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Mulch effect on successive crop yields and soil carbon in Tonga

V. Manu[1], A. Whitbread[2] & G. Blair[3]
[1]*Ministry of Agriculture, Alaivahamama'o Bypass, Nuku'alofa, Tongatapu, Tonga,* [2]*ICRISAT, Patancheru, Hyderabad 502324, India, and* [3]*Agronomy and Soil Science, School of Environment and Rural Science, University of New England, Armidale, NSW 2351, Australia*

Abstract

Intensification of crop production in Tonga has resulted in a move to mechanical soil preparation, often with a rotary hoe, and a consequent loss in both chemical physical fertility. An experiment was conducted on a clay loam soil (Typic Argiudoll) on the Forestry Vaini Research Station, Tongatapu Island, Tonga, to investigate the effect of a once-off application of mulch on yield and quality of watermelon, maize and capsicum grown in rotation over a 1-yr period. The treatments applied were a nonmulched control, transparent plastic and 200-mm-thick applications of locally available coconut sawdust, guinea grass and mature coconut fronds. The fresh fruit yield of watermelon in all the mulch treatments was 7.3–18.1% higher than in the nonmulched control. There was no significant effect of thick vegetative mulch on maize grain dry matter yield; however, the maize yield was significantly lower in the transparent plastic mulch than in the other treatments. The capsicum marketable fruit yield in the following crop was increased by 49–73% in all the vegetative mulch treatments compared to the non-mulched control. The higher crop yields with the vegetative mulch were attributed to the measured lower soil temperatures and higher soil moisture in these treatments. There was no effect of mulch on soil total N (TN), but soil total C (TC), soil labile C (LC) and the carbon management index (CMI) were increased.

Keywords: Mulch, Pacific islands, soil carbon, weeds, economics, Guinea grass

Introduction

Soil C decline, consequent loss of productivity and increase in erosion risk are significant problems in many areas of the world. This is particularly a problem in the developing world where population increase is forcing intensification on existing cropping land and cultivation of marginal lands. Repeated cultivation and mismanagement of plant residues contribute to this soil degradation.

Research in Tongatapu Island in Tonga reported by Manu *et al.* (2014) found that soil where guinea grass mulch had been applied for more than 5 yr had 46% higher total C concentration compared to soil that had been repeatedly mechanically cultivated. Similarly, the mean weight diameter of aggregate was 244% higher and the percentage of aggregates <125 μm was 78% lower in the soil where guinea grass mulch had been applied.

Correspondence: G. Blair. E-mail: gblair@une.edu.au
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In Tonga, the main island of Tongatapu has a land area of approximately 26 844 ha. The climate is characterized by the 'hot wet season', from December to April with monthly rainfall of up to 230 mm and mean monthly maximum temperatures of more than 29 °C and minimum temperatures of more than 24 °C. The 'cool dry season', from May to November, has a mean monthly rainfall of less than 130 mm and mean monthly maximum temperatures of more than 25 °C and minimum temperatures of more than 20 °C. A 4- to 8-week drought often occurs during this season which affects the growth of the root crops. Most farmers have access to an abundant supply of organic materials such as mature coconut fronds and between 15 and 25 t DM/ha of guinea grass (*Panicum maximum* Jacquin) which grows in the fallows. The latter was introduced into Tonga as cattle feed and has become endemic. Currently, mulching with vegetative materials is practised only by vanilla growers in Tonga and the materials used depend on their availability and accessibility.

The common method of land cultivation for root, grain and vegetable crops involves incorporating this substantial grass fallow biomass by mechanical tillage, or more commonly by burning it prior to tillage. A small number of farmers manage it traditionally by hand weeding, slashing and maintaining it on soil surface as mulch. Previous research by Manu *et al.* (2014) has shown that a marked decline in soil C, wet aggregate stability and nutrient status occurred as land use changed from forest to cropping and has suggested that addition of mulches could be a way to arrest this decline in the resource base.

