Effect of mulches on organic kumara production

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Abstract

The area in kumara (*Ipomoea batatas*) in the Gisborne region is increasing, particularly in the organic sector. However, cool soil temperatures may limit yield early in the growing season. The objective of this project was to evaluate the effect of different mulches on soil temperature and kumara growth. Experiments were established on organic farms at Tikapa (2005-06) and Kiekie (2006-07) in the Gisborne region. In Experiment 1, at Tikapa, kumara cuttings (*tipu*) were hand planted on 7 December 2005 into raised beds covered with black polythene (P) or ryegrass-hay (H) or were planted in bare soil. In Experiment 2, at Kiekie, *tipu* were machine planted on 23 November 2006 into flat beds, but only the P and C treatments were used. Weeds were controlled by the mulches and regular hand weeding (Tikapa and Kiekie) and with mechanical weeding (Kiekie only) of H plots. Average daily soil temperature, prior to canopy closure, was warmest in P (24.0 and 20.1 ^{o}C at Tikapa and Kiekie respectively) followed by C (21.6 and 18.6 ^{o}C) and H (19.5 ^{o}C; Tikapa only). Average daily air temperature (10 cm above the ground) was unaffected by the treatments. Total storage root yields were significantly higher in P (38.5 and 14.6 t ha^{-1}; Tikapa and Kiekie respectively) than in C (15.2 and 7.7 t ha^{-1}). Yields were lowest in H (2.4 t ha^{-1}; year 1 only) because of poor weed control. Plastic mulch increased early shoot and root growth, total shoot and root biomass, and radiation interception, relative to C and H. Although a high capital outlay is required for P, gross margins in P were substantially higher than in C.

Additional key words: mulch, organic production**,** sweet potato, yield development

Introduction

Kumara (*Ipomoea batatas* L.), or sweet potato, is an important tropical/sub-tropical crop grown in many parts of the world. It is particularly important for Gisborne's Maori growers because of cultural ties (*tikanga*) dating back to pre-European times. In tropical climates sweet potatoes are often grown all year round, but in temperate climates such as in New Zealand they are strictly a summer crop. The use of polythene to control weeds and warm the soil is a common practice of Japanese growers (Steve Lewthwaite, pers. comm.). Although most of New Zealand's kumara production is based around Dargaville (Northland), an increasing number of growers are producing kumara organically in the cooler (early and late in the season) Gisborne region.

Most Gisborne kumara growers do not use chemical weed control, preferring "organic" or traditional methods involving a combination of mechanical and hand weeding. However, these growers often struggle to keep on top of weeds due to large weed seed banks, antiquated equipment, insufficient labour and, for some growers, a limited understanding of weed/crop dynamics. Mulches offer an alternative weed control option that could reduce weed infestations, alleviate labour shortfalls, and provide other benefits such as water conservation and warmer soil temperatures. Combined, these factors may enhance production.

The aim of this project was to investigate the effects of mulches of polythene and hay on kumara growth and development in the Gisborne district to provide recommendations on the best management options for weed control for the region's growers. This paper gives the results for kumara growth and development. The weed control results will be published elsewhere.

Materials and Methods

Experiments evaluating the effect of different mulches on weed control, soil temperature, and kumara growth and development were established on organic farms at Tikapa (2005-06; full Bio-Gro certification) and Kiekie (2006-07; C1 status). Both sites were in the northern part of the Gisborne district. At Tikapa, kumara *tipu* (cuttings) were hand planted on 7 December 2005 into raised beds covered with either black polythene (P) or ryegrass-hay (H) or into bare soil (C; control). The P and H were applied the day before transplanting. At Kiekie, treatments were applied and *tipu* were machine planted on 23 November 2006 into flat beds. Only the P and C treatments were used. The H treatment was omitted at Kiekie because of poor weed control and low yields at Tikapa in the first year.

