growth of seedlings was poor in all treatments, even in the bare soil treatment. The poor growth in the bare soil plots may have been caused by slumping of the beds from several irrigation cycles during the growth period of the cover crops, since the bare soil plots were formed at the same time as the other beds in the experiment.

Despite the relatively poor appearance of capsicum plants in the trial compared with plants in the adjacent transported mulch trial, the plants still grew in a sigmoidal growth response as determined by measurement of plant height. No difference in the height of capsicum plants grown in the 7 mulch treatments was detected at any measuring time. Indeed, the day after final harvest, the dry weight of the root systems of 5 randomly picked plants grown in the

weeded subplots of each mulch treatment did not differ at the 5% level of probability (range 22.7-28.9 g/ 5 root systems).

The concentrations of all measured elements in the blades of leaves sampled at 41 (flowering) and 55 (fruit set) DAT from the weeded subplots of the bare soil treatment were either within or above the range considered to be adequate (Huett *et al.* 1997) for the youngest mature leaf of a capsicum crop, suggesting that nutrient supply was non-limiting to optimal crop growth. Furthermore, petiole sap nitrate concentrations of the capsicum plants did not differ among the mulch treatments at 62 DAT (fruit set, range 3,410-4,435 mg/L), whereas at 41 DAT (first anthesis), the concentration for the sorghum treatment (3,045 mg/ L) was lower ( $P<0.05$ ) than those for the other treatments (5,855-7,190 mg/L). Apart from plants at first anthesis grown in the sorghum treatment, the concentrations of nitrate in the petiole sap of plants grown at first anthesis or fruit set were within or well above the concentration range at first anthesis (5,550-6,000 mg/ L) or fruit set (520-1,220 mg/L) associated with 95 and 100% of maximum marketable fruit yield for capsicum plants grown in the autumn/ winter season at Bundaberg (Olsen and Lyons 1994).

The small range of tensiometer suction encountered in the trial (Table 7) indicated that soil moisture was probably not a limitation to yield of the capsicum plants. Despite this small range of values, tensiometer suction differed among mulch treatments at 11, 26, 53, and 60 DAT (Table 7), with lower suctions (higher moisture content) in those plots which tended to have a thick covering of mulch.

**Table 7. Tensiometer suction (kPa) at a depth of 20 cm for weeded subplots at 11, 26, 53, and 60 DAT.**

Means followed by the same letters are not significantly different at  $P=0.05$  (F-test in the ANOVA for the mulch treatment)

Cover crop species	11 DAT	26 DAT	53 DAT	60 DAT
Sorghum	7.5a	8.5a	8.0a	8.0a
Indian couch	8.5ab	8.8a	8.8abc	7.8a
Centro	9.0abc	9.0a	8.5ab	7.8a
Lablab	9.0abc	10.5b	9.5bcd	9.8c
Vetch	9.8bc	10.5b	10.0cd	9.3bc
Cowpea	10.3c	10.8b	10.0cd	8.3ab
Bare soil	10.0bc	11.3b	10.5d	9.3bc
l.s.d. ( $P=0.05$ )	1.6	1.2	1.3	1.2

The mean daily air temperature and irradiance and the total rainfall for each month spanning the duration of the field trial (from sowing on 8 April to final harvest on 24 August 1999) compared favourably with the Bureau of Meteorology 30-year average for these parameters. These data have been presented previously in Fig. 1.

On an individual day (36 DAT) with high solar irradiation ( $16.4 \text{ MJ/m}^2 \cdot \text{day}$ ), minimum soil temperatures occurred between 6:30 and 7:00 a.m. and maximum values were recorded around 2:00 p.m. in the weeded subplots of the bare soil, centro, Indian couch, and sorghum whole plots in Blocks 2 and 3 (Fig. 9).

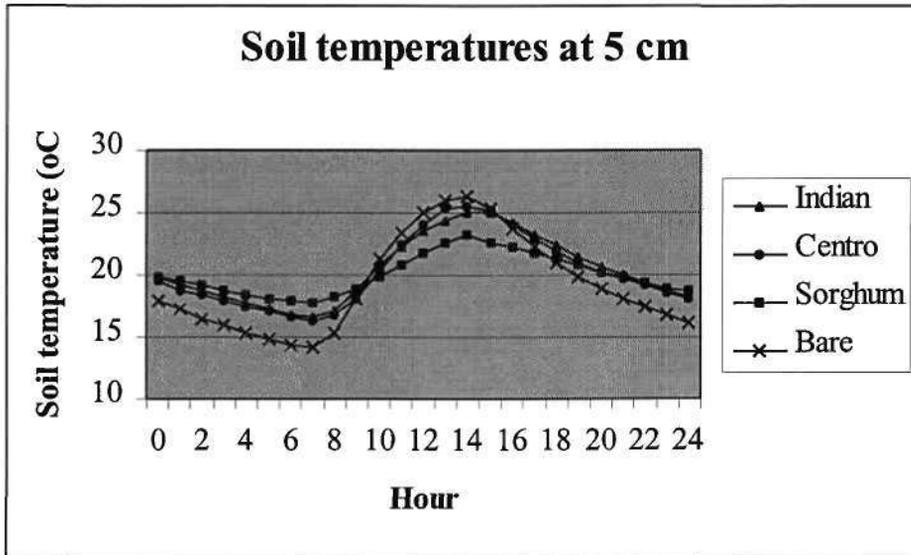


Fig. 9. Soil temperatures at 5 cm depth within the E row of capsicum plants grown in the weeded subplots of the bare soil, Centro, Indian couch, and sorghum treatments during 14 May 1999 (36 DAT). Values are means at each hour (E standard time) for Blocks 2 and 3. Total radiation received on this day was 16.4 MJ/m<sup>2</sup>.day, maximum air temperature was 28°C, minimum air temperature was 11°C, and no precipitation occurred.

Minimum soil temperatures tended to be higher under the thicker mulches than under the bare soil or poorly covered beds, whereas the converse was true for maximum soil temperatures. For either maximum or minimum soil temperatures, values were ranked similarly at each measuring time, as shown at 20, 27, 40, and 68 DAT in Table 8. The low maximum soil temperature under the sorghum mulch may be explained by a significant amount of air space within the mulch. The low thermal conductivity of air (Marshall and Holmes 1979) would preclude the conductance of a large amount of absorbed heat from the mulch to the soil. Closure of the leaf canopy of the capsicum plants probably accounted for the non-significance of the F-test for maximum soil temperatures at 68 DAT (Table 8). The mean soil temperature recorded for all measuring times was lower ( $P < 0.05$ ) under the sorghum mulch (19.9°C) than under the other mulch treatments, whereas the mean soil temperature was higher ( $P < 0.05$ ) for the bare soil treatment (20.7°C) than the other mulch treatments, except Indian couch (20.4°C) and cowpea (20.5°C).

**Table 8. Minimum and maximum soil temperatures (depth 5 cm) under the killed *in-situ* mulch treatments at 20, 27, 40, or 68 days after transplanting the capsicum seedlings.**

Means within columns followed by the same letters are not significantly different at  $P=0.05$  (F-test for the main effect of mulch treatments).

Cover crop Species	20 DAT		27 DAT		40 DAT		68 DAT	
	Min	Max	Min	Max	Min	Max	Min	Max
Sorghum	15.9d	21.0a	18.6c	22.3a	17.4b	22.1a	13.0bc	17.6
Indian couch	16.0d	22.8bc	18.5bc	23.9bc	16.6a	23.1bc	12.6bc	17.6
Centro	16.2d	22.5b	18.7c	23.7b	17.2b	22.4ab	13.3c	16.8
Lablab	15.1c	23.2bc	18.5bc	24.3bc	16.5a	23.5cd	11.7a	17.5
Vetch	14.4ab	23.9cd	18.2a	24.2bc	16.3a	23.3c	12.3ab	17.2
Cowpea	14.9bc	23.9cd	18.5bc	24.5c	16.5a	24.1d	11.8a	17.0
Bare soil	14.2a	24.8d	18.3ab	24.4bc	16.3a	23.7cd	11.8a	17.9
l.s.d. ( $P=0.05$ )	0.64	1.26	0.26	0.8	0.39	0.81	0.71	0.8

Percent cover of the sorghum, centro, and Indian couch mulches were higher ( $P<0.05$ ) than the other mulch treatments at all measuring times up to 68 DAT, and the values for 6, 20, 40, and 68 DAT are presented in Table 9. Depth of mulch was greater ( $P<0.05$ ) for the sorghum mulch than for the other mulches at all measuring times, and decreased progressively from 7.5 cm at 6 DAT to 3.9 cm at 68DAT. Observations from previous trials have indicated that about 7.5 cm of organic mulch is required to suppress weed growth. On this basis, only the sorghum mulch would have been thick enough to suppress weed growth, although the thickness of this mulch cover quickly declined as the experiment progressed (Table 9). Although the F-test for the main effect of mulch treatments was not significant for the total dry weight of weeds removed from the weeded subplots on 4 occasions during the trial, the total weight removed from the sorghum subplots (14.8 kg/ha) and Indian couch (12.7 kg/ha) were low and ranked lower than the others (vetch 17.2 kg/ha < bare soil 21.6 kg/ha < centro 21.7 kg/ha < cowpea 22.6 kg/ha < lablab 22.9 kg/ha).

**Table 9. Depth (cm) and cover (%) of the various killed *in-situ* mulches in the weeded subplots at 6, 20, 40, or 68 days after transplanting the capsicum seedlings.**

Means within columns followed by the same letters are not significantly different at  $P=0.05$  (F-test for the main effect of mulch treatments).

Cover crop species	6 DAT		20 DAT		40 DAT		68 DAT	
	Depth	Cover	Depth	Cover	Depth	Cover	Depth	Cover
Vetch	0.6ab	39b	0.7a	39b	0.2a	18b	0.3ab	15b
Cowpea	1.6bc	72c	1.3b	80c	0.7b	64c	0.3ab	61c
Lablab	1.7bc	76c	2.1c	80c	1.3c	74c	0.6ab	64c
Indian couch	2.4cd	92d	1.6b	93d	1.0b	92d	0.7bc	86d
Centro	2.8d	96d	2.1c	97d	1.4c	91d	1.2c	88d
Sorghum	7.5e	93d	4.8d	95d	3.7d	95d	3.9d	94d
l.s.d. ( $P=0.05$ )	1.2	15	1.2	13	0.4	16	0.6	14

The interaction of mulch treatment x weeding was not significant for the yield parameters measured in this study. Therefore, only means of whole plots will be presented in this section. The marketable yield of capsicum plants grown in the sorghum mulch was lower ( $P < 0.05$ ) than those of plants grown in all the other mulch treatments, except cowpea (Fig. 10). The yield of marketable fruit of plants grown in the Indian couch, vetch, bare soil, and centro mulch treatments did not differ. In order to compare the yield of plants growing in the guard rows which were covered with plastic mulch with those of plants growing in the mulch treatments in the trial, 4 areas of 20 plants were marked out in the guard rows for an assessment of yield. The average weight of marketable fruit from these guard plants (26.2 t/ha) was nearly twice that of plants in the highest-yielding mulch treatment. These guard rows had been through the same wetting and drying cycles as the rows used for the trial, but covered with plastic mulch prior to planting the capsicum seedlings.

The weights of unmarketable fruit harvested from capsicum plants grown in the cowpea, sorghum, and lablab mulch treatments were lower ( $P < 0.05$ ) than those grown in the other mulch treatments. Crop response in these mulch treatments was poor, given the fact that low yields of marketable fruit were also measured in these mulch treatments.

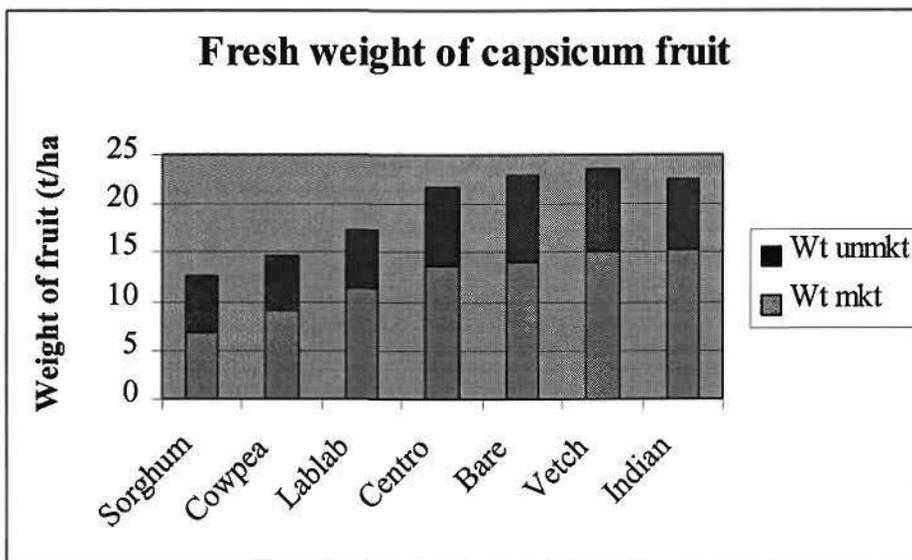


Fig. 10. Effects of mulch treatment on the weights of marketable fruit and unmarketable fruit harvested from capsicum plants grown in the killed *in-situ* mulch field trial. The l.s.d. at  $P = 0.05$  are 3.4 for marketable and 2.0 for unmarketable fruit weights.

The cost of establishing a killed *in-situ* mulch is relatively low (\$300/ ha, Table 10) compared with the cost of purchase and disposal of plastic mulch film (\$1,100/ ha). However, the considerably lower yields of capsicum plants grown with killed *in-situ* mulch than with plastic mulch was demonstrated in this study. Despite the benefits to soil health which may be imminent from using biodegradable mulch materials, use of the killed *in-situ* mulch system would not be an option for most commercial capsicum growers.