An experiment was conducted to evaluate the effect of a single application of different types of mulch on a crop rotation of watermelon (*Citrullus lanatus* Schrader), maize (*Zea mays* L.) and capsicum (*Capsicum annum* L.) which is commonly used in Tonga. The objective of the study was to investigate whether the use of thick vegetative mulch from *in situ* or off-site material, and the retention of crop residues as surface mulch enhanced crop yields, increased soil nitrogen and carbon and was profitable.

Materials and methods

Experimental setup

The experiment was conducted on a Vaini clay loam soil (Typic Argiudolls, very fine, halloysitic, isohyperthermic) located on the Vaini Research Station, on Tongatapu Island, Tonga. The site had been under root crop cultivation for 3 yr and then abandoned to guinea grass fallow for the following 3 yr. The soil had a pH (1:5 soil: water ratio) of 6.5, total C of 3.6% and total N of 0.21%.

The experimental area was pegged out in June and six replications of the following mulch treatments were applied: non-mulched control; transparent plastic mulch; mature coconut fronds (200 mm thick); coconut sawdust mulch (200 mm thick); guinea grass mulch (200 mm thick).

There are a number of ways in which the amount of mulch applied could have been decided. They could have been applied at the same rate, to the same depth or to a constant addition of a particular nutrient. It was decided to apply to the same depth in order to allow the relative insulation properties to be examined and to avoid crop establishment problems with excessively deep mulches as would occur with fronds. The thickness of the mulch was based on the mass of guinea grass that accumulates after cropping. The dry matter content of the mulch materials applied to 200 mm thickness was equivalent to 90 t/ha dry matter for coconut fronds, 160 t/ha for coconut sawdust and 65 t ha for guinea grass. Each plot was 8.0 m × 8.4 m and surrounded by a 1.5 m border. The treatments were arranged in a completely randomized block design. Three crops were grown and harvested in rotation, with a single application of the mulch treatments to the first crop.

The watermelon crop

The experimental area was disc ploughed three times within 6 weeks, incorporating the existing grass vegetation into the soil. Seedbeds 3 m wide and 1 m apart were prepared and consisted of six rows of 14 plants per row, with one row as border between treatments.

The total amounts of fertilizer applied were 138 kg N/ha, 165 kg P/ha, 117 kg K/ha and 73 kg S/ha applied as urea (46% N), mixed NPKS (11.9:28.6:28.1 + 4.8S) and single superphosphate (0:20.6:0 + 27.5S). On July 9, an amount of 40% of the N, 90% of the P, 70% of the K and 70% of the S were applied as basal fertilizer in 200-mm bands and incorporated by hand means to 300 mm depth on both sides of the seedbed. On July 19, watermelon (*C. lanatus* var Candy Red) was direct seeded (3 seeds/planting hill) at a spacing of 700 mm between plants and 3000 mm spacing between rows across the seedbed and 1000 mm spacing between rows across the furrow. Ten days after emergence (July 25), the seedlings were thinned to one/hill. The mulch treatments were partially applied to the 1000 mm space from both the rows to the centre of the seedbed. As the watermelon grew, the vines were trained to remain within the 3000 mm spacing leaving the 1000 mm space between the rows free of vegetation.

After 30 days of growth (August 18), the remaining fertilizer was side dressed onto the soil surface at 1000 mm from the plants within the seedbed and the mulch treatments applied to the remainder of the plot. The plots were manually weeded every 10 days after sowing, and after 30 days of growth, crop protection sprays were applied. The crops were protected from gummy stem blight with benomyl applied alternately with mancozeb, powdery mildew disease with ®Topaz and ®Afugan and the aphid vector for the cucumber mosaic virus disease with ®Perfekthion with ®Orthene. The watermelon crop was grown to maturity, and fruits from 40 plants per plot were harvested on November 1 and 12. Marketable fruits were graded as greater than 2 kg and free from defects. Crop residues were left on the plots.

The maize crop

Following the harvest of the watermelon crop, a maize crop (*Z. mays*) was established in the same plots. The maize crop was planted by hand into the mulch and watermelon residue on December 2. The experiment was manually weeded every 10 days. No additional fertilizer or crop protection pesticide sprays were applied during the growth of maize. A cyclone in March partially damaged the crop when it was nearing maturity and harvested on April 10.