At both sites the experimental design was a randomised block with five replicates. The cv. Owairaka Red was used at both sites but two of the five replicates at Tikapa were planted with cv. Beauregard because of a shortage of Owairaka Red *tipu*. Soil samples were taken from the top 15 cm before planting at both sites and standard fertility indicators determined (Table 1). Plant in-row and inter-row spacings were 30 and 85 cm respectively at Tikapa and 40 and 75 cm at Kiekie, giving plant populations of 39,000 and 33,000 plants ha^{-1} respectively. Individual plots were 2 rows wide at both locations and were 9 m long at Tikapa and 5 m long at Kiekie.

Table 1. Soil test results (0-15 cm) at the two experimental sites.

Test	Tikapa	Kiekie
Soil pH	5.9	6.0
Mineralisable nitrogen (kg N ha^{-1})	148	-
Olsen P (µg g^{-1})	18	7
Calcium (me 100 g^{-1})	8.7	11.7
Magnesium (me 100 g^{-1})	3.1	3.0
Potassium (me 100 g^{-1})	0.9	0.4
Sodium (me 100 g^{-1})	0.2	0.1
Sulphate-S (µg g^{-1})	7	4
CEC (me 100 g^{-1})	18	18
Base saturation (%)	72	86
Dry weight/volume (g ml^{-1})	0.86	0.85

The soil at Tikapa was a Hikuwai fine sandy loam derived from alluvial material, on an intermediate terrace on the lower reaches of the Waiapu River. The soil at Kiekie is an 'unnamed' clay loam on an upland terrace adjacent to the Kiekie Marae, approximately 5 km north-west of Waipiro Bay.

Trickle irrigation was installed beneath the mulches (but not buried). At Tikapa; the farmer irrigated, as required, during the season. There was no irrigation at Kiekie. Weeds were controlled by the mulches, by regular hand weeding (Tikapa and Kiekie), and by mechanical weeding (Kiekie) of the H plots. At Tikapa, a larger area of the plot was allocated to the final harvest, which was to be used for the weed control study. In these areas weed control was left solely to the respective treatments i.e. mulched plots were not hand weeded.

Soil temperature at 7.5 cm below the soil surface, in the plant row (Tikapa and Kiekie) and air temperature at 10 cm above the soil in the furrow (Tikapa only) was measured hourly using two-channel Gemini (Tiny-tag) data loggers (model TGX-3520). At Tikapa, the temperatures was only measured in one replicate of each treatment due to restricted data logger capacity. At Kiekie soil temperature was measured in three replicates because treatment did not affect mean daily air temperature at Tikapa in the first experiment. Meteorological data was collected, at both sites, using Weatherpro-plus weather stations installed approximately 50 m from the experimental sites. However, the weather station at Kiekie stopped logging mid-way through the season.

Total root, shoot and leaf biomass, root number and leaf area index (LAI) were measured throughout the experiments (Table 2). At each harvest, shoots were collected and roots dug from six plants (in-season harvests at both sites) or an average of nine plants (final harvest at Tikapa; 3 m of row) or eleven plants (final harvest at Kiekie; 6 m of row). At the final harvest at Tikapa (119 days after transplanting; DAT) it was not possible to measure shoot growth because the farmer had grazed the field with sheep prior to the harvest.

Table 2. Experimental sampling regime. (DAT = days after transplanting. Yield components = leaf, stem and root biomass, root number and leaf area index).

Location	Sample No.	Date	DAT	Measurements
Tikapa	1	14 Dec 05	7	Yield components
	2	21 Dec 05	14	Yield components
	3	11 Jan 06	35	Yield components
	4	14 Feb 06	69	Yield components and radiation interception
	5	22 Mar 06	105	Yield components
	6	5 Apr 06	119	Root yield and quality
Kiekie	1	12 Dec 06	19	Yield components
	2	8 Feb 07	77	Yield components
	3	12 Apr 07	140	Yield components

Roots were washed, air-dried, weighed, sub-sampled and separated into fibrous roots (thin white parallel roots), pencil roots (coloured, parallel roots with no visible swelling) and storage roots (coloured roots with visible swelling at some point). Shoots were separated into stem and leaves (including petioles). Each root and shoot fraction was weighed and oven dried at 70 ^{o}C. Leaf area was measured using a LICOR (LI-3100) area meter. Light interception was measured on 14 February 2006 at Tikapa using a Delta-T (Sunscan) canopy analyser. Six readings were taken at equal distances across the inter-row of the plot parallel to the plant rows at one location in each plot.