**Table 10. Costs of establishing a killed *in-situ* mulch.**

	No. units (units/ha)	Unit description	\$/unit	\$/ha	Total (\$/ha)
<b>VARIABLE COSTS (\$/ha)</b>					
<i>KILLED IN-SITU MULCHES</i>					
<b>Machinery operations (F.O.R.M.)</b>					<b>27.30</b>
Seed Sower	1.0	pass	14.16	14.16	
Boom Spray (Roundup)	1.0	pass	3.44	3.44	
Pump (Trickle)	0.5	ML	19.39	9.70	
<b>Seed</b>					<b>200.00</b>
Jumbo sorghum/ or Lab Lab etc.	80.0	kg	2.50	200.00	
<b>Fertiliser</b>					<b>56.55</b>
Urea (2 @ 43.5 kg/ha)	87.0	kg	0.65	56.55	
<b>Irrigation</b>					<b>20.00</b>
Water Resources charges	0.5	ML	40.00	20.00	
<b>TOTAL ADDITIONAL COSTS OF KILLED IN-SITU MULCH (\$/HA)</b>					<b>303.85</b>

The results from this factorial field assessment of killed *in-situ* mulches indicated that the low yields of capsicum plants grown in this system would be a major impediment to its adoption by commercial growers. The low yields were the result of poor weed control and difficulties encountered at planting the capsicum seedlings through the mulch cover and into the root-bound soil below. Another potentially yield-limiting factor is the build-up of root-disease organisms by the cover crop – this aspect will be examined in the section below. The time required to establish the cover crop (about 9 weeks) is an added input. For the killed mulch system to be more effective, machinery would need to be sourced which will loosen soil around the transplanted seedling to improve soil contact, whilst ensuring adequate mulch cover remains on the soil surface around the seedling. The inadequacy of the vigorous cover crops used in this study to arrest weed growth as killed *in-situ* mulches would be an ongoing problem for growers adopting this system.

#### *Assessment of nematode susceptibility of the cover crop species*

The cover crop species used in the factorial field trial varied considerably in their susceptibility to root-knot nematode (Table 11). Apart from the American joint vetch which showed no galling or egg masses, the legume crop species were highly susceptible to *Meloidogyne javanica* infection and reproduction. Of these, centro was the most susceptible to root-knot nematode. Therefore, in the absence of soil-applied nematocides or fumigants, a killed *in-situ* mulch formed by centro would dramatically increase the population of root-knot nematodes in the soil. Use of a heavy clay soil would probably reduce the rapidity with which nematodes would increase under this cover crop.

The tolerance of the grass species to root-knot nematode was also highlighted by this experiment, with no galls or egg masses measured for the Indian couch or Jumbo sorghum plants. Use of either of these crop species as a killed *in-situ* mulch would limit an increase in the population of root-knot nematode in the soil.

**Table 11. Ratings for galling caused by root-knot nematode *Meloidogyne javanica* and confirmation of the presence of egg masses for a susceptible tomato cultivar and the cover crop species which formed the killed *in-situ* mulches in the factorial field experiment.**

Gall were rated using the following scale: 0 = no galls; 1 = 1-25%; 2 = 26-50%; 3 = 51-75%; 4 = 76-99%; 5 = 100% of roots galled.

Cover crop species	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Aver.	Egg mass
Centro	5	5	6	5	5	5.2	Yes
Cowpea	5	6	4	4	4	4.6	Yes
Indian couch	0	0	0	0	0	0	No
Lablab	4	5	5	4	5	4.6	Yes
Sorghum	0	0	0	0	0	0	No
Vetch	0	0	0	0	0	0	No
Tomato (Control)	6	6	6	6	6	6	Yes

## **5. A field assessment of the suitability of two forage sorghum cultivars to form a killed *in-situ* mulch in capsicum**

by Ross M. Wright, Queensland Horticulture Institute, DPI Bowen Research Station

### **5.1 Summary**

This field trial was conducted to assess the effect of a killed *in-situ* mulch of sorghum on the growth and yield of a transplanted capsicum crop. Whole plots were raised beds which were fitted with trickle irrigation tubing, sown with one of 2 forage sorghum species and grown for 7, 6, or 5 weeks before being sprayed with herbicide. Capsicum seedlings were transplanted 4, 6, or 8 weeks after herbicide application into subplots allocated randomly within each whole plot. Poor and uneven growth of the capsicum transplants occurred in all treatment plots, most probably due to poor contact of roots with the tightly bound soil in the sorghum whole plots or the slumped soil of the untilled control plot following several irrigation cycles. The depth and cover of the mulch provided by the killed *in-situ* sorghum plants was insufficient to prevent vigorous weed growth. Volunteer sorghum plants also emerged midway through the life of the first field planting, presumably due to late germinating seed, and would have competed with the crop for light, water and nutrients. Capsicum plants grown in guard rows covered with plastic mulch and formed using standard tillage practices appeared much healthier than plants grown in the trial. The results indicated that the poor and uneven growth of capsicum transplants in the killed *in-situ* mulch system was considered to be a major impediment to the adoption of these mulches as a replacement for plastic mulch film. Specialised equipment would be required to loosen soil around the transplanted seedling to improve soil contact, whilst ensuring adequate mulch cover remained on the soil surface around the seedling. However, even hand-planting the capsicum seedlings causing minimal disturbance to the mulch resulted in inadequate weed control by the mulch. The relatively long period of time required to establish a suitable killed *in-situ* mulch (at least 9 weeks) is also likely to have a negative effect on adoption of the technique by all but the most committed growers.

### **5.2 Introduction**

From the 1998 evaluations of mulch species, 2 forage sorghum varieties were identified as having the best potential to provide sufficient dry matter as a mulch for vegetable crops after some 4-8 weeks of growth. Spraying the mulch off with a herbicide within this period and allowing time for the forage sorghum to collapse and form a suitable ground cover was proposed as a possible alternative to the use of plastic mulch. Identifying more closely the most suitable time to kill off the forage sorghum crop, the variety most suited to this purpose, the most suitable time to plant into the mulch cover and the performance of a capsicum crop grown under these conditions were the major objectives of this study.

### **5.3 Materials and methods**

The forage sorghum varieties used in this study were *Zulu* (equivalent to the variety *Rambo* used in the 1998 evaluation) and *Bettadan*. Trickle irrigated beds were formed up at 1.5m centres and seed of these 2 forage sorghum varieties was sown on 3 occasions at weekly intervals on 25/5/99, 31/5/99 and 7/6/99, giving 6 main treatments (2 sorghum cultivars x 3

sowing dates). A further treatment added was kept weed free through the growth period of the forage sorghum. Four replicates for each main treatment were used. On 14/7/99, the forage sorghum plots were sprayed with glyphosate giving growth periods for both of the varieties of 7, 6 and 5 weeks.

Whole plots were divided into 3 sub-plots and capsicum planting times were allocated randomly to these. The treatment kept weed free was covered with plastic mulch just prior to the first planting date. This design provided 7 mulch whole plots split into 3 capsicum planting time subplots. Capsicum seedlings variety *Merlin* were transplanted in double rows with bed centres 1.5m apart into the respective subplots following rolling of the cover cropped plots at intervals of 4, 6 or 8 weeks (12/8/99, 25/8/99 and 9/9/99) after spraying off the forage sorghum. Guard rows were formed in the normal manner on the 2 outside rows of the trial block, following cultivation, rotary hoeing, bedforming and laying plastic mulch, just prior to transplanting. This operation differed from the plastic mulch treatment which merely covered the existing weed free beds with plastic mulch with no cultivation since trickle irrigation lines were already in place. The guard rows were transplanted on the first planting occasion on 12/8/99.

Harvesting was carried out when fruit was in the 50% to full red stage. Five harvests were carried out from 10 plant sub-plots over the period from 9/11/99 to 15/12/99 and divided into marketable and reject fruit, weighed and counted. Some 48mm of rain fell on the trial site over the first 2 weeks in November followed by 75mm over the last 10 days of November.

## 5.4 Results and discussion

Following spraying with glyphosate the forage sorghum plots began to collapse within one week and all treatments had collapsed within 3 weeks of spraying. The *Bettadan* plots generally produced a finer flatter surface than the *Zulu*, particularly where growth had been for only 5 or 6 weeks. However it was necessary to roll all cover cropped plots to even up the surface of the mulch and make transplanting easier. Both forage sorghum varieties fell in the same direction, that of the prevailing wind which aided in producing a more even surface. The cover crops generally covered the soil over the bed quite well although the 5 week growth produced a few areas where soil was visible through the mulch.

At transplanting, great difficulty was experienced in planting seedlings into the forage sorghum mulch treatments. The density of roots from the cover crop made soil contact with the transplant seedlings very difficult to achieve. The plastic mulch treatments were also difficult to plant into due to slumping of the beds from irrigating the forage sorghum during its growth and lack of cultivation prior to laying the mulch. Subsequent drying out of the plastic mulch treatments after spraying off the cover crops and cessation of irrigation made these plots more difficult to wet up again. All treatments within the trial had to be planted by hand as the waterwheel planter could not successfully plant into the mulch treatments, but was used successfully on the guard rows.

Poor and uneven growth of transplants occurred in all treatment plots most probably due to the poor soil contact with the capsicum plants in the forage sorghum treatments and the tight soil conditions in the plastic mulch treatment. This uneven growth was particularly evident in the early September planting when higher temperatures prevailed. Poor and uneven

growth continued through to harvest in all treatments despite the provision of nutrients through the irrigation system. Poor foliage cover resulted in heavy losses to sunburning. This sunburn damage was particularly evident in the plastic mulch treatments where weed growth within the plots was minor and restricted to smaller weeds emerging through the planting holes. In the forage sorghum treatments, giant pigweed *Trianthema portulacastrum* was the major weed and a significant problem within the plant rows and was fairly evenly distributed through all the treatments. It became obvious that the density and depth of mulch on the surface provided by the forage sorghum treatments was insufficient to prevent light penetration through to the soil surface even in the plots of longest growth periods, resulting in weed growth through all the treatments. Volunteer sorghum plants also emerged midway through the life of the first field planting, presumably due to late germinating seed. This weed growth tended to favour the forage sorghum treatments by reducing sunburn in the hot conditions around harvest, but also competed with the capsicum plants for light, water and nutrients. A similar problem of emergence of mulch species volunteers as weeds in the time when a vegetable crop is grown was reported by Sutton (1998). He stated that there was no easy solution to this problem, except meticulous attention to sowing time. Many fruit in the plastic mulch treatments tended to rot on the bushes possibly due to bacterial rots entering sunburnt parts of the fruit. There were also plant losses after the commencement of harvesting due to root rots in one replicate of the plastic mulch treatments and the last sown forage sorghum treatments in 2 replicates, which appeared not to be associated with any treatment effect. There were further losses due to breakdown and surface rots following the November rain during harvest. All treatments were affected but the latest planting was more affected than the first 2 as reflected in the means of the sub-plot yields for each planting time across all treatments (Table 12).

**Table 12. Effects of the planting time of the capsicum seedlings on fruit yield.**

Planting date of capsicum seedlings	Mean marketable fruit wt (kg/ subplot)	Mean total fruit wt (kg/ subplot)
12/8/99	4.55	7.37
25/8/99	4.20	7.05
9/9/99	3.0	4.83
l.s.d. (P= 0.05)	0.52	0.89

Whole plot effects of mulch type also showed differences ( $P < 0.05$ ) when the yield of capsicum fruit were compared across sowing dates of the sorghum cultivars (Table 13). The earliest sown forage sorghum treatment produced higher ( $P < 0.05$ ) yields of marketable fruit than the plastic mulch treatment. There were also differences ( $P < 0.05$ ) of marketable capsicum fruit between the earliest sown *Zulu* and *Bettadan* and the mid sowing of *Bettadan* or the last sowing of *Zulu*. The mean yields of capsicum fruit in the various mulch whole plots are shown in Table 13.

**Table 13. Effects of the whole-plot mulch treatment on the yield of capsicum fruit.**

Whole-plot mulch treatment	Growth period of sorghum (weeks)	Mean marketable capsicum fruit wt. (kg/ subplot)	Mean total capsicum fruit wt. (kg/ subplot)
Zulu	7	4.47	7.37
Bettadan	7	4.47	7.30
Zulu	6	4.24	6.88
Bettadan	6	3.63	6.55
Zulu	5	3.00	5.53
Bettadan	5	3.75	6.07
Plastic mulch	0	3.61	5.22
l.s.d. (P=0.05)		0.80	1.02

There were significant interactions between mulch whole plot treatments and capsicum planting time subplots, but these did not suggest any consistent trends and interpretation of any meaningful result was not possible, no doubt due to the poor performance of the trial block overall. The inconsistent crop growth is reflected in the high coefficient of variation for yield of 25%. The combination of difficulties with plant establishment and the seasonal lateness of the last planting particularly made a reasonable assessment of alternative mulches difficult. The guard rows which were not included in the trial proper gave an indication of how the plastic mulch would have performed if normal commercial procedures were employed. Within the guard rows, growth of the capsicum plants was relatively even and plants were leafier while fruit production was observed as being superior in quantity and average size than plants within the trial, although no data were recorded. Sunburn was significant and some plant deaths through root rots occurred but overall, growth problems of the capsicum plants grown in the guard rows were much reduced compared with the plastic mulch treatment within the trial

## 5.5 Conclusions

The major conclusions that can be drawn from this experiment were as follows:

- The relatively long period of time required to establish a killed *in-situ* mulch treatment before planting a capsicum crop into the mulch (9 weeks at the very least) is likely to have a negative effect on adoption of the technique.
- A thicker layer of mulch than that developed from the sorghum treatments in this study may be required to effectively control weed growth.
- Emergence of volunteer sorghum plants from late-germinating seed would involve at least one to 2 additional applications of herbicide specific for grasses.
- The poor and uneven growth of capsicum transplants in the killed *in-situ* mulch treatments were considered to be a major impediment to the adoption of these mulches as a replacement for plastic mulch film. Establishment of capsicum seedlings under the killed *in-situ* mulch system may require an engineering input to produce equipment capable of loosening soil at the plant position, planting the seedling and ensuring a suitable mulch cover remains around the seedling.
- Whereas soil fertility in this experiment was probably sufficient to allow for all nutrients to be supplied through the irrigation as shown in the guard rows, less fertile soils may require a method of adding additional solid fertiliser to the system at time of transplanting.

## 6. Mulch and soil management in broccoli production

by Craig Henderson Queensland Horticulture Institute, DPI Gatton Research Station.

### 6.1 Summary

Our previous research showed some vegetable crops did not grow or yield as well under a killed *in-situ* mulch system, compared with conventional production. Killed *in-situ* mulch systems involve transplanting vegetable seedlings into undisturbed beds, in which a cover crop such as forage sorghum was previously grown for 6-7 weeks, killed with herbicide, and flattened to form a protective mulch layer. This experiment sought to isolate which components of killed *in-situ* mulch systems were limiting crop performance. We investigated cover crop, tillage, and residue management combinations in broccoli production at Gatton Research Station between February and July 2000. Treatments included growing conventional fallow and cover crops, conventional and zero tillage, and mulch incorporation, retention or addition, in a series of treatment combinations.