At harvest, cobs were harvested from 32 undamaged plants in each plot to determine yield. Following removal of the cobs from all plants, the remaining crop residues were returned to the surface of each plot.

The capsicum crop

On May 5, following the maize crop, a crop of capsicum (*C. annum* var. Yolo Wonder) was planted into the existing mulch and crop residues on the plots. Six-week-old seedlings were transplanted at a spacing of 70 mm between plants and 800 mm between rows. There was 8 weeks of drought from June to July. The capsicum was harvested continuously from July 16 to October 14.

Rainfall data for the site recorded over the three crops, together with mean data is presented in Figure 1.

Soil sampling

Following the harvest of the capsicum crop, 30 soil samples were taken from the 0 to 100 mm layer in each plot taking care to avoid the fertilizer bands. Any visible surface organic debris was carefully brushed aside prior to sampling. As fertilizer had not been reapplied to the maize or capsicum crops, the samples represent the residual from the initial application either by direct addition or recycling from the mulches and crop residues. These samples were air-dried at 40 °C, ground to pass a 0.5-mm sieve and stored for carbon analysis.

Measurement of soil temperature and moisture and weed scoring

Soil moisture in the plots was monitored at weekly intervals using an 'Aquaterr' soil moisture probe inserted to a depth of 100 and 200 mm. A total of five readings were taken in each plot at each measurement time, and the values were averaged. The probe was calibrated in water according to manufacture specifications prior to each reading so that a value of 100 represented free water.

Soil temperature was measured with a 'Barnant 100' thermocouple thermometer with a M12 temperature probe. The temperature of the surface soil just beneath the mulch was recorded. Measurements were made around 2.00 pm on the same day each week as the soil moisture measurements were made. The probe was inserted at five locations within each plot, and the mean values calculated. Following the measurement in each plot, a reading was taken of the air temperature.

A delay in receiving and commissioning the soil moisture probe and thermocouple thermometer meant that these measurements were not made in the initial capsicum crop.

Weed infestation was visually ranked on a scale of 1–5 at 2-weekly intervals in the watermelon and capsicum crops (at the same time as temperature and moisture). At each ranking, the plot with the least weeds was ranked 1 and that with the most ranked 5.

Soil analysis

The total carbon (TC) was determined using a Carlo Erba NA1500 Automatic Nitrogen and Carbon Analyser Mass Spectrometer (ANCA-MS). Labile carbon (LC), carbon lability (L) and the carbon management index (CMI) were determined using the procedure described by Blair *et al.* (1995). Total nitrogen (TN) was determined using a Carlo Erba NA1500 Automatic Nitrogen and Carbon Analyser Mass Spectrometer (ANCA-MS).

Statistical analysis

All the yield and soil data from the three crops were subjected to analysis of variance using the Minitab statistical package. Differences between treatments were determined to be significant when $P < 0.05$.

Results

Crop yield

The rate of watermelon biomass accumulation was excellent during the experimental period due to the favourable

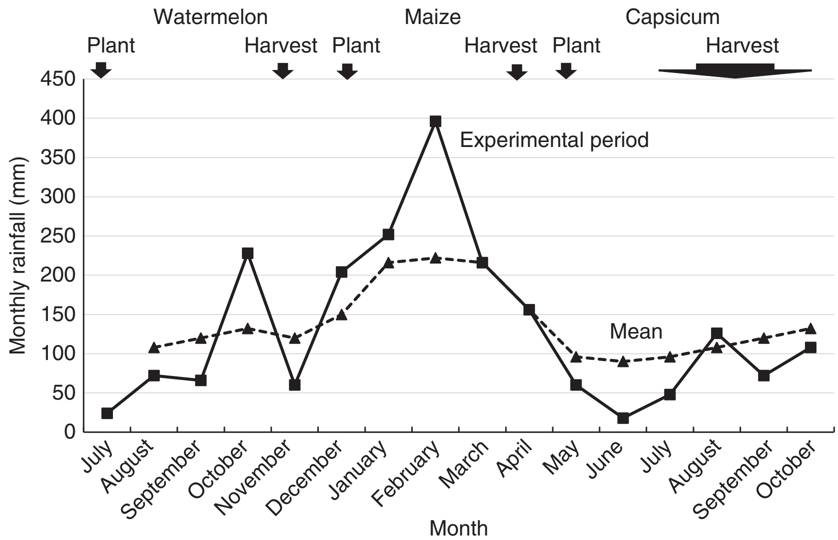

Figure 1 Monthly rainfall received during the experimental period and mean data for the site. Crop planting and harvesting times are shown as arrows.