As well as assessing kumara yield at the time of commercial harvest, roots were graded. Roots were photographed and a simple computer image analysis technique was developed to grade each root according to Turners and Growers (TAG) standards for fresh market kumara grading (www.turnersandgrowers.com). Because there was only a low proportion of tubers in the marketable size range at Kiekie this analysis was only done at Tikapa. The image analysis technique involved photographing all roots after arranging them on a board with a 25 mm square grid printed on it. Roots were visually graded in relation to size (length and diameter), shape, colour and defects. To estimate the fresh mass

(FM) and grade of each storage root in a sample, data (length, diameter and FM) of 48 roots were measured and fed into Equation 1. The density conversion factor (1.0485) was estimated by simple linear regression (Figure 1). The correlation between actual FM and estimates for hand-measured roots was high (r^2 = 0.92). Estimated individual root FM for each sample was summed, and, using linear regression, correlated against measured total root FM of each sample (r^2 = 0.97, Figure 2). However, Equation 1 overestimated total root FM by about 17 %. Because the aim was to estimate fresh yield in each of the TAG grades, this overestimation needed to be corrected. To do this, the estimated FM of individual roots, in each sample, was scaled so the sum of the (scaled) estimated individual root FMs in a sample was equal to the total measured root FM when the sample was collected. To do this for the FM of each of the roots in a sample we multiplied by the fractional difference between the measured total sample root FM and estimated total sample root FM.

$$FM = 4/3 * \pi * R^2 * L * 1.0485 \qquad (1).$$

Where: L = maximum root length (mm) and R = maximum root radius (mm).

The density conversion factor (1.0485) was estimated by simple linear regression.

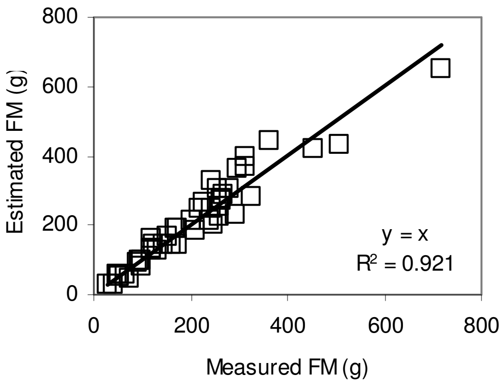


Figure 1. Estimated individual root fresh matter (FM) (from Equation 1) vs. measured individual root FM.

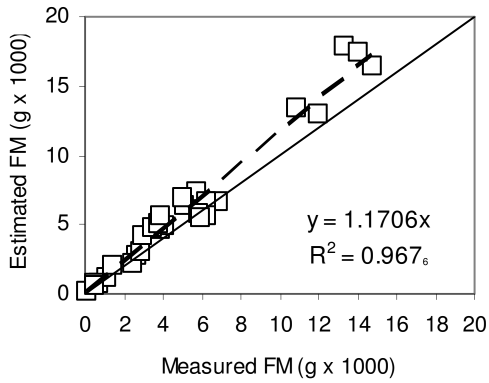


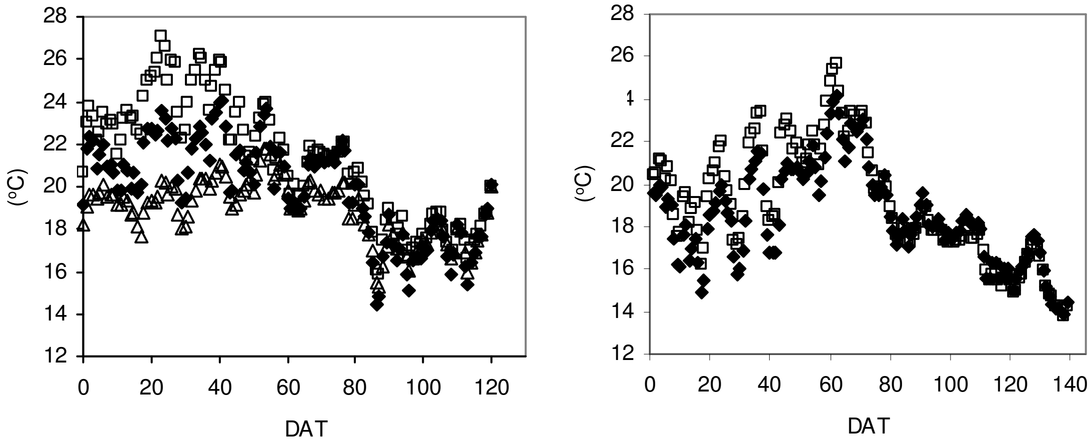
Figure 2. Total measured storage root fresh matter (FM) in each sample vs. total estimated storage root FM in each sample.