Jumbo forage sorghum produced 15 t/ha of dry matter, forming a good cover, either as a killed *in-situ* mulch, or transported mulch, hand laid. Planting broccoli through mulch was much easier where the mulch was still anchored to its root structure in defined rows. Where mulch was loose on the surface, straw pinned around the tines of planting equipment, causing blockages.

Broccoli grew slightly slower in ground that was cover cropped prior to planting. Slower growth could be due to either nutritional tie up or release of allelopathic chemicals as the sorghum roots degraded. The surface component of sorghum residues, i.e. surface straw, did not affect broccoli growth, either by locking up nutrients or increasing disease incidence. Neither pre-plant tillage, nor removal of surface residues, ameliorated reduced broccoli growth after cover cropping.

There were positive yield benefits from having a surface mulch of sorghum straw present, either grown *in-situ*, or transported in. Hypotheses include; improved soil temperature (slightly cooler), improved surface soil water relations (slightly moister), or a combination, giving a better surface soil microenvironment and hence surface root growth.

There were no responses in broccoli growth to tillage treatments. This absence suggests that in our structured, black earth soils, a recently disturbed seedbed is not essential for acceptable vegetable performance, provided we achieve reasonable initial transplant-to-soil contact.

Our experiment confirmed that conditions leading to good establishment, early growth and high yields, are associated with earlier and more synchronous head development, reducing the need for extended, multiple harvests.

In the absence of herbicide applications, surface mulches reduced weed establishment. The reduction in hand weeding times using a mulched, no till strategy, (such as in the killed *in-situ* mulch system compared with the conventional strategy), would be an important

commercial consideration in the absence of herbicidal weed management. In a low chemical or organic system, this would be a significant management factor. However, a mechanism for killing the tall, vigorous forage sorghum would be an interesting difficulty in the latter. In vegetables, such as brassicas produced with chemical management options, where there are some effective herbicide choices, and hence minimal hand weeding, the weed management from mulches is not as important.

Apart from factors not considered in this experiment (such as build up of nematodes and soil borne diseases), the important points in implementing a killed in-situ mulch system are:

1. The cover crop must be sown and managed to provide clear rows, into which the vegetable crop can then be planted.
2. Good contact between the transplant root cell and soil is required for acceptable vegetable growth and yield, however full soil disturbance is not.
3. There are benefits from the presence of surface mulches that may compensate for disadvantages of cover cropping prior to planting.
4. Improved crop nutrition may be a solution to poorer growth following a cover crop, however pre-planting tillage is not.

## 6.2 Introduction

Organic mulches are an innovative method for managing weeds in vegetable production. Killing cover crops and then planting through them has been investigated in vegetable production in other parts of the world and in southern states of Australia. This experiment established a series of cover-crop management plots, following which we imposed tillage and residue management treatments. The objectives of this study were to

- To determine which components of a killed *in-situ* mulch system cause problems with broccoli crop performance and yield.
- To observe the practical difficulties of using a killed *in-situ* mulch system, and suggest methods for ameliorating those problems.

## 6.3 Materials and methods

We conducted the experiment on a black earth soil (*Ug5.15*) at Gatton Research Station (lat. 27°33'S, long. 152°20'E). We used a randomised complete block experiment, with eight treatments replicated 4 times in blocks. Our total experiment comprised a strip approximately 100 m long and 10 m wide, arranged in 32 3.0 m wide plots running east-west across the width of the main strip. Our 8 treatments involved 2 cover cropping practices, 2 tillage practices, and 2 residue handling practices, as outlined Table 14.

**Table 14. Killed *in-situ* mulch system evaluation treatments.**

Treat no.	Pre-crop activities to form the mulch treatment	Tillage treatment	Additional activity
1	Conventional fallow	Tilled	
2	Conventional fallow	No till	
3	Conventional fallow	Tilled	Sorghum tops transported in
4	Conventional fallow	No till	Sorghum tops transported in
5	Sorghum cover crop grown, then tops cut at soil level and removed	Tilled	
6	Sorghum cover crop grown, then tops cut at soil level and removed	No till	
7	Sorghum cover crop grown, then sprayed with glyphosate and allowed to lodge to form a mulch	Tilled	
8	Sorghum cover crop grown, then sprayed with glyphosate and allowed to lodge to form a mulch	No till	

Research Station staff ripped the site before preparing the ground for planting using conventional cultivation. On 8 February 2000, they sowed *Jumbo* forage sorghum at 50 kg/ha into the designated plots, leaving 12 cm wide gaps for broccoli planting. After a few weeds emerged, we removed them by hand on 22 February, and again on 7 March. After 7 weeks, we sprayed the experimental area with 4 L/ha of ROUNDUP® herbicide, to kill the forage sorghum and any late emerging weeds. On 10 April (62 days after planting the sorghum), we cut off the dried forage sorghum at ground level from the designated plots (Treatments 5, 6), and removed the straw beyond the ends of the plots. We rotary hoed all the tilled treatments (Treatments 1, 3, 5, 7). After we completed the tillage, we replaced the cut sorghum onto the designated plots (Treatments 3, 4), and flattened the sorghum on Treatment 8.

As a consequence of these practices, we had a conventionally prepared treatment (1), and the following comparisons:

Whether absence of soil disturbance affected broccoli growth (1 vs 2)

Whether the presence of surface mulch affected broccoli growth (1 vs 3)

Whether growing a cover crop previously affected broccoli growth (1 vs 5)

Whether incorporating killed, dry sorghum tops into the root zone affected broccoli growth (1 vs 7)

Whether a killed *in-situ* mulch system affected broccoli growth (1 vs 8).

Whether the presence of cover crop roots in a killed *in-situ* mulch system affected broccoli growth (4 vs 8).

Whether the absence of soil disturbance in a killed *in-situ* mulch system affected broccoli growth (3 vs 4).

We transplanted broccoli cv. Greenbelt into the experimental area 2 days after the residue manipulation and tillage, on 12 April 2000, with inter-row spacing of 0.75 m and an intra-row spacing of 0.33 m. Farm staff spread the compound fertiliser CK77S on 13 April at a rate of

400 kg/ha. Only one side dressing of 25 kgN/ha as urea was broadcast over the experimental area on 19 April, 7 days after transplanting (DAP).

We hand weeded the broccoli crop on one occasion, 5 weeks after transplanting, and recorded the time taken in each of plot.

Chemicals applied to the broccoli throughout the growing period were;

Insecticides

- 0.75 L/ha of PIRIMOR® (pirimicarb) 29 DAP
- 0.25 mL/ha of REGENT® (fipronil) 29, and 36 DAP
- 2.1 L/ha of LANNATE® (methomyl) 37, and 72 DAP

Fungicides

- nil

Herbicides

- nil

Irrigation

We irrigated the broccoli with lines of solid-set sprinklers running down the long edges of the block. We installed tensiometer stations in the forage sorghum crop 4 weeks after planting, and in the broccoli crop 8 weeks after transplanting. The tensiometers were installed 15 cm and 60 cm below ground level in one plot of each block. We used Soilspec tensiometers, which consist of a standard ceramic tip and tube, but no vacuum gauge. To obtain readings, a hollow syringe is forced through the rubber septum at the top of the tensiometer, and an electronic vacuum gauge senses the vacuum in the small air gap below the septum. Tensiometer readings were recorded around 8-9 am daily.

## *Measurements*

### *Forage sorghum cover crop*

We counted the weeds present in each plot (30 m<sup>2</sup>) on 22 February (14 days after sowing), just before the initial hand weeding. On 28 March (49 days after sowing), we again counted the weeds present in each plot, and cut 2 0.2 m<sup>2</sup> quadrats of forage sorghum per plot. We weighed these sorghum samples, and then dried sub-samples to enable conversion of the data to a dry weight basis.

### *Broccoli*

One week after transplanting, we removed 2 0.2 m<sup>2</sup> quadrats of forage sorghum residues from the respective plots, weighed these samples, and dried sub-samples to enable conversion of the data to a dry weight basis. We undertook a final measurement of remaining sorghum residues biomass on 4 July (83 DAP), using the same procedure as above.

We measured the widths of 20 randomly selected broccoli plants from each plot on 4 May (22 DAP), and photographed representative plots. At the same time, we counted the weeds present in eight 0.2 m<sup>2</sup> quadrats per plot, prior to hand weeding the whole area. We rated plots for general health, using a 1-4 scale, on 25 May (43 DAP). We counted the numbers of broccoli heads greater than 5 cm diameter in each plot on 22 June (71 DAP).

We harvested mature broccoli heads on 29 June (78 DAP), 3 July (82 DAP), 6 July (85 DAP), and conducted a final clean-up harvest on 19 July (98 DAP). At each harvest, we counted the heads and recorded the total weight per plot. On 13 July, we counted any weeds

that had emerged over the whole plots, cut the weeds off at ground level and recorded their fresh weights.

**Data analyses**

We analysed all plant growth and yield variables using standard analysis of variance. Owing to the nature of their distributions, we log-transformed weed counts and biomass before analysis. We converted the data back to its original form prior to presentation in this report.

**6.4 Results and discussion**

**Irrigation**

A total of 36 mm of rain fell during the cover cropping phase, with a further 94 mm during the broccoli growing period (Fig 11). Because of significant soil water storage, the cover crop was able to grow without supplementary irrigation. By the time we implemented the cover crop treatments, most of the water had been extracted from the crop root zones, with deep cracks in the cover-cropped plots.

We applied 237 mm of irrigation during the broccoli cropping period, following an additional 30 mm irrigation 2 days before transplanting. As we did not install the tensiometers until late in the cropping period, we can only estimate the water status of the crop during the vegetative and early reproductive phases. The irrigation frequency suggests that there should have been sufficient water to prevent any significant water stress. There may have been a 5-7 day period around 11 weeks after transplanting when the broccoli was slightly stressed, indicated by shallow tensiometer values greater than 40 kPa, and extraction of moisture from deeper in the soil profile. This slight stress did not appear to affect yield or head quality.

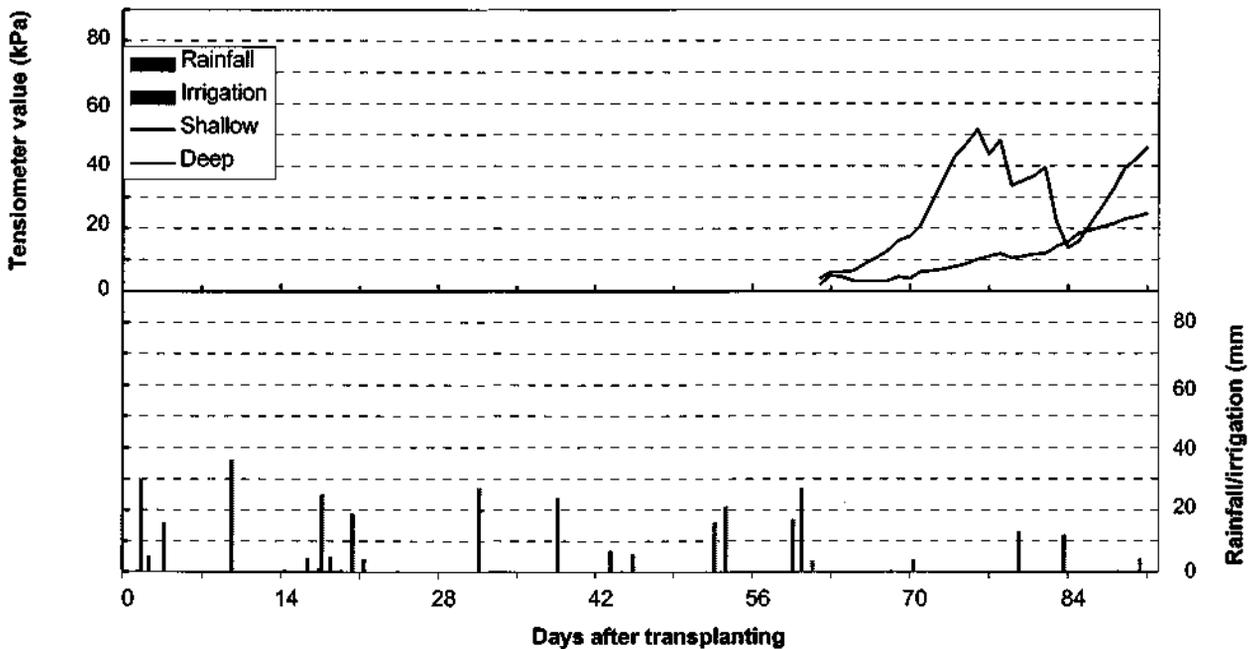


Figure 11. Fluctuation in tensiometer values with rainfall and irrigation during the broccoli growing period.

## Forage sorghum cover crop

### Weed incidence

There were few weeds present 2 weeks after planting the forage crop (Fig. 12). There were significantly more weeds in the uncropped areas, compared with those plots where the forage sorghum was growing. Sowthistle (*Sonchus oleraceus*) and giant pigweed (*Trianthema portulacastrum*) were the species most obviously suppressed by the forage sorghum.

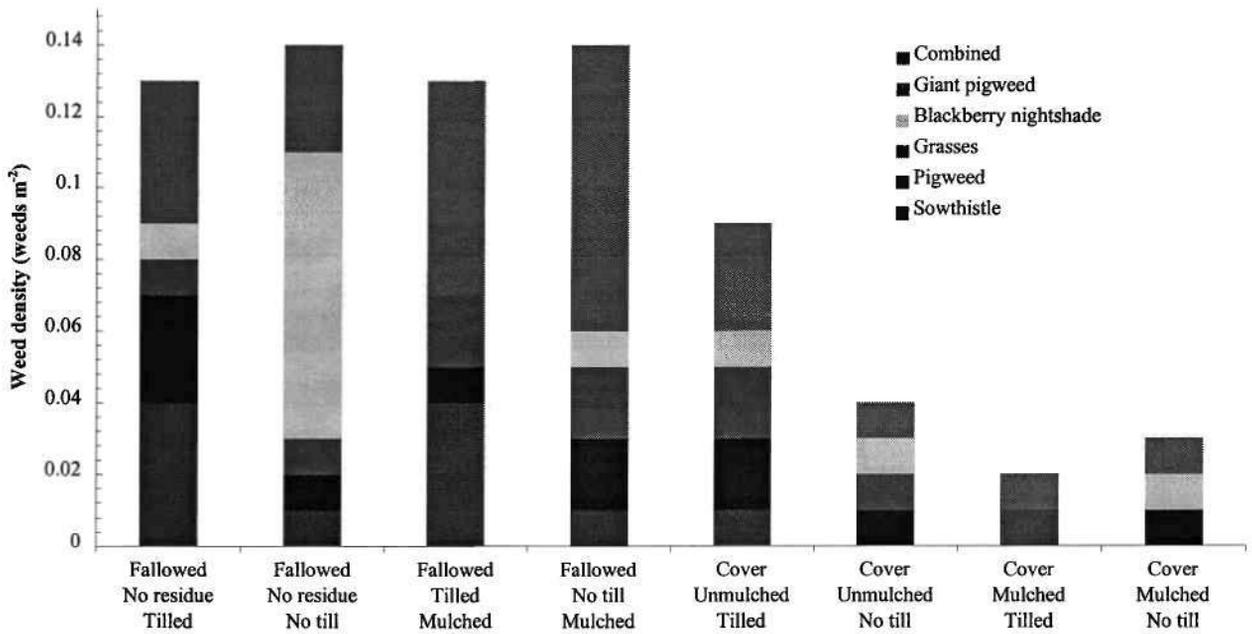


Figure 12. Forage sorghum reduces the presence of weed species 2 weeks after sowing.