climatic conditions. Average rainfall was recorded, and its distribution during the first 6 weeks of growth was the main factor contributing to favourable growth. A smaller number of rain days was recorded during the fruit-set period in September, and above-average rainfall was recorded during the fruit maturation stage. The temperature was cool (approx. 20 °C) at planting and increased together with day length towards fruit set and harvest. This resulted in sufficient germination to allow thinning to 1 plant/hill, vigorous vegetative growth, negligible first fruit set which is normally pruned, and a low percentage of blossom-end rot fruits at harvest. At the first harvest, there was few, but heavy fruits (maximum 15.1 kg/fruit), whereas the second harvest yielded more, but lighter fruits. The watermelon marketable fruit yield ranged from 58.6 to 69.2 t/ha (Table 1).

The fresh fruit yield of watermelon in all the mulch treatments was 7.3–18.1% higher than that of the nonmulched control (Table 1). Yield was significantly higher in the sawdust and grass mulch treatments than in the plastic and frond mulch treatments, and all were higher than the control. In terms of number of watermelon fruits harvested per plant, the number of fruits in the sawdust and the grass mulch treatments were both significantly higher than in the control, but only the sawdust treatment was significantly higher than the plastic mulch treatment (Table 1). The fruit number in the frond and plastic mulch treatments was not significantly different from the control. This indicates that the significant increase in the yield of watermelon under mulch was due largely to the production of more fruits per plant and to a lesser extent heavier fruits per plant.

The germination of the maize plants was sufficient to allow thinning to 1 plant/hill due to rainfall just after the December planting and most treatments grew well due to the long day length (14–15 h) and high humidity. During the first 2 weeks of growth, about 25% plants in the plastic mulch treatment died. A hurricane in March twisted some of the maize plants as the wind direction changed and because these plants did not recover, a subsample of the undamaged plants was harvested 3 weeks later.

There was no significant effect of thick vegetative mulch on maize grain dry matter yield; however, the maize grain dry matter yield was significantly lower in the transparent plastic mulch than the other treatments (Table 1). There was no significant difference between the treatments in the number of maize cobs harvested per plant.

Despite the dry climate in the first half of the experiment, the capsicum plants grew moderately well. Because of the dry weather, the plants were hand watered at planting, and 10 days after planting. No more water was applied despite the 7 weeks of drought in June and July. A number of fruits were damaged by birds and minor damage resulted from attacks by other pests of capsicum. The capsicum marketable fruit yield in tonnes per hectare was 49–73% higher in all the vegetative mulch treatments than in the non-mulched control. The vegetative mulch treatments applied about 1 yr before, and the retention of previous crop residues from watermelon and maize crops remained effective in this third crop.

Soil carbon and nitrogen

The treatment effects on soil TC and LC of the 0–100 mm soil sample were highly significant (Table 2). The soil TC in the sawdust treatment was 13% higher than that in control treatment. The soil LC and lability (L) in the grass mulch and sawdust treatments were significantly higher than in other treatments. The CMI for the sawdust mulch was significantly higher than the other mulch treatments, and the CMI in the grass mulch treatment was significantly higher than the fronds and plastic treatments (Table 2).