Statistical analysis of the treatments was undertaken using general and repeated measurement analysis of variance where appropriate (Genstat v9). For a statistically significant result, a P value of 0.05 was used.

Results and Discussion

At Tikapa, there were marked soil temperature differences among treatments in the first part (0 to 50 DAT) of the season. Mean daily soil temperature was 2.6 ^{o}C higher in P (24.0 ^{o}C) than in C (21.6 ^{o}C). The hay gave the lowest soil temperature at 19.5 ^{o}C ((B) Figure 3). Differences in soil temperature among treatments were minimal after 60 DAT because the crop canopies began to close around this time, shading the soil from the sun's radiation. There was no effect of treatment on the mean daily air temperature at 10 cm above the soil. However, treatment C had a markedly higher mean daily minimum air temperature (18 ^{o}C) and a lower mean daily maximum temperature (22 °C) than P and H, which had similar temperatures (means 13.4 and 28.6 °C respectively). Other studies have shown soil under polythene has a significantly higher surface temperature than bare soil but similar air temperatures (Ham *et al.*, 1993; Tarara and Ham, 1999).

Similar soil temperature results were observed at Kiekie. From 0 to 50 DAT soil temperature in P (20.1 °C) was significantly warmer ($P < 0.001$) than in C (18.6 °C). The drop in soil temperature after 60 DAT again corresponded with canopy closure. The lower positive effect of P on soil temperature at Kiekie compared to Tikapa was probably due to differences in the way the polythene was laid on the ground. Laying polythene on raised beds (Tikapa) allows more rapid soil warming compared to when it is laid flat on the ground (Kiekie).



(A) **(B)**

Figure 3. Mean daily soil temperature (7.5 cm beneath the soil surface) in the plant row at Tikapa (A) and Kiekie (B), for polythene (□), bare soil (♦) and hay (▲ Tikapa only). (DAT = days after transplanting).

In treatment P kumara root and total shoot (leaf + stem) biomass and LAI were significantly higher than in the other treatments at most harvests. Root growth, at the first sampling date, was generally more prolific (greater biomass and root number) in P than in C, with H having significantly less root growth (Table 3). These effects are probably due to differences in soil temperature. Nakatani (1993) found that root proliferation (total root length and weight) of kumara, one week after planting, increased linearly with soil temperatures from 19 to 31 °C. The minimum temperature for root growth was 15 °C. There were similar results for total root number. At the second sampling at 15 DAT, at Tikapa (Table 4) there were no significant treatment effects on shoot or root biomass or LAI. Contrasts suggested that total root biomass in P at 0.51 g plant^{-1} was marginally (although not significantly) higher than in H 0.24 g plant^{-1} ($P = 0.086$), which was not significantly different ($P > 0.1$) from C (0.46 g plant^{-1}).

At 36 DAT at Tikapa (Table 5), LAI was significantly higher in P (0.05 m^2 m^{-2}) than in C and H (both 0.03 m^2 m^{-2}). The rate of leaf appearance on kumara propagules increases linearly with air temperature from 23 to 32 °C (Fujiwara *et al.*, 2004). However, the enhanced leaf area in P does not appear to be related to higher air temperature because mean daily air temperatures were similar for all treatments. Further, P had almost identical maximum and minimum temperature regimes to H. However, the temperature regimes for P differed markedly from those of C. Soil temperature in the pre-canopy closure phase may therefore be a key factor affecting LAI development in kumara. Although not measured, heat radiated from the surface of the polythene to leaves and meristems in close proximity to the mulch may also have influenced this result.