After 7 weeks growth, the forage sorghum had produced 14.1 t/ha of dry matter, evenly across all the cover crop treatment plots. The presence of the sorghum had basically eliminated any further weed emergence, whilst there were some new weeds in the uncropped plots (Fig. 13), predominantly sowthistle and pigweed (*Portulaca oleracea*), with a few residual giant pigweed.

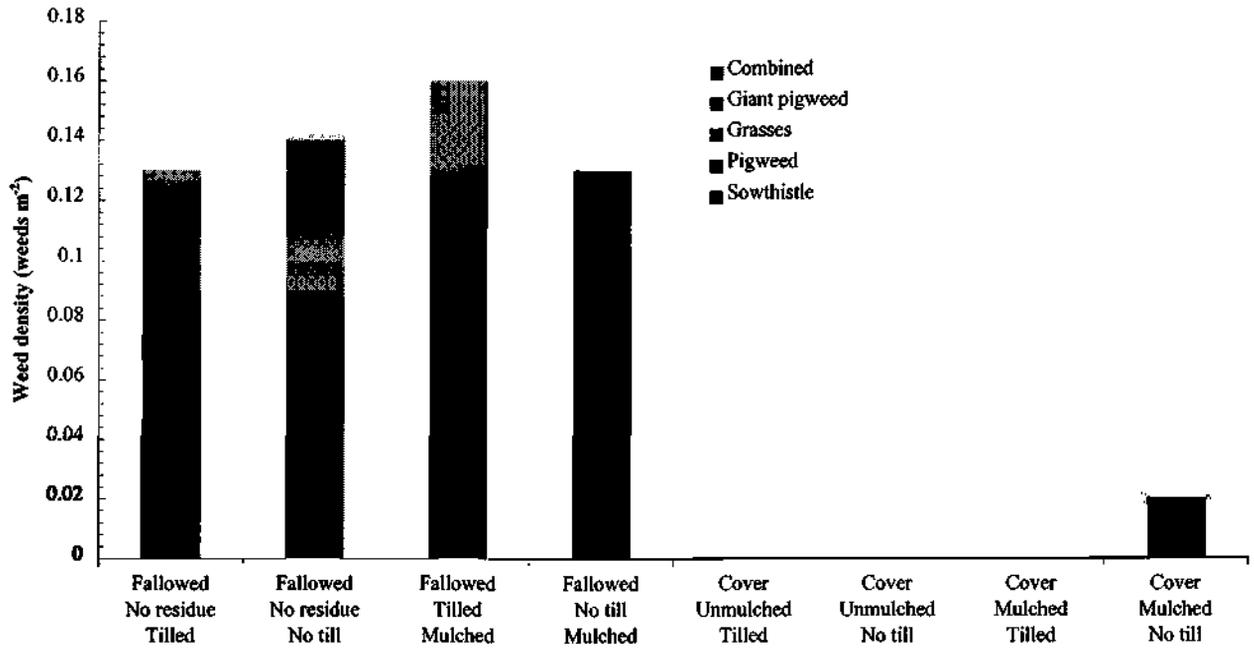


Figure 13. Forage sorghum reduces the presence of weed species 7 weeks after sowing.

### ***Broccoli crop***

Where residues were present during broccoli transplanting, the planting was much more difficult where the residue was not anchored between the planting tines (e.g. Treatment 7), as it tended to pin around the tines. In the standard killed *in-situ* mulch treatment (8), where the sorghum was sprayed and then flattened, the transplanting proceeded relatively smoothly, with only occasional disruption.

One week after transplanting the broccoli, about 15.0 t/ha dry weight of sorghum stubble remained on the surface mulched treatments (3, 4, 8), with 2.9 t/ha of surface residue on Treatment 7, where we incorporated the sorghum cover crop with a rotary hoe before broccoli transplanting.

Three weeks after planting, none of the cover crop, tillage, or residue retention treatments (Fig. 14) consistently affected the widths of broccoli plants, even though there were some significant differences between the individual treatment combinations.

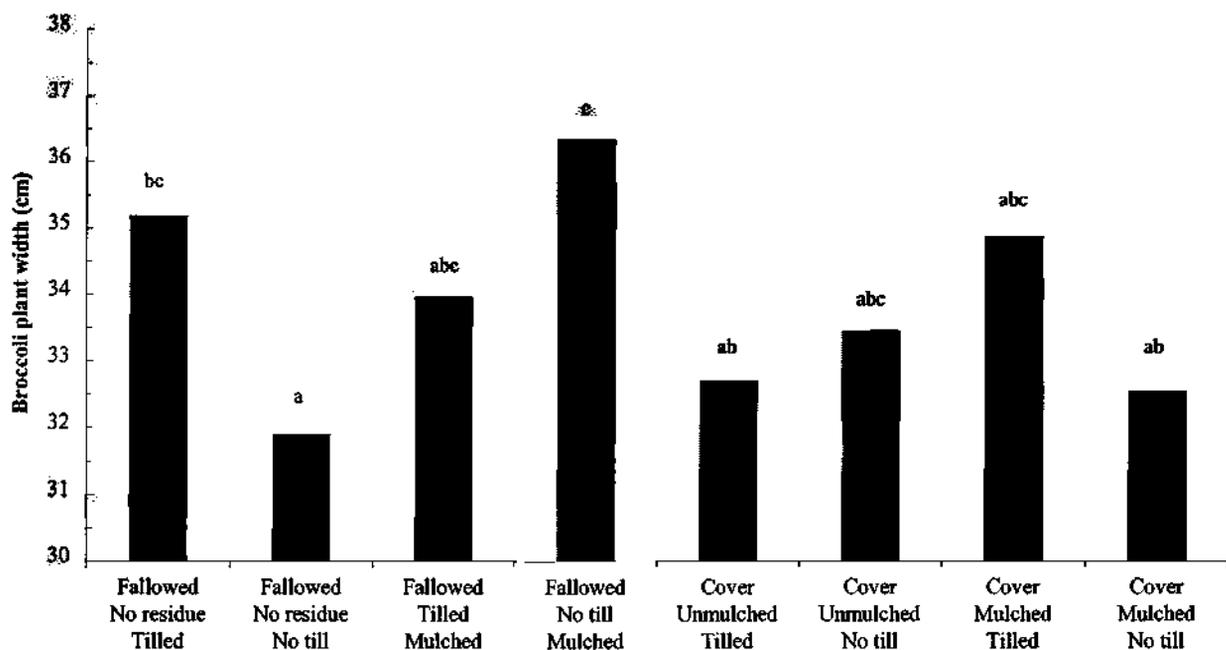


Figure 14. Soil and cover crop residue management marginally affected broccoli plant widths 3 weeks after transplanting.

Six weeks after transplanting, the broccoli plants in plots which had been previously fallowed appeared more vigorous than plants growing in cover cropped soil (Fig. 15). The worst performed treatment was the killed *in-situ* mulch practice (8), where the broccoli was transplanted into undisturbed sorghum residue. Similarly, broccoli head development appeared slightly more advanced in the treatments with a fallow preparation, compared with the cover cropped areas, although this effect was not consistent (Fig. 16). The killed *in-situ* mulch treatment (8) had the fewest developed heads, whilst its companion treatment, where the sorghum was simply turned into the soil (7), had the most.

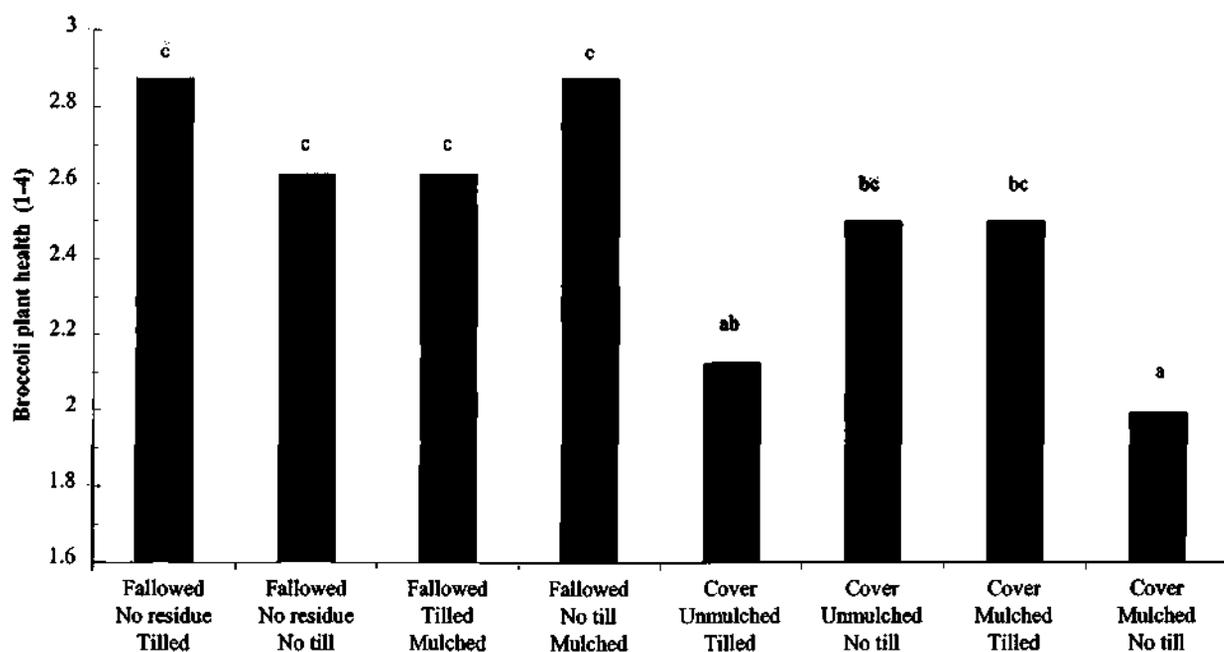


Figure 15. Soil and cover crop residue management affected broccoli plant vigour 7 weeks after transplanting.

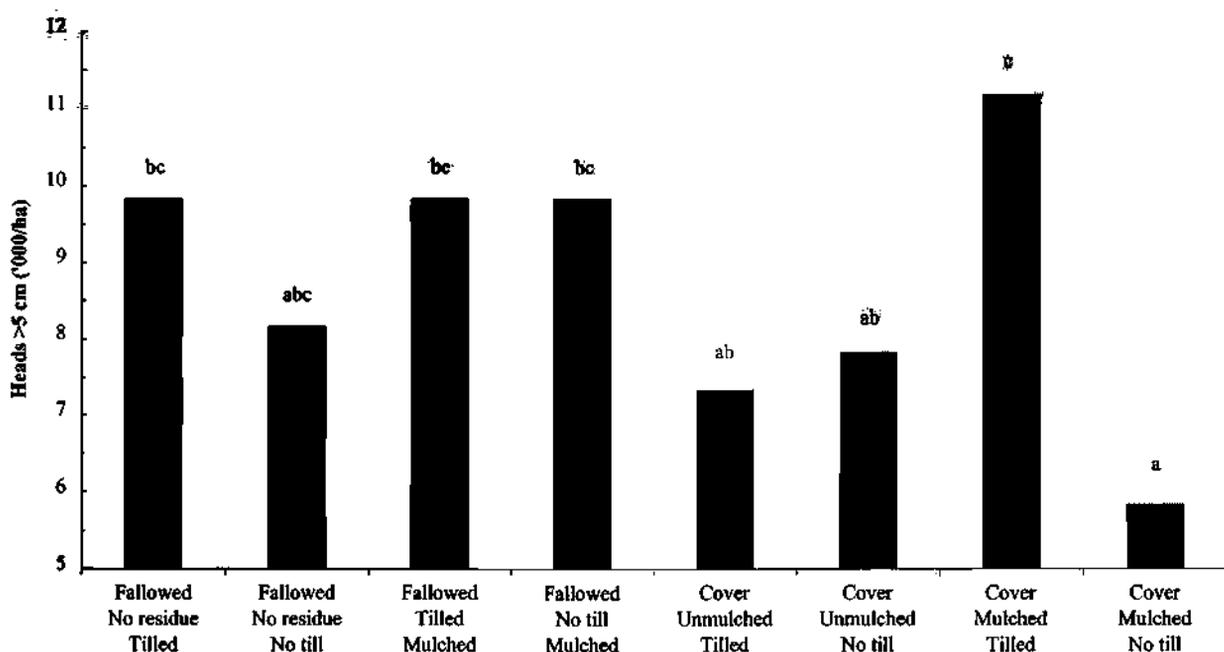


Figure 16. Soil and cover crop residue management affected broccoli plant head development 10 weeks after transplanting.

There was surprisingly little difference in total broccoli yields across the experiment (Fig. 17). There was a trend for slightly greater yields in the treatments with a fallow preparation, compared with the cover cropped areas. There was also a trend for slightly greater broccoli yields in treatments with a surface sorghum residue presence (3, 4, 7, 8), than where there was no mulch on the surface. The best performed treatments were those where the sorghum residue was manually spread over plots with a fallow preparation (3, 4). Interestingly, any improvement in yield from disturbing the soil (i.e. till vs no till) was only marginal. Higher yields were associated with treatments where the bulk of the crop was cut in the first 2 harvests.