There was no significant difference between the treatments in the soil N_T (Table 2). The soil $\delta^{13}C$ value for the sawdust treatment was significantly higher than the other treatments (Table 2) indicating that a significant amount of C-3 sawdust

Table 1 Yield and number of watermelon, maize grain and capsicum in different mulch treatments

Treatments	Non-mulched control	Plastic	Coconut fronds	Coconut sawdust	Guinea grass
Watermelon					
Fruit yield (t/ha)	58.6 c	62.9 b	63.6 b	69.2 a	68.0 a
Fruit (no./plant)	1.6 c	1.7 bc	1.8 abc	2.0 a	1.8 ab
Maize					
Grain yield (t/ha)	1.59 a	1.33 b	1.68 a	1.56 a	1.69 a
Cob no./plant	1.8 ns	1.7	1.9	1.9	1.9
Capsicum					
Fruit yield (t/ha)	5.02 c	6.68 bc	7.92 ab	8.66 a	7.50 ab
Fruit (no./plant)	6.9 ns	6.7	6.8	6.9	6.9

Numbers within a row followed by the same letter are not significantly different according to DMRT at $P = 0.05$.

Table 2 Carbon fractions, CMI, total N and $\delta^{13}C$ of soils sampled during the growth of the capsicum crop that was the third crop grown after the single application of mulch

Mulch	TN (%)	TC (%)	LC (mg/g)	L	CPI	LI	CMI	$\delta^{13}C$ (‰)
Control	0.38 ns	3.62 b	6.72 ab	0.23 a	1.00	1.00	100	−16.58 b
Plastic	0.39	3.54 b	5.69 b	0.21 b	0.98 b	0.91 c	89 c	−16.36 b
Coconut fronds	0.38	3.72 ab	7.25 ab	0.19 b	1.03 b	0.83 c	85 c	−17.07 b
Coconut sawdust	0.42	4.67 a	8.88 a	0.24 a	1.29 a	1.04 a	134 a	−18.66 a
Guinea grass	0.39	3.76 ab	7.72 a	0.24 a	1.04 b	1.04 a	108 b	−16.29 b

Numbers within a column followed by similar letters are not significantly different according to DMRT at $P = 0.05$.

carbon was present in the soil, which initially contained predominantly C-4 guinea grass carbon.

Soil temperature and moisture

The temperature of the soil surface was significantly lower, by 4.0–5.9 °C, relative to the air temperature in all the vegetative mulch treatments in the maize crop (Table 3). The soil temperature underneath the plastic mulch was significantly higher, by 10.3 °C, whereas the soil temperature of the nonmulched control was similar to the air temperature (Table 3). The soil moisture at 100 mm and 200 mm depth was 9.8–21.4%, higher in all the mulch treatments than in the nonmulched control (Table 3). There was no significant difference in soil moisture between the mulches at 100 and 200 mm soil depths.

Measurements made in the capsicum crop, some 12 months after the mulch application, showed that the mean soil surface temperature under the plastic mulch was significant higher, by 1.4 °C than in the nonmulched control treatment (Table 3). The soil surface temperature under the vegetative mulch treatments was significantly lower by 1.1–2.2 °C than in the control. The soil temperature under the frond treatments was significantly lower than under the grass and sawdust mulches.

The soil moisture at 100 mm depth under the frond and the sawdust mulch in the capsicum crop was significantly higher, 4.4 and 3.9%, respectively, than the nonmulched control (Table 3). The soil moisture under grass mulch was significantly higher than in the nonmulched control and under the plastic mulch. There was no significant difference in soil moisture between the control and the plastic mulch treatments.

Weed rating

The weed infestation in the maize crop was significantly higher in the nonmulched control treatment than in the other treatments (Table 3). The weed score in the coconut fronds treatments was significantly higher than in the grass, sawdust and the plastic treatments which were not different from each other.

In the capsicum crop, weed infestation was significantly higher, in the nonmulched control than in the other treatments (Table 3). The weed score for the grass mulch treatment was significantly higher than the plastic, coconut sawdust and frond treatments. There was no significant difference in weed infestation between the frond, sawdust and plastic treatments. Therefore, after about 1 yr, the vegetative and the plastic mulches were still effective to different degrees in suppressing weed growth.