Table 3. Yield components at the first sampling at Tikapa (8 days after transplanting; DAT) and Kiekie (19 DAT). (C = bare soil; P = polythene; H = hay).

Location	Yield component	C	P	H	LSD	F-pr
Tikapa	Shoot biomass (t DM ha^{-1})	0.03	0.03	0.02	0.01	0.683
	LAI (m^2 m^{-2})	0.02	0.02	0.02	0.01	0.864
	Root No. ($plant^{-1}$)	15.1	24.6	9.4	12.3	0.059
	Root biomass (t DM ha^{-1})	0.001	0.003	0.001	0.001	0.012
Kiekie	Shoot biomass (t ha^{-1})	0.02	0.02	-	0.01	0.457
	LAI (m^2 m^{-2})	0.02	0.03	-	0.01	0.266
	Root No. ($plant^{-1}$)	26.1	38.5	-	9.5	0.020
	Root biomass (t ha^{-1})	0.19	0.25	-	0.11	0.200

Table 4. Yield components at the second sampling at Tikapa at 15 days after transplanting. (C = bare soil; P = polythene; H = hay).

Yield component	C	P	H	LSD	F-pr
Shoot biomass (t DM $ha^{-1)}$	0.03	0.04	0.03	0.02	0.242
LAI (m^2 m^{-2})	0.03	0.03	0.03	0.02	0.914
Root biomass (t DM ha^{-1})	0.02	0.02	0.01	0.01	0.171

The number of pencil roots at 36 DAT was higher in P than in C, and the number in C was higher than in H (Table 5). At this time there were no significant difference in total shoot or root biomass.

Table 5. Yield components at the third sampling at Tikapa 36 days after transplanting). (C = bare soil; P = polythene; H = hay).

Yield component	C	P	H	LSD	F-pr
Shoot biomass (t ha^{-1})	0.04	0.05	0.04	0.02	0.193
LAI (m^2 m^{-2})	0.03	0.05	0.03	0.02	0.047
Pencil root no. (m^{-2})	13.7	21.7	7.3	4.2	<0.001
Root biomass (t ha^{-1})	0.022	0.027	0.016	0.012	0.142

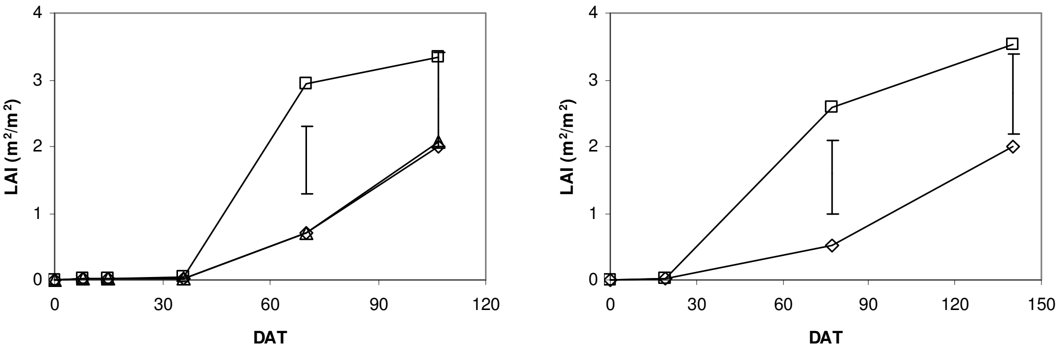
By mid season (70 DAT at Tikapa and 77 DAT at Kiekie; Table 6) treatment P had significantly higher total shoot and root biomass and LAI than the other two treatments. Light interception was measured at Tikapa at 69 DAT. In P the fraction of radiation intercepted (FRI) (data not shown) and LAI (Figure 4a) were 0.94 and 3.0 m^2 m^{-2} respectively. These values were significantly higher than in C (0.58 and 0.7 m^2 m^{-2}) and H (0.64 and 0.7 m^2 m^{-2}), which were not significantly different. Development of LAI at Kiekie, over time, was similar but light interception was not measured.