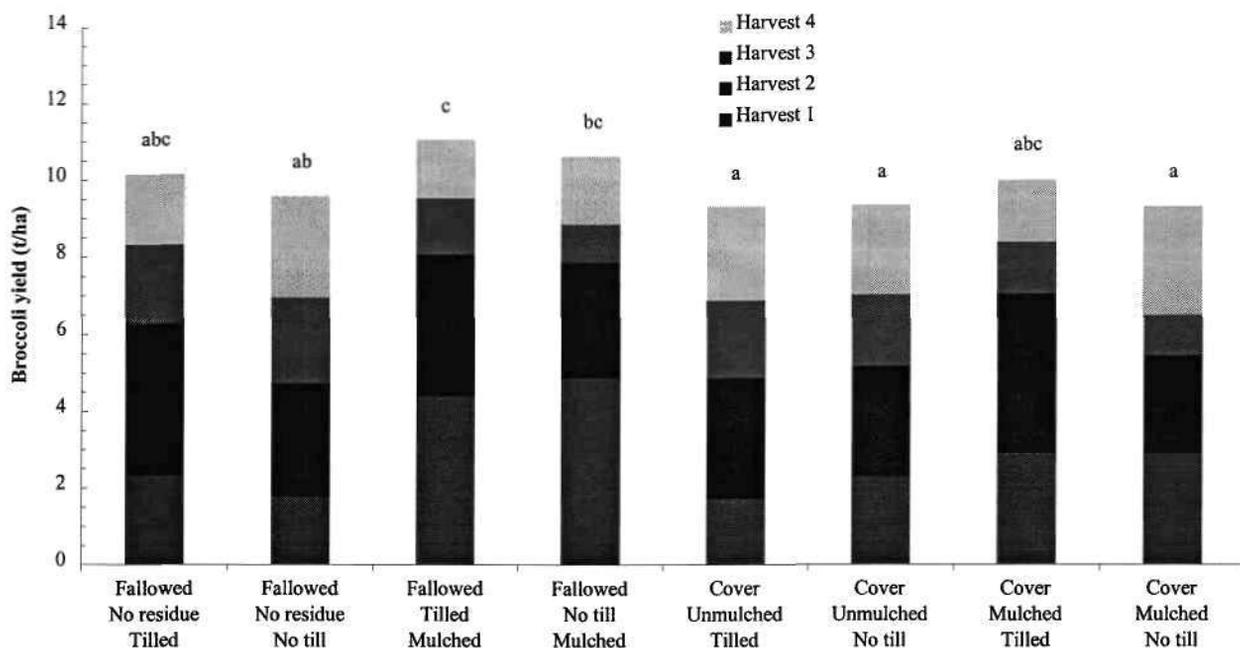


Figure 17. Soil and crop residue management affected broccoli yields.

We consistently cut 36,100 heads/ha (90%) across the experiment, with little variation amongst the treatments (Fig. 18). The data also confirmed the earlier head maturity in the higher yielding plots.

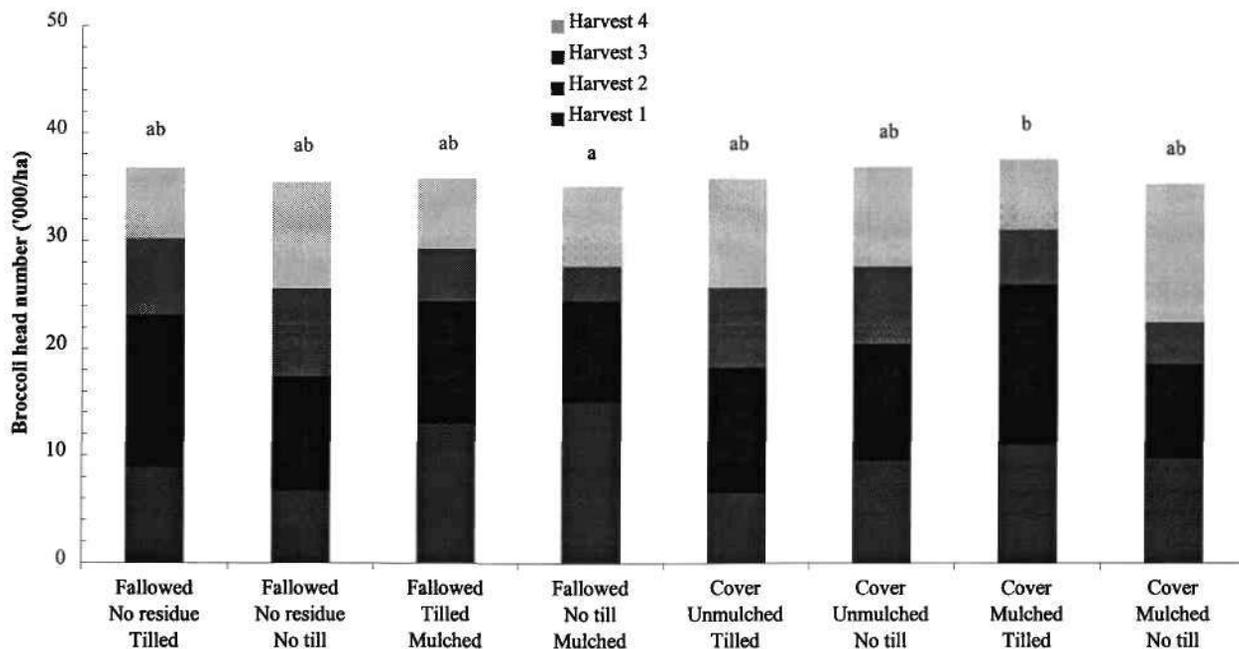


Figure 18. Soil and crop residue management did not affect total heads harvested, but did affect time of head maturity.

Broccoli areas with a fallow preparation, followed by manual mulching of transported sorghum straw (Treatments 3, 4), had consistently heavier heads than the other broccoli plots (Fig. 19).

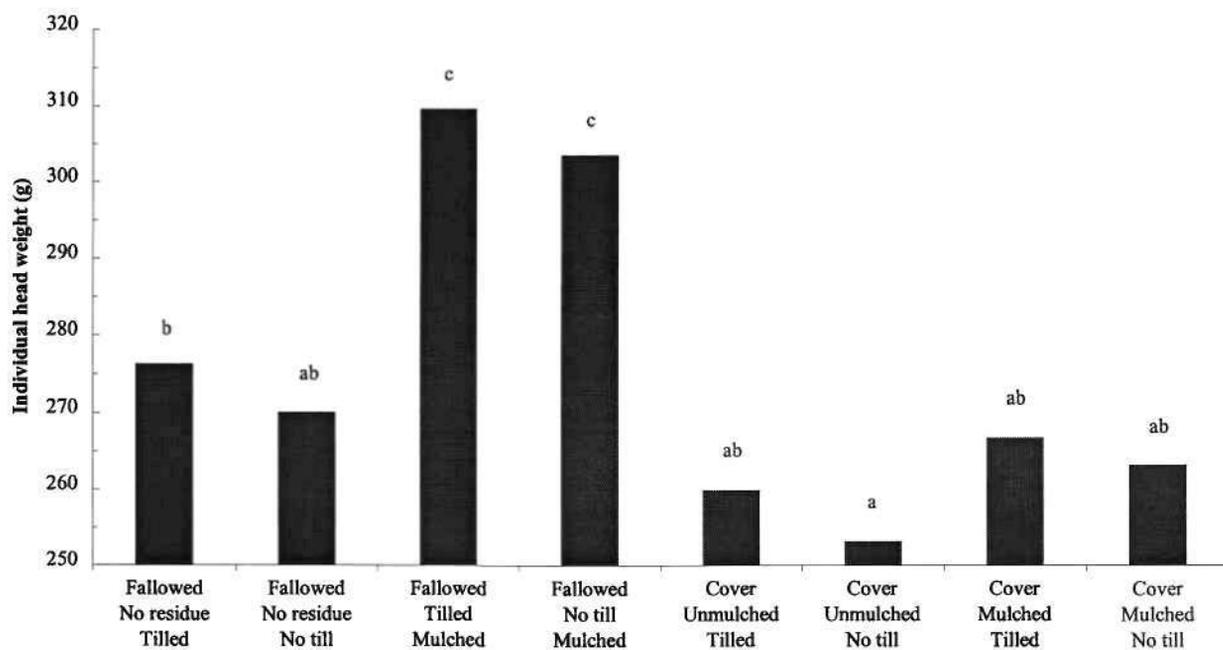


Figure 19. Soil and crop residue management affected individual broccoli head weights.

### Weed management

Once we transplanted the broccoli, the main weeds present in the experimental area included sowthistle (*Sonchus oleraceus*), pigweed (*Portulaca oleracea*), various grasses, blackberry nightshade (*Solanum nigrum*), deadnettle (*Lamium amplexicaule*), London rocket (*Sisymbrium irio*), shepherd's purse (*Capsella bursa-pastoris*), with a few other species sporadically present.

Three weeks after transplanting, total weed populations were reduced in the presence of surface mulch residues (Fig. 20), indicated by Treatments 3, 4, and 8. Individual species showed the same trends. The populations of sowthistle, pigweed, and grasses were also reduced by the no tillage practice, whilst this effect was not significant with blackberry nightshade, deadnettle, or the 2 brassica species.

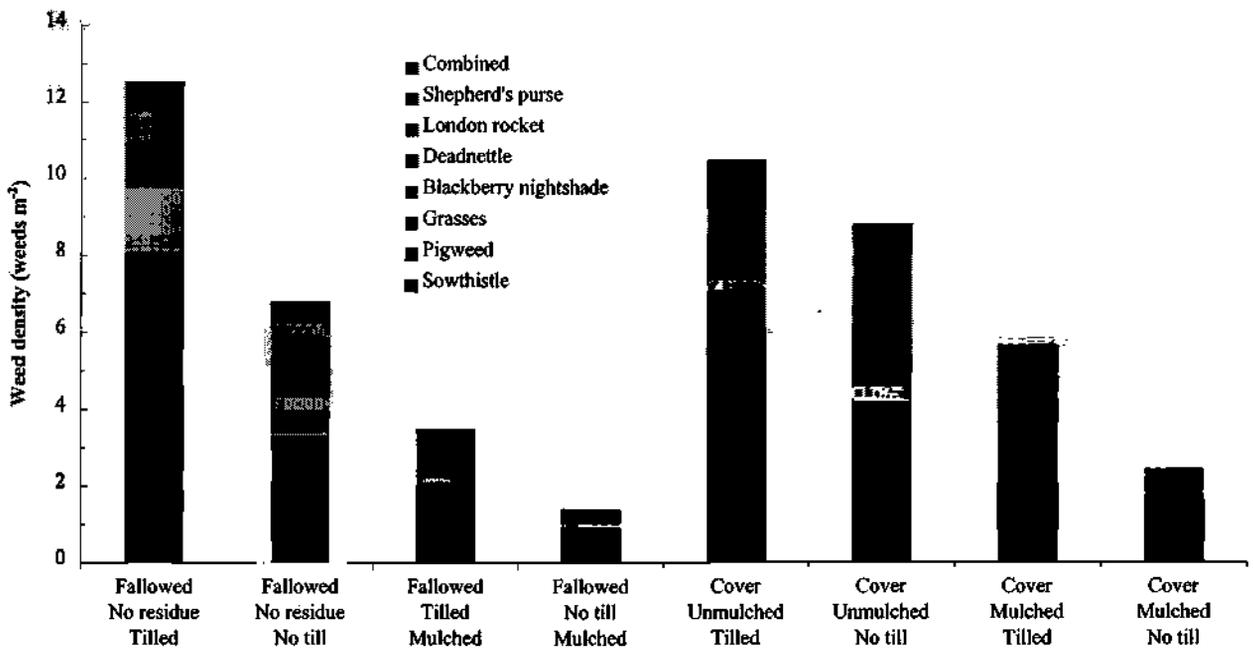


Figure 20. Tillage and the presence of surface mulch reduced the populations of weed species 3 weeks after transplanting.

The time taken to hand weed the various treatments reflected weed abundance (Fig. 21). An equivalent of 55 hours/ha was needed to weed the tilled plots with no surface residue (Treatments 1, 5). Implementing a no till practice reduced that time to about 38 hours/ha, whilst mulching the tilled treatments reduced weeding time to about 32 hours/ha. The least weeding was needed on no till, mulched plots (26 hours/ha).

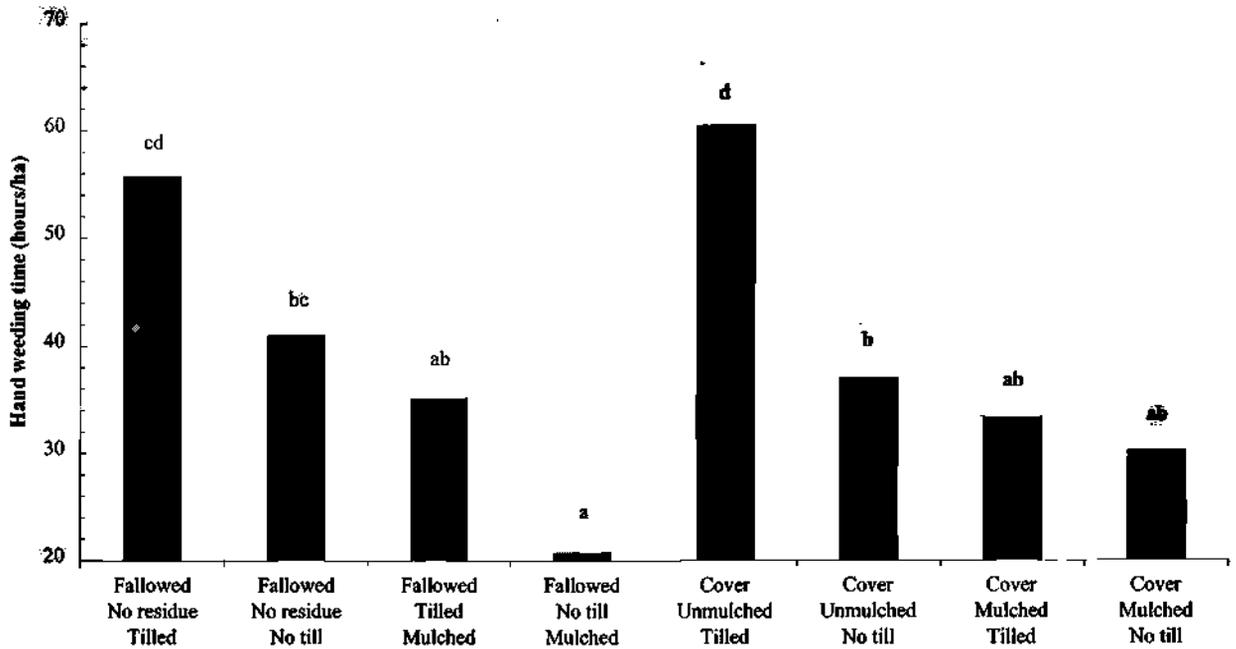


Figure 21. Tillage and the presence of surface mulch reduced hand weeding times 3 weeks after transplanting.