The higher LAI in P, throughout the season, increased the amount of total radiation intercepted (RI). Unpublished models of LAI development and RI (Searle and Shaw, 2004-2006), calibrated using data from this study, were used to estimate total (full season) RI. The total RI in P at Tikapa was 1,027 MJ m^{-2}. This was much higher than in C and H, both of which intercepted about 690 MJ m^{-2}. A similar result was anticipated at Kiekie but the midseason weather station malfunctioned preventing their estimation.

In all treatments, in both years, the rate of biomass accumulation increased as the season progressed Figure 5). However, the proportion of biomass partitioned between roots and shoots during later growth stages differed among treatments and between years. In P, at Tikapa, approximately 85 % of the biomass accumulated between the last two harvests (70 and 107 DAT; Figure 5a) was partitioned into roots, compared to 60 % at Kiekie over a similar period (Figure 5b). The relative amounts of biomass partitioned into roots between the last two harvests in C (63 and 44 %) and H (70 %) at Tikapa and Kiekie respectively were significantly less than in P. When left until maturity, kumara shoot growth follows a classical sigmoidal pattern (Searle and Shaw, 2004-2006; unpublished). In year 1 P was the only treatment, which showed a significant trend towards slower shoot growth over later growth stages (Figure 4a, b). Therefore, the apparent seasonal and treatment effects in biomass partitioning seen here could be due to differences in relative maturity stages and/or ontogeny between the last two sampling dates.

Table 6. Mid season yield components at Tikapa (70 days after transplanting; DAT) and Kiekie (77 DAT). (C = bare soil; P = polythene; H = hay). (Storage root number was not measured at Kiekie).

Location	Yield component	C	P	H	LSD	F-pr
Tikapa	Shoot biomass (t ha^{-1})	0.6	3.0	0.6	0.7	<0.001
	LAI (m^2 m^{-2})	0.7	3.0	0.7	1.0	0.001
	Storage root No. (m^{-2})	11.9	17.8	13.0	8.1	0.268
	Root biomass (t ha^{-1})	0.6	1.7	0.3	0.6	0.002
Kiekie	Shoot biomass (t ha^{-1})	0.4	1.9	-	0.6	0.002
	LAI (m^2 m^{-2})	0.5	2.6	-	1.0	0.004
	Storage root No. (m^{-2})	-	-	-	-	-
	Root biomass (t ha^{-1})	0.03	1.0	-	0.03	0.004



A **B**

Figure 4. Development of Leaf area index from days after transplanting (DAT) for polythene (□), bare soil (◊) and hay (Δ; Tikapa only) at Tikapa (A) and Kiekie (B). Data = means of five replicates. Error bars are the LSD's of treatment means (P = 0.05).

The final harvest areas of treatments P and H, at Tikapa were not kept weed-free like the in-season harvest areas of all treatments and final harvest areas of C. There were differences in the efficacy of weed control among treatments in these final harvest areas (data not shown). Weed control was poor in treatment H but good in P and C, although a few grass weeds managed to establish in P around the base of some kumara plants. As a result H had a significantly lower root yield than C (Table 8), an effect that was not apparent at the previous harvest at 105 DAT (Table 6).

Table 7. Yield components at the end of season at Tikapa (107 days after transplanting; DAT) and Kiekie (140 DAT). (C = bare soil; P = polythene; H = hay).

Location	Yield component	C	P	H	LSD	F-pr
Tikapa	Shoot biomass (t DM ha^{-1})	2.0	4.1	1.9	1.4	0.010
	LAI (m^2 m^{-2})	2.0	3.3	2.1	1.4	0.110
	Storage root No. (m^{-2})	18.6	20.4	23.0	6.6	0.348
	Root biomass (t DM ha^{-1})	3.5	8.1	2.9	2.6	0.003
Kiekie	Shoot biomass (t DM ha^{-1})	2.3	4.0	-	1.2	0.019
	LAI (m^2 m^{-2})	2.0	3.5	-	1.2	0.022
	Storage root No. (m^{-2})	15.2	20.0	-	6.2	0.095
	Root biomass (t DM ha^{-1})	1.81	3.4	-	1.3	0.025

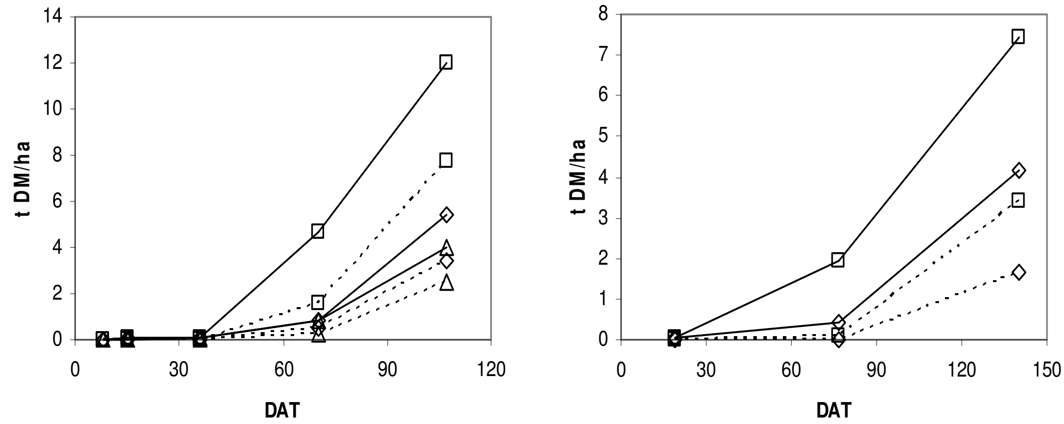


Figure 5. Total (root + shoot) biomass (———) and total root biomass (- - - -) accumulation from days after trans-planting for kumara grown under polythene (□), hay (Δ) and bare soil (◊) at Tikapa (A) and Kiekie (B). Data are treatment means of five replicates.

At final harvest kumara roots were graded into marketable size classes. The results are given in Table 8. Although roots were not graded at Kiekie, similar trends were apparent. Grading kumara based on visual appearance, using photographs showed that kumara from P were similar in appearance to those from C and H (data not shown). Treatment P significantly increased yield and numbers of premium grade roots and the yield in jumbo grade compared to C, and increased yield and root numbers in all classes compared to H (Table 8). Treatment C had significantly more roots in the cull:canner grade (the sum of all storage roots less than the minimum size requirements for premium grade) and premium grades and root numbers in the cull:canner grade than treatment H. The mean root dry matter percentage (DM %) at Tikapa was significantly lower in treatment C than in P and H (Table 8). At Kiekie there was no significant difference in root DM % between treatments P and C). However, this observation appeared to be confounded by one outlier (31 % DM) from treatment C; when that plot was removed, P (23.4 % DM) had a significantly (P = 0.041) higher DM % than C (19.8 % DM). These differences among treatments in storage root DM % may have been due to relative maturity differences.

Gross margin analysis was only performed on the Tikapa data (Table 10). Production costs were much higher in P (\$16,120 ha^{-1}) than in C (\$8,450 ha^{-1}). However, the higher yields in marketable sizes in P, with no apparent loss of quality (in fact DM % rose), gave a much higher gross margin than for C (\$11,760 ha^{-1} and \$370 ha^{-1} respectively). The prices used in the analysis (Table 3) are very conservative as some wholesalers over the study period were consistently paying growers \$2.50 kg^{-1} for premium and \$2.00 kg^{-1} for jumbo grade kumara. If these prices are used then the gross margin of P becomes \$54,780 ha^{-1} and C \$13,220 ha^{-1}. Although these margins seem unrealistically high, the data are from hand-harvested plots without any harvesting or curing costs or storage losses factored in. In 1997, the average loss of sweet potato (kumara) yield in the USA during curing and storage was 20-25 % (Boyette *et al.,* 1997). A 20 % loss in marketable yield would bring Tikapa's gross margins at \$2.50 kg^{-1} (premium) and \$2.00 kg^{-1} (jumbo) prices to around \$40,600/ha and \$8,960/ha for treatments P and C respectively. At \$1.00 kg^{-1} and \$0.75 kg^{-1} prices the respective gross margins would be \$6,200 ha^{-1} and -\$1,300 ha^{-1}. Harvesting losses would further reduce these margins.