As the broccoli was being harvested, there was still about 9.2 t/ha dry weight of sorghum residues remaining on the surface of the mulched treatments (3, 4, 8), and 2.0 t/ha of mulch where the sorghum had been incorporated with the rotary hoe (Treatment 7).

Late emergence of sowthistle was substantially lower in those treatments that were cover cropped prior to planting broccoli, compared with treatments with a fallow preparation (Fig. 22, 23). The overall weed presence was very low (less than one weed every 5 m<sup>2</sup>), so this is not a particularly meaningful result in a commercial context.

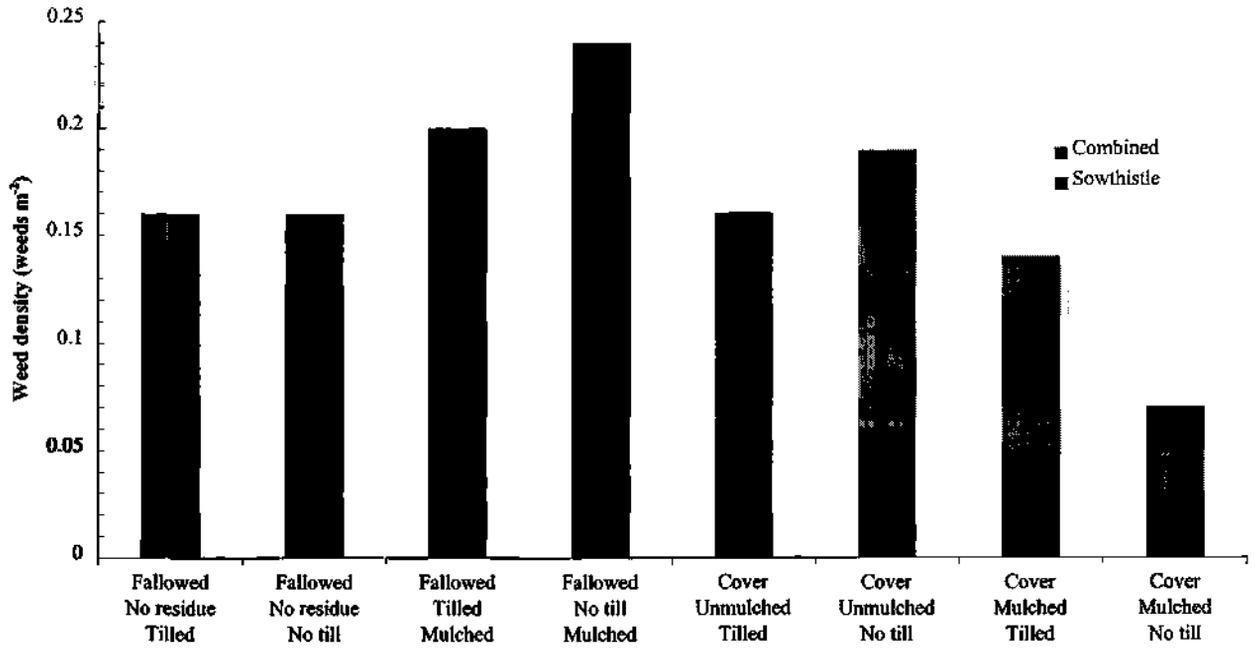


Figure 22. Cover cropping prior to broccoli transplanting reduced late sowthistle emergence.

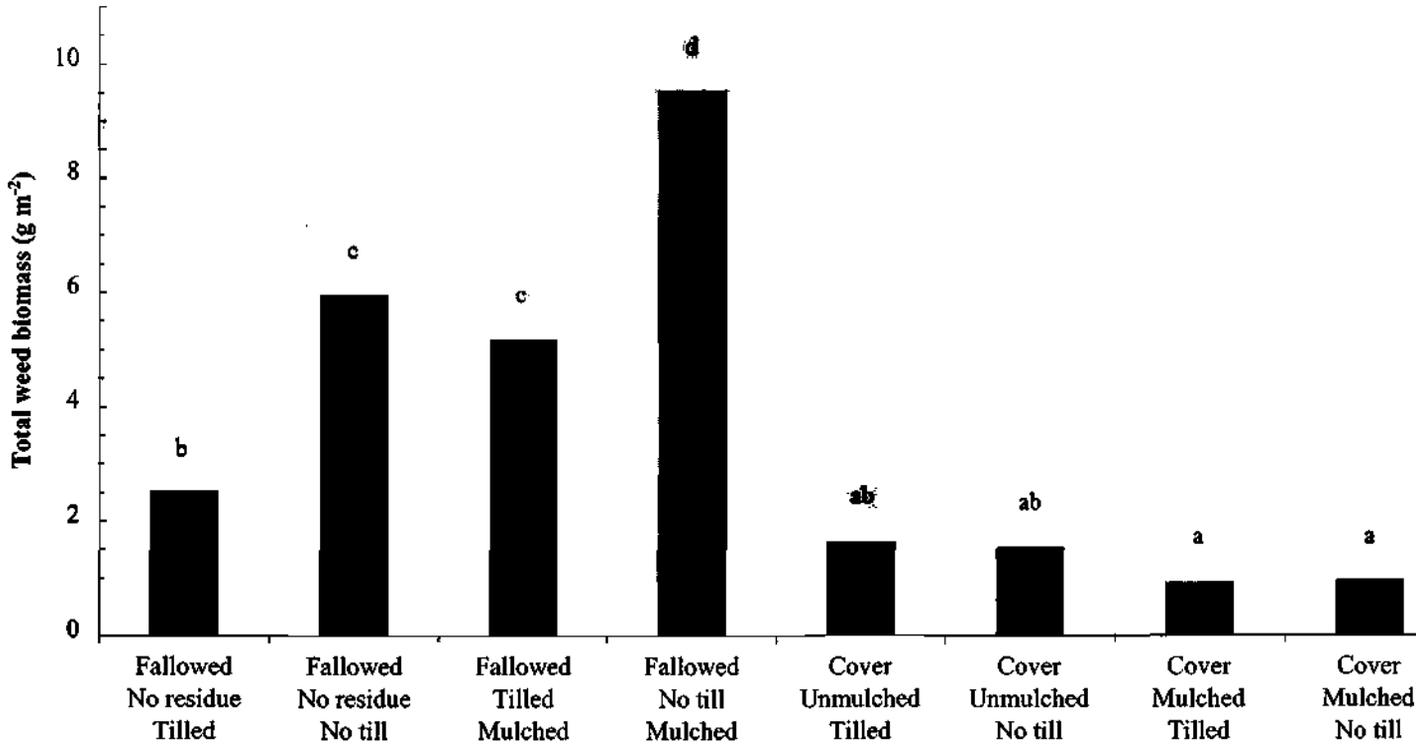


Figure 23. Cover cropping prior to broccoli transplanting reduced late weed biomass development.

## 6.5 Conclusions

As expected, growing a cover crop suppressed weed emergence and growth prior to planting the broccoli. The volume of mulch produced by the forage sorghum (15 t/ha of dry matter), was sufficient to form a good surface cover, either as an *in-situ* (Treatment 8) or transported mulch (Treatments 3, 4). Even where we incorporated the mulch with a rotary hoe, there was still 2-3 t/ha of mulch remaining on the surface.

Planting through the mulch was much easier where there were clearly defined rows and the mulch was still anchored to its root structure. This confirms that in planting and managing the killed *in-situ* mulch:

1. The mulch should be sown in defined rows, with sufficient inter-row spacing to enable the transplanter to plant vegetables between mulch rows.
2. Once killed, the mulch should be rolled rather than chopped up and spread.
3. Any cultivation required for the planting operation should be confined to the planting row.

There may be some slight reduction in initial vegetable crop performance associated with the presence of a cover crop prior to planting (Fig. 14-16). This may be a nutritional effect, from the cover crop tying up elements such as nitrogen, which are not released back into the soil sufficiently quickly once the vegetable crop is planted. Alternatively, it may be due to the presence of sorghum root residues having an allelopathic impact as they break down. Whatever the cause, tillage immediately before transplanting the broccoli did not ameliorate that slight disadvantage.

There was no adverse impact on early vegetable growth from having surface mulch of sorghum residues. There was no evidence of nutrient tie up, or increased disease.

The slight reduction in broccoli performance associated with growing a prior crop of forage sorghum continued through to yield, and could not be ameliorated by removing the surface mulch, or tilling the root zone (Fig. 17). The disadvantage of adopting the killed *in-situ* mulch system (Treatment 8) compared with the conventional system (Treatment 1) was only about 8% in this experiment, much less than in previous investigations. This may indicate we achieved better planting performance with the improved design of the sorghum mulch rows. The obvious benefits of having a surface mulch cover (seen when comparing the best Treatments 3 and 4 with Treatments 1 and 2) may also compensate for the disadvantages associated with cover cropping.

The reasons for improved yields where surface mulch was present are unclear. Three hypotheses are; improved soil temperature (slightly cooler), improved surface soil water relations (slightly moister), or a combination giving better surface soil microenvironment and hence surface root growth. It does indicate that there are positive benefits from a system that retains surface residues.

The absence of any significant tillage responses suggests that in the structured, black earth soils, a recently disturbed seedbed is not essential for acceptable vegetable performance, provided reasonable initial transplant-to-soil contact can be achieved.

This experiment confirmed that conditions leading to good establishment, early growth and high yields, are associated with earlier and more synchronous head development, reducing the need for later, and multiple harvests.

In the absence of herbicide applications, the presence of surface mulch is obviously very beneficial in reducing weed establishment (Fig. 20). The reduction in weed emergence in a no till system is often recorded, although frequently it is also associated with a shift in weed spectrum. Interestingly, in this experiment, populations of sowthistle were reduced both by adopting no till and mulching strategies. In previous investigations, sowthistle was one species that was more resistant to those practices than other weeds. Perhaps the proportion of reduction was less than other species in this instance as well.

The halving of hand weeding times using a mulched, no till strategy, such as in the killed *in-situ* mulch system, compared with the conventional strategy, would be an important commercial consideration in the absence of herbicidal weed management. In a low chemical or organic system, this would be a significant management factor, however a mechanism for killing the tall, vigorous forage sorghum would be an interesting difficulty in the latter. In vegetables, such as brassicas produced with chemical management options, where there are some effective herbicide choices, and hence minimal hand weeding, this implication is not as important.

Apart from factors not considered in this experiment (such as the build up of nematodes and soil borne diseases), the important points in relation to implementing a killed *in-situ* mulch system are:

1. The cover crop must be sown and managed to provide clear rows into which the vegetable crop can be planted.
2. Good contact between the transplant root cell and soil is required for acceptable vegetable growth and yield, however full soil disturbance is not.
3. There are benefits from the presence of surface mulch that may compensate for the disadvantages of cover cropping prior to planting.
4. Improved crop nutrition may be a solution to poorer growth following a cover crop, however pre-planting tillage is not.

## 7. Technology transfer

A number of activities were undertaken to ensure industry is aware of the findings of the project. These activities, in reverse chronological order, included:

- 5 December 2000 - Acceptance by the Australian Journal of Experimental Agriculture of the following paper which reports the work conducted on biodegradable transported mulches at Bundaberg: Olsen JK, Gounder RK (2001) Alternatives to polyethylene mulch film – a field assessment of transported materials in capsicum (*Capsicum annuum* L.). *Australian Journal of Experimental Agriculture* 41, in press (EA00077).
- 15 November 2000 - Presentation of posters at the Queensland Fruit and Vegetable Growers Growing for Profit day at Gympie. Samples of the most promising transported mulches (viz. paper film and biodegradable polymer film) were on display. Interested growers asked questions which were answered on the basis of the project's findings. An abstract which provided a summary of details presented in the posters was published in the proceedings given to participants on the day: Olsen, J. K. (2000) Alternatives to plastic mulch film – a field assessment of transported materials in capsicum. QFVG Ltd Growing for Profit Proceedings, page 35.
- 17 May 2000. Article by Craig Henderson in the 'Gatton Star Newspaper' entitled 'Mulching alternatives for vegetable growers'.
- 28 April 2000 – Article published in Bundaberg Newspaper 'The News Mail' entitled 'Alternative answers to plastic mulch located', page 16.
- 17-18 March 2000 – Poster/ presentation by Craig Henderson at EXPO 16 entitled 'Environmentally friendly mulches'.
- March 2000 – The following article was published to provide information re the farm walk on 25 January 2000: Olsen, J. K. (2000). QDPI: vegetable mulch farm-walk. Good Fruit and Vegetables. p. 29, March edition.
- 17 February 2000 – Article published in Queensland Fruit & Vegetable News entitled 'Paper mulch shows potential as alternative to plastic', page 27.
- 25 January 2000 – Conducted a farm walk at Don Halpin's farm at Calavos, attended by 47 growers, consultants, agricultural industry representatives, and DPI staff, to demonstrate paper mulch being laid and to present the findings and recommendations of the project.
- 12 January 2000 - ABC radio interview by phone with Bundaberg Radio interviewer re upcoming mulch alternatives farm walk at Don Halpin's farm on 25 January 2000.
- 16 July 1999 – 'News Mail' article entitled 'Comparing notes on mulch alternatives', page 20.
- 14 July 1999 – Organised and held a meeting of stakeholders at Bundaberg Research Station to review the disposal issues of plastic mulch and assess possible solutions. The meeting was attended by representatives from Queensland Horticulture Institute, Applied Horticultural Research Pty Ltd, Bundaberg Fruit and Vegetable Growers, Ausveg/HRDC, Burnett Shire Council, and Queensland Fruit and Vegetable Growers. The forum reviewed current research being conducted in alternatives to plastic mulch around Australia, and made an assessment of the future research requirements. A synopsis of the minutes of the meeting is provided in **Appendix 1**.
- 14 December 1998 – Interview by phone with ABC Radio Bendigo reporter Mary Kylie about the outcomes from the project. The target audience was growers/ listeners in western Victoria.

- November 1998 – ‘Acres Australia’ article entitled ‘Grow-it-yourself an alternative to plastic’, page 49.
- 16 October 1998 - A radio interview of Craig Henderson by Sally Nichol (rural ABC Toowoomba), which included killed *in-situ* mulch strategies for weed management.
- 15 October 1998 - A field walk organised by Craig Henderson at a collaborating grower’s property where a simulated killed *in-situ* mulch was used to show how organic crop mulches could be utilised in a cucurbit production system (attended by 25 growers).
- 14 October 1998 – Article by Craig Henderson in ‘The Gatton, Lockyer and Brisbane Valley STAR’ article entitled ‘Alternatives to plastic mulch?’, page 35.
- 1998 - An article by Craig Henderson entitled ‘Alternatives to plastic mulch’ published in the annual Rural Report supplement of the Gatton Star newspaper
- 14-17 October 1998 – Presented the following poster at the forth Australian Horticulture conference: Olsen, J. K., Gounder, R. K. Wright, R. M., and Henderson, C. W. L. (1998). Plastic mulch – disposal problems and possible solutions. *Fourth Australian Horticulture Conference* ‘Managing our future for innovation, sustainability, continuity’, Carlton Crest Hotel, Melbourne, Vic.
- 1998 – The following article was published in HRDC’s Hort Report 98. Olsen, J. K. (1998). Replacing plastic mulch in intensive vegetable production. p. 24. Horticultural Research & Development Corporation Hort Report 98, The Craftsman Press Pty Ltd.
- 17 June 1998 - A seminar by Craig Henderson for Queensland Horticulture Institute staff at Gatton Research Station on ‘Interactions in managing insects and weeds’. Part of the seminar dealt with the possible impacts of killed *in-situ* mulch production systems on insect ecology.
- 11 June 1998 - An industry field walk conducted by Craig Henderson (attended by about 30 producers on 11 June 1998) on ‘Weed management in brassicas’ at Gatton Research Station, which included discussions on the use of killed *in-situ* mulches.
- June 1998 – Farm walk organised by Ross Wright at Bowen Research Station (attended by about 10 interested growers) to show a range of possible species for use as killed *in-situ* mulches which could be killed off on site and used as a mulch into which vegetable crops could be planted. The results of the late 1997 trial which involved bringing in mulches and laying them on pre-formed beds prior to planting a capsicum crop, were also discussed.
- 21-22 May 1998 - A display at EXPO 15 horticultural expo manned by Craig Henderson on which had in-ground demonstrations of strategies using alternative mulches. Several thousand visitors attended, including local, national and international.
- 14 May 1998 – ‘Queensland Fruit & Vegetable News’ article entitled ‘Field day inspects alternatives to plastic mulch’, page 15.
- 3 April 1998 - A talk by Craig Henderson on ‘Alternative mulches in vegetables’ at Peter Mackintosh’s property, Helidon.
- 17 March 1998 - A successful farm walk held at Bundaberg Research Station. The walk was well attended by about 30 growers, consultants, agricultural industry representatives and Queensland Horticulture Institute staff who inspected a range of transported and killed *in-situ* mulches into which a crop of capsicum was planted. Members of the project team (Jason Olsen, Craig Henderson, Ross Wright, and Reg Gounder) spoke about trial results, the transported versus killed *in-situ* mulch systems, mulch costs, and starch-based polymer mulches.
- 16 March and 26 May 1998 - An instructional field-based tutorial on ‘Weed management in vegetables’ given by Craig Henderson for 25 fourth-year Gatton College students

(26/5/98) and 20 Lockyer District High School students (16/3/98) at Gatton Research Station. Included were discussions on the use of killed *in-situ* mulches in vegetable crops.

- 13 March 1998 – ‘New Mail’ article entitled ‘Farm walk part of activities’, page 26.
- 12 March 1998 – ‘Queensland Fruit & Vegetable News’ article entitled ‘Alternatives to plastic mulch’, page 26.

## 8. Recommendations

Work conducted in this project centred around 2 systems for applying mulch to the surface of soil in which vegetable seedlings are planted. The first is the transported mulch system, as used for plastic mulch, whereby mulch materials (organic or inorganic) are transported to the farm and laid on the surface of the soil bed prior to planting the vegetable crop. The second is the killed *in-situ* mulch system which involves growing a cover crop in designated soil beds, applying herbicide to kill the cover crop to form an *in-situ* mulch, followed by transplanting the vegetable seedlings. Using these 2 systems, biodegradable alternatives to plastic mulch were investigated. The recommendations of the project are given below.

### 8.1 The transported mulch system

A large range of biodegradable transported mulch materials were tested in this project for weed suppression, soil effects, and crop response. Paper film (Gromulch<sup>®</sup>, Edwards Dunlop Paper, Brisbane, Australia, or Gromulch<sup>®</sup>, St. Regis Paper Company Ltd, Maidenhead, UK), biodegradable polymer film (Mater-Bi<sup>®</sup>, Novamont S.p.A, Novara, Italy; Bastioli 1998), and 7.5 cm thick layers of sugarcane trash, sorghum hay, and waxed fibre cartons provided weed suppression equal to that of plastic mulch. However, 7.5 cm layers of composted vegetative mulch, bagasse, or sawdust, a 3 cm layer of recycled newspaper, or a fabric of hessian did not. Of the transported mulch materials that suppressed weeds, the biodegradable polymer and the paper film could be laid with conventional equipment used to lay plastic mulch, although care was required when laying the paper film to avoid tearing. Since the weight of paper film per hectare (0.8 t) is 4 times that required for plastic film (0.2 t), the cost to lay paper film was more than that to lay plastic due to time lost in changing paper rolls onto equipment and extra costs associated with handling. For the other mulch materials that suppressed weed growth (7.5 cm layers of sugarcane trash, sorghum hay, and waxed fibre cartons), a major obstacle to their adoption by farmers relates to the logistics of transporting and applying these materials to large areas of land. No development of equipment for applying these alternatives has been undertaken, and future work should focus on equipment modification or changes in methodology which allow seedlings to be planted into these mulches, but not be buried by them. The biodegradability of the waxed fibre carton is also doubtful due to the paraffin wax coating over the fibreboard.

The similar weight of marketable fruit of capsicum plants grown in the biodegradable polymer film, paper film and plastic mulch indicate that the biodegradable polymer and paper films have the agronomic potential to replace plastic mulch film. The generally poorer performance of capsicum plants grown in the sugarcane trash, sorghum hay, and waxed fibre carton treatments than in the plastic mulch treatment suggested that these organic materials appear to offer limited potential to replace plastic mulch, although their long-term benefits to soil fertility and structure should not be discounted.

Additionally, the material cost alone of some of the transported mulch materials may rule them out as alternatives to plastic mulch. The costs per hectare of all of the biodegradable materials trialed were in excess of that of the plastic mulch as follows: plastic mulch (\$860) < recycled newspaper (\$1,300) < sawdust (\$1,600) < paper film (\$1,630) < sorghum hay (\$2,000) < biodegradable polymer (\$3,300) < hessian (\$4,000) < sugarcane trash (\$5,900) < composted mulch (\$9,300).

Since work with paper mulch film commenced in this project, the manufacture of this material commenced in October 1998 in Australia, with the cost of paper film about twice that of plastic film. Conversely, the lack of local supply and generally high cost of biodegradable polymers in Australia is currently a major limitation to their acceptance by commercial vegetable growers. Although technologies for the formulation of low-cost starch-based polymers are currently under examination (e.g. Anon. 1999; Cooperative Research Centre for International Food Manufacture and Packaging Science – Drs P. Halley and G. Christie), production of these materials as mulch film for large-scale farming enterprises may still not become a commercial reality for several years.

Provided the practical difficulties of laying paper film can be overcome (tearing at laying and degradation at the soil surface) and the high cost of biodegradable polymer is reduced, these materials appear to be the best of the biodegradable alternatives tested to plastic mulch film. However, while the cost of disposal remains low, widespread use of plastic mulch is likely to continue.

## 8.2 The killed *in-situ* mulch system

About 7.5 cm of organic mulch on the soil surface was found to satisfactorily suppress weed growth. Only the most vigorous of the pasture species tested (e.g. cultivars of forage sorghum) were able to provide a thick layer of mulch approaching 7.5 cm. Compared with plastic mulch, the inadequacy of the vigorous cover crops grown in this study to arrest weed growth as killed *in-situ* mulches suggests that weed control would be an ongoing problem for growers adopting this system and not wishing to apply soil fumigants through the trickle irrigation system at planting or herbicides applications regularly during the vegetable crop cycle. Even hand-planting the capsicum seedlings causing minimal disturbance to the mulch resulted in inadequate weed control by the mulch.

The poor and uneven growth of capsicum seedlings transplanted into the killed *in-situ* mulch treatments tested and the subsequent low yields of the crop would be major impediments to the adoption of this system by commercial growers who normally use plastic mulch to grow this crop. Slower growth of seedlings and lower yields of broccoli plants grown in soil covered with a killed *in-situ* mulch of sorghum than in an unmulched soil that was conventionally tilled demonstrated the same effect. For the killed *in-situ* mulch system to be more effective, machinery would need to be used to loosen soil around the transplanted seedlings to improve soil contact, whilst ensuring adequate mulch cover remained on the soil surface around the seedlings. Future research needs to be conducted into ways of overcoming the poor soil contact of the root-ball of the vegetable seedling at planting by trialing and sourcing suitable implements. Overcoming potential nutrient tie-up problems or allelopathy should also be addressed.

The time required to establish the cover crop (about 9 weeks) is an added constraint to adoption of the killed *in-situ* mulch system. Emergence of volunteer sorghum plants from late-germinating seed would involve at least one to 2 additional applications of herbicide specific for grasses. These constraints need to be balanced with the long-term benefits of applying organic material to the soil.

Growers wishing to try killed *in-situ* mulches should be aware of their potential to increase root pathogens in the soil which may affect the vegetable crop. In general, with the exception of American joint vetch, the legume species tested in this project were highly susceptible to

root-knot nematode, especially centro. In the absence of soil-applied nematocides or fumigants, a killed *in-situ* mulch formed by centro would dramatically increase the population of root-knot nematodes in the soil. Use of a heavy clay soil would probably reduce the rapidity with which nematodes would increase under this cover crop. The grass species tested (sorghum and Indian couch) were highly tolerant to root-knot nematode, and use of either of these crop species as a killed *in-situ* mulch would limit an increase in the population of root-knot nematode in the soil.

The cost of establishing a killed *in-situ* mulch is relatively low (\$300/ ha) compared with the cost of purchase and disposal of plastic mulch film (\$1,100/ ha). However, considerably lower yields of capsicum plants grown with killed *in-situ* mulch than with plastic mulch was demonstrated in this study. Despite the benefits to soil health which may be imminent from using biodegradable mulch materials, use of the killed *in-situ* mulch system would not be an option for most commercial capsicum growers.

## **Acknowledgments**

I wish to thank the dedicated team of researchers who worked on this project, including Mr Ross Wright, Mr Craig Henderson, Mr Reg Gounder, Ms Angelina Gilbert. My gratitude is also expressed to the Australian vegetable industry and the Horticultural Research and Development Corporation for their financial support of this project. I would also like to thank Mr Gary Blight for biometrical advice, Mr Ian Bramer for assistance with field work, and Mr Alan Beswick for sourcing the long-term meteorological data.

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## **Appendix 1. Overcoming the disposal issues of plastic mulch - meeting of stakeholders**

The meeting was held at Bundaberg Research Station on Wednesday 14 July 1999.

The meeting was attended by Jason Olsen (Queensland Horticulture Institute QHI, Bundaberg), Reg Gounder (QHI, Bundaberg), Ross Wright (QHI, Bowen), Craig Henderson (QHI, Gatton), Angelina Gilbert (QHI, Gatton), Gordon Rogers (Applied Horticultural Research Pty Ltd AHR, Sydney), Shaun Jackson (AHR, Brisbane), Steve Silcock (AHR, Bowen), Phil Cheeseman (Bundaberg Fruit and Vegetable Growers BFVG), Don Halpin (BFVG), Tony Cavallaro (BFVG and Ausveg/ HRDC), Tracey Jensen (Burnett Shire Council), and Larissa Bilston (Queensland Fruit and Vegetable Growers).

### **Executive summary - conclusions and recommendations arising from the meeting**

The practice of dumping plastic mulch, whether at Council tips or down mine shafts, appears to be coming under increasing pressure. At the very least, the price of dumping this material is expected to rise significantly in the next 3 to 5 years. At worst, dumping will be completely banned and will attract massive fines. Therefore, the need to continue researching alternatives to plastic mulch film has never been greater.

The QHI project revealed that the biopolymer material Novamont produced capsicum yields at least equivalent to those attained using conventional polyethylene mulch film. Novamont can be ploughed back into the soil where it biodegrades, thus obviating the need for disposal. However, the cost of biopolymer mulch films is presently prohibitive at \$7,500/ ha compared with \$800/ ha for plastic. The price of biopolymers may reduce in the future if demand increases and the cheap blends which are being tested by QHI for the CRC for food and packaging science are successful. Paper mulch on rolls may be an immediate option available to growers, but is extremely bulky to handle (3½ times the weight of plastic mulch) and is therefore expensive to lay. Paper mulch on rolls cannot be laid without modifications to conventional equipment used to lay plastic mulch. Mulches of sugarcane trash, sawdust or shredded paper cannot be recommended at this stage since they are expensive, need to be at least 5 cm thick to prevent weed growth, and cause problems at transplanting.

The killed *in-situ* mulch system is being investigated by AHR, Lionel Williams (a tomato grower at Bowen), and QHI. In this system, a cover crop species is grown *in situ* in the soil beds and then killed with herbicide and allowed to lie on the surface of the soil bed prior to planting the vegetable crop. Some problems with establishment of the vegetable seedlings have been encountered using this system, possibly from allelopathic effects from the cover crop or from nutrient tie-up in the soil, but more likely from poor soil contact with the root system of the vegetable seedling plug at the time of transplanting. There may be 2 reasons for this poor soil contact: (1) the planting spike pushes dead plant material into the plant hole and (2) there is a dearth of friable soil needed to 'bed in' the seedling. It is possible that these problems may be overcome by (1) extending the length of time between herbicide application and transplanting the seedling plugs of the vegetable crop and by (2) designing a suitable planting implement. The killed *in-situ* mulch system offers the benefits of increased soil organic matter and improved soil health, so should be considered in the overall strategy of finding alternatives to plastic mulch.