Conclusions

Kumara growers in the Gisborne district could benefit from introducing polythene mulch into their production systems. In this study, in both years polythene dramatically increased kumara production.

The yield benefits, from the black polythene, were due to enhanced soil temperature prior to canopy closure, which increased early root growth (root biomass and numbers of roots). This in turn increased shoot growth (leaf and stem) and radiation interception. At Tikapa, fresh market kumara yield (i.e. premium and jumbo grade) grown on beds covered with black polythene was 64 % higher than when grown on bare soil. A similar result was obtained at Kiekie where total storage root yield under polythene was 53 % higher than on bare soil. Root DM % was also increased under polythene.

The polythene controlled weeds well and only a few grass weeds managed to establish around the base of some kumara plants. Kumara shoot and root biomass production in hay mulched plots that were kept weed-free gave similar biomass production to weed free bare soil. However, when unweeded the hay mulch gave the lowest yields of all treatments.

Gross margin analyses indicated that growing kumara under polythene is much more profitable than on bare soil, although a much higher capital outlay is required.

Table 8. Total storage root yield of various grades of fresh market kumara at final harvest at Tikapa at 119 days after transplanting. (C = bare soil; P = polythene; H = hay). Root DM % is the mean dry matter % across all size classes. Culler:canner is the sum of all roots less than the minimum size requirements for premium.

	Root yield (t ha^{-1})				Root	Root No. (roots m^{-2})		
	Cull/canner	Premium	Jumbo	Total	DM (%)	Cull/canner	Premium	Jumbo
C	6.3	7.4	1.4	15.2	18.4	10.2	2.6	0.1
P	8.3	20.6	9.7	38.5	21.2	12.9	6.6	1.3
H	2.2	0.2	0.0	2.4	21.8	4.9	0.1	0.0
F-pr	0.001	<0.001	0.027	<0.001	0.025	0.004	0.012	0.063
LSD	2.4	5.5	7.1	10.3	2.4	3.9	3.8	1.2

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Table 9. Total kumara yield and root number at final harvest at Kiekie at 141 days after transplanting. (C = bare soil; P = polythene). Removing an outlier from the DM % of C gave a significantly higher (P = 0.041; LSD = 3.3% DM) DM % in P (23.4 % DM) than in C (19.8 % DM).

	Total root yield (t ha^{-1})	Root DM (%)	Root No. (roots m^{-2})
C	7.7	22.7	15.0
P	14.6	23.4	19.8
F-pr	<0.001	0.977	0.104
LSD	2.6	9.5	6.4

Table 10. Tikapa gross margin, ha^{-1}, analysis for polythene and bare soil treatments. The data assumes no curing or storage losses. Curing costs were set at \$30 t^{-1}, harvesting costs \$640 ha^{-1} (tractor and lifter) + \$60 t^{-1} (labour); based on information from New Zealand Kumara Distributors. Other costs were based on real (quoted) or estimated rates. Not included are transport costs or trickle irrigation used in P and overhead irrigation in kumara (energy costs not included).

	Polythene	Bare soil
Cost of production (COP)		
Cultivation	$500	$500
Mounding	$2,590	$150
Irrigation	$3,100	$1,000
Polythene	$1,560	-
Cuttings	$2,000	$2,000
Planting	$1,000	$1,000
Hand weeding	-	$2,000
Removing plastic	$2,000	-
Curing	$910	$260
Harvesting	$2,460	$1,170
Marketable yield		
Premium (\$1.00 kg^{-1})	20.6 t ha^{-1}	7.4 t ha^{-1}
Jumbo (\$0.75 kg^{-1})	9.7 t ha^{-1}	1.4 t ha^{-1}
Revenue	$27,875	$8,080
Total COP	$16,120	$8,450
Gross margin	$11,760	$370

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