## **Minutes from the meeting**

Jason opened the meeting at 11 am. He described briefly the projects currently being undertaken by the Queensland Horticulture Institute (QHI) and Applied Horticulture Research Pty Ltd (AHR). The projects are aimed at identifying alternatives to plastic mulch or alternative systems which obviate the need for this material. Both of these projects are being funded by the national Ausveg levy and the Horticultural Research and Development Corporation (HRDC). Jason then introduced the speakers as follows:

### **Tracey Jensen**

Tracey said that the issue of disposal of plastic mulch has emerged as problem for the Burnett Shire Council. Spent plastic mulch is bulky and wraps around the machinery used to push it into the land-fill pits. The plastic mulch works its way to top of these pits. Many of the pits only have a 3-year life expectancy. The regional land-fills don't have a lot of capacity left, and the transfer stations will not accept spent plastic mulch. Total cost recovery will need to be enforced by the Council in the future. She said that urban dwellers currently subsidise the dumping of plastic mulch by some members of the rural community. Currently there is no charge for dumping plastic mulch at some of the smaller dumps. However, charges of \$40 for >3 ton truck, \$20 for <3 ton truck and \$5 for a ute-load applies at the main dump.

The target of a 50% reduction in waste disposal to land-fill by the year 2000 has almost been attained and currently stands at 40%.

She said that the costs of dumping plastic mulch will increase considerably in the next 3 years as some of the smaller dumps close. If government enforces full cost recovery, costs will rise even more in the future.

### **Don Halpin**

Don provided a history of his involvement in the issues of plastic mulch disposal. In January 1995 he became a member of the Agricultural Plastics Working Group. He developed a machine to remove spent plastic mulch from the farm, and the process allowed the material to be compacted. A number of these units have been sold by P & H Produce. Some funding from QFVG was put towards a plastic compactor to reduce the volume of the plastic, but the prototype which was built was too small, and no-one has adopted this methodology.

Don outlined the benefits of using plastic mulch, including conservation of water, reduced need for fungicide sprays, reduced herbicide use, reduced wastage of fruit and so better use of resources, reduced fertiliser leaching, and reduced need for cultivation.

Many of the environmental issues in the past have stemmed from the manufacture and use inferior plastics which break up into small pieces prior to lifting, from people burning plastic, and from the dumping of plastic into watercourses.

Don outlined the problems in using spent plastic mulch as fuel in steam boilers that currently use brown coal briquettes. The biggest problem is soil contamination, and since the plastic needs to be cut, the blades of the cutting machinery wear out quickly if the plastic has soil adhering to it. The Bowen coke works was going to burn plastic, but due to work-place health and safety reasons, they decided not to proceed. It was about this time that plastic mulch from Bowen was transported to the Collinsville mine site.

CRC's started looking at opportunity costs of using biopolymer mulches which could decompose and obviate the need for removal and dumping.

The Bundaberg company Independence Incorporated Pty Ltd are looking at washing the plastic before shipping to Brisbane for recycling. The firm P & H are convinced that they can build a plastic washer to clean the plastic. However, the mechanics of washing the used plastic seem to be the key problem as some of the plastics lose their integrity and would still involve considerable human involvement.

Tony Cavallaro re-affirmed the benefits of plastic, and that without plastic mulch, growers would not be able to grow as big an area due to a much higher maintenance effort.

### Steve Silcock

Steve described the work that AHR were conducting on the farm of Lionel Williams at Bowen. He said that Lionel has produced a commercial crop of tomatoes using the killed *in-situ* mulch system with Centro as the cover crop.

The cover crops trialed include Centro, Hatch, Keppel, forage sorghum, sorghum mulch. One trial looked at the effects of these cover crops in regards to the allelopathic effects on capsicum by successive plantings of capsicum every 14 days. He suspected that there was a nutritional tie-up in the soil due to the decomposition of each cover crop.

Lionel currently has 4 ha of land planted to Centro.

Steve provided an outline of the advantages and disadvantages of the various mulches that he has trialed as follows:

Cover crop	Advantages	Disadvantages
Centro	Legume. Easy to sow, very stable mulch. Smothers weeds	Slow establishment Problems with herbicide treatment. Nematode host
Hatch	Stable mulch, easy to kill. Good control of weeds if well established	Difficult to sow difficult to transplant into
Keppel	Very stable mulch easy to kill Good control of weeds if well established	Difficult to sow. Difficult to transplant into
Forage sorghum	Easy to sow. Excellent establishment and weed control	Difficult to kill after flowering. Difficult to plant into
Sorghum mulch	Flexibility in application	Relatively unstable mulch as it can be blown around and be washed into drains. No root structure.
Plastic (control)	Flexibility in application. Excellent weed control	Degrades soil structure. Disposal problems.

A summary of trial issues include:

- Difficulties in implementing a killed *in-situ* mulch system in regards to a set time schedule (i.e. being able to set a date for transplanting seedlings)
- Establishing cover crops can be restricted by wet conditions and need to be sure of 100% kill from herbicide treatments.
- Establishing time restraints in regard to transplanting date after herbicide treatment. This includes determining possible residual effects from herbicide treatments, allelopathic effects from individual crop species, and nutrient tie up in the soil.

Gordon reported some effects of poor growth of capsicum plants grown in the cover crop residues when compared with plastic mulch. Possibly due to allelopathic effects or nutrient tie-up.

Don Halpin said that he has had problems on his farm with the regrowth of clover which he originally used as a cover crop.

Gordon said that there is a definite window for these cover crops in which certain practices should be carried out. For example, the cover crop needs to be sprayed prior to flowering and seed set to avoid regrowth during the crop cycle.

Don said that if cover crops were used in a semi-permanent bed system in Bundaberg, they would need to be irrigated. However, irrigation was not required for the cover crops in Bowen.

Steve said their permanent bed system had a double row of trickle which hasn't needed to be replaced.

### **Gordon Rogers**

Gordon said AHR were looking at a whole system, not just alternatives to plastic mulch. The long-term approach is to develop a long-term system which can be used consistently. The use of establishing permanent vegetable beds with cover crops is the connection with alternatives to plastic mulch.

Centro was one of the main cover crops being investigated. Some of the benefits of the killed *in-situ* mulch system is an improvement in soil health, improved soil structure, increased soil organic matter levels, improved aggregate stability and an increased population of earth worms.

Tomato yields in 1998 from Centro, sorghum and bluegrass beds were equal to or excess of the commercial tomato yields.

The current status of AHR's research is

- Determining the minimum time to plant crops into cover crop residues
- Nutrient draw-down versus allelopathy which may be causing problems for the yields of tomatoes
- Effect of Centro on nematode populations in the soil,
- Soil health effects
- Commercial size trials established in Qld
- Evaluation of cover crops for cooler periods and in other areas, e.g. Richmond NSW

Don questioned the depth of the trickle irrigation in Lionel's beds. Steve indicated 150-200 mm depth. Craig said at that depth, there would be no doubt that leaching of fertiliser would be significant.

Ross mentioned problems with a water-wheel-planter pushing down crop residues into the holes, making seedling establishment a problem.

### **Ross Wright**

Ross described the problem in 1994 of the Bowen rubbish tip which was over-flowing with plastic mulch waste. This situation led the council to declare that they could no longer take plastic mulch at the dump.

Ross then documented the results from trials he conducted at Bowen Research Station with various transported mulch materials including waxed fibre cartons coarsely shredded, recycled newspaper finely shredded, composted vegetative mulch Bagasse, forage sorghum hay, and plastic mulch. There were no significant differences between treatments.

He found that weed growth was a problem in the killed *in-situ* mulches and that the cover crop species needed to out-compete the weeds. Blue-grass and Centro could not out-compete the weeds. The duration from sowing to a herbicide spray of Roundup was tested for forage sorghum cv's Betadan and Rambo. At 4 weeks the sorghum plants did not lodge to form a thick enough mulch, at 6 weeks there was a reasonable mulch cover, at 8 weeks the lodged sorghum plants were a bit too coarse to plant into, and at 10 weeks the sorghum plants did not form a prostrate mulch due to coarse stalks.

The estimated cost of removing spent plastic mulch from Bowen to Collinsville is \$65/ ha. Dumping down the Collinsville mine shaft is probably not sustainable, and the new owners are concerned about work-place health and safety issues. Also, the issue of plastic catching alight and burning in these mine-shafts is cause for concern.

Ross outlined the results that he and Craig did with the CRC to test some of their biopolymers. Photo-degradation, rather than biodegradation, seemed to be the major factor at work with these mulches since, in the short term, the material which was buried under the soil maintained its integrity.

The Italian mulch Novamont and the Japanese Bionolle were successful as they stood up the elements for 16 weeks without degradation. These mulches are expensive, but the CRC are looking at reducing the price of the biodegradable mulches by using blends of Novamont and Bionolle with their materials.

### **Craig Henderson**

Craig spoke briefly in the field about weed management issues in alternative mulches. He said that weed suppression is more dependent on the light interception by the mulch rather than on the actual weight of mulch material covering the soil bed.

### **Jason Olsen**

Jason spoke initially in the field about the findings of the latest trials being conducted at Bundaberg. The adjacent field trials, one comparing transported mulches and the other comparing killed *in-situ* mulches were being run concurrently, so everyone had the opportunity to compare not only mulches but systems as well. It was obvious to the group

that capsicum plants growing in the killed *in-situ* mulch plots were inferior to those growing in the transported mulch plots. A discussion then proceeded as to the reasons for this effect. Jason explained that he believed the poorer growth of capsicum plants in the killed *in-situ* mulch trial than in the transported mulch trial was due to poor seedling establishment. He said that poor contact of the seedling roots with friable soil in the killed *in-situ* mulch trial was probably the reason for poor seedling establishment. Because soil beds in the killed *in-situ* mulch trial were formed 3 months before planting the capsicum seedlings and had packed down and grown root systems from the killed *in-situ* mulch crop species, little friable soil was available to contact with the seedling roots. He said that both trials were treated exactly the same and had optimum nutrient and water conditions. Allelopathy from the cover crop species was not an issue in the killed *in-situ* mulch trial since bare soil control plots provided a comparison between the trials.

The transported mulch trial showed that the biopolymer material Novamont produced plants equal to or better than conventional polyethylene plastic mulch film. The group showed considerable interest in this material.

Back in the meeting room, Jason summarised the findings from work conducted in the QHI project. These findings are as follows:

**Cost and other considerations of various alternative mulches to plastic mulch.**

Mulch	Cost (\$/ m row)	Comment
Polyethylene plastic film	0.12	Extra cost of \$0.04/ metre to dispose and remove used film
<b>TRANSPORTED MULCHES</b>		
Composted mulch	1.60	Impurities such as broken glass, wire
Novamont® biopolymer film	1.13	High cost. Otherwise works well
Hessian	0.90	High cost. Weeds grow underneath
Sawdust	0.52	Poor weed control. N draw-down
Cane trash	0.50	Seedling transplanting made difficult
Sorghum hay	0.30	Seedling transplanting made difficult
Teralass bitumen spray	0.27	Long term effects in soil. Poor weed control
Gromulch® paper	0.21	Good weed control
Recycled newspaper	0.19	Poor weed control
<b>KILLED IN-SITU MULCHES</b>		
Jumbo sorghum	0.04	Includes costs of establishment and herbicide application. Poor growth of subsequent crop. Disease build-up in some legume species
Lab lab	0.04	

#### Killed *in-situ* mulch system

- Technology requires a paradigm shift by growers
- Poor growth of subsequent vegetable crop an issue
- Jumbo sorghum gives best cover and weed control and least soil-borne pathogen build-up, but is associated with some of the poorest establishment of the subsequent vegetable crop
- Poor establishment in the semi-permanent beds would most likely require modifications to present planting equipment to obtain good establishment of the vegetable seedlings
- Cheap in terms of financial inputs, but not in time and management by the grower – “just another crop to grow”

#### Transported mulch system

- The expense of the best alternative biopolymers is prohibitive at their present cost (\$800/ ha plastic versus \$7,500/ ha Novamont). Price may come down if CRC project has some success
- Paper may be OK (a modified plastic mulch layer designed to lay paper mulch has been made), but is extremely bulky to handle (3½ times the weight of plastic mulch) and is therefore expensive to lay
- Difficult to plant into mulches of cane trash, sawdust or shredded newspaper which need to be 5 cm thick to prevent weed growth
- Considerable interest in alternatives to plastic mulch has arisen from the organic vegetable industry

### Discussion

Don suggested that work on the disposal options of spent plastic continue until we find suitable alternatives. He said that killed *in-situ* mulch systems could provide soil health benefits and that perhaps some cover crop or mixture of cover crops may be the answer. Perhaps a thinner mulch layer, but better herbicides may be the answer.

Don said that washing the plastic appears to be the key as to whether or not plastic can be recycled. A machine may be designed, but the labour component to deal with small bits of plastic is a real problem.

Craig said that the price of alternative mulches must be comparable to polyethylene mulches manufactured from conventional sources.

Tracey Jensen said one of the key factors stopping the company Independence Incorporated Pty Ltd from setting up is a suitable site for wash-down facilities.

Craig said that the CRC materials will probably be no better in this present round than in previous years.

Craig said that out of the mulches, there weren't too many options – maybe paper, but there were problems with that material due to its bulkiness.

The issue of poor establishment in killed *in-situ* mulch system was discussed. Jason raised the issue of poor contact with friable soil at planting. Gordon said that at 4 months after spraying Centro with herbicide, they didn't have problems with the growth of tomato

seedlings transplanted into soil beds. However, there was a replant problem with capsicum seedlings planted into a Centro mulch which was sprayed with herbicide after a shorter time than 4 months. Jason said that the issue of poor soil contact with the seedling root system may still be the issue (not allelopathy), since a 4-month period could still result in friable soil. Also, because tomato plants have a more vigorous root system than do capsicum plants, the difference in response between tomato and capsicum plants may have resulted from crop differences in root vigour. Jason said that the key issue with the killed *in-situ* mulch system is trying to sort out why poor regrowth may occur. Gordon said that AHR are presently doing a sequential planting trial with Centro and Indian blue grass with capsicum as the test crop species which may elucidate some of the issues. Discussion followed re machinery which could be designed to plant into killed *in-situ* mulch system.

The issue of nematode infection of the cover crop species was raised. Tony said that a capsicum–eggfruit–zucchini rotation in the same bed is a good combination for control of nematodes.

Tony said that Lionel’s experience in Bowen with killed *in-situ* mulches may not be the answer in Bundaberg, and each centre may have different best bets.

Jason asked Ross and Tracey to outline the future for dumping of plastic in Bowen and Bundaberg, respectively. Tracey said that the 3 small dumps in the Burnett shire will not take plastic mulch within 3 years. Therefore, there will be limited dump capacity at Bundaberg for spent plastic mulch in the future. Ross said that MIM hold a licence with the EPA for the disposal of plastic mulch at Collinsville. Ross said that the long-term situation is unknown.

Craig suggested that the research results need to be put together in the near future to understand where we are. Shaun suggested and that email or teleconferences are a cheap and effective way of doing this.

The meeting closed at 3 pm.