Table 3 Mean weekly difference between soil and air temperature ($T_{trt}-T_{air}$, °C), mean weekly relative soil moisture taken at 2.00 pm and weed score (1 = least weeds, 5 = most weeds) during the maize and capsicum crops

Treatments	Nonmulched control	Plastic	Coconut fronds	Coconut sawdust	Guinea grass
Maize					
$T_{trt}-T_{air}$ (°C)	−0.2 b	10.3 a	−4.0 c	−5.5 c	−5.9 c
Moisture 100 mm (%)	14.6 b	24.0 a	24.4 a	22.6 a	20.8 a
Moisture 200 mm (%)	30.0 b	51.4 a	51.4 a	47.5 a	45.6 a
Weed score (1–5)	4.3 a	1.0 c	2.3 b	1.6 c	1.2 c
Capsicum					
$T_{trt}-T_{air}$ (°C)	0.0 b	1.4 a	−2.2 e	−1.6 d	−1.1 c
Moisture 100 mm (%)	10.6 c	10.8 c	15.0 a	14.5 a	12.0 b
Weed score (1–5)	4.2 a	2.9 c	2.8 c	2.8 c	3.3 b

Numbers within a row followed by the same letter are significantly different according to DMRT at $P = 0.05$.

Economic analysis

The economic analysis of the input costs and returns of the treatments showed a higher net profit from the watermelon crop for the mulch treatments compared to the nonmulch control (Table 4). The treatment cost was the cost for procuring, transporting and application of the mulch treatments. The treatment cost was very high for the mulch treatments, but the weeding cost was very much reduced. As a result, the net profit for the mulch treatments was 10–16% higher than the bare soil control with the guinea grass and coconut sawdust mulches producing the highest net returns.

Discussion

Crop yields

The production of squash in Tonga for export to Japan has had significant impacts on crop rotations and farmer's incomes. As the crop was introduced into the farming system, the use of pesticide and fertilizer and mechanized tillage using bulldozers and tractors to pull cultivators had increased twofold to 10-fold (FAOSTAT 2012). The latest data available indicate that 21 404 t of squash was produced in 2013 (FAOSTAT) and much of this grown with a fallow of guinea grass of at least 5 months. An alternative strategy to the usual burn and/or tillage incorporation of this grass fallow would be to use such biomass as surface mulch.

This research has shown that thick vegetative mulch increased yields of short-term annual crops (3–4 months) watermelon and capsicum. The maize crop planted after the watermelon failed to respond because yield limitations resulting from cyclone damage.

Increased watermelon fruit yield with polyethylene mulch, fertilizer and irrigation has been reported by Baker *et al.* (1998) and Sanders *et al.* (1999). Vos *et al.* (1995) found capsicum production to be superior with mulch, with variable yields with straw mulch compared to black plastic mulch. Gonzaga *et al.* (2014) found similar advantages of mulch in the Philippines as that reported here and that silvered plastic was superior to vegetative mulches.

The crop responses to application of mulch recorded in this experiment can be attributed mainly to modification of soil surface temperatures, preserved soil moisture and suppressed weed infestations. In Malaysia, Lim & Maesschalck (1980) found 3 t/ha of cut lalang (*Imperata cylindrica*) grass weed mulch reduced soil surface temperature by 7.5 °C and increased soil moisture at 100 mm and 400 mm depth by 37.5 and 14%. Olasantan (1999) found that mulching with 12.5 t/ha of vegetative mulch on yam (*Dioscorea alata*) mounds in Nigeria lowered the soil surface temperature by 2–7 °C and increased soil moisture by 5–12% at 150 mm soil depth. Simpson & Gumbs (1986) found that guinea grass mulch of 50 and 100 mm thickness significantly increased cowpea seed yield by 27 and 34%, respectively, due to higher soil surface moisture and lower temperature. Kwakye *et al.* (1995) working in Ghana reported that the annual application of 5 t/ha grass mulch on continuous groundnut–maize–cassava–maize rotation for 10 yr and cassava for 30 yr consistently increased yield of each crop.

Compared to the nonmulched control, the reduction in weed infestations in the maize crop with the vegetative mulch was as high as 72%. In the following capsicum crop, coconut fronds and sawdust were more effective than the guinea grass. A similar finding has been reported by Rippin *et al.* (1994) who found that mulching with 10 t/ha of *Erythrina* loppings reduced weed infestation by 39%. Haywood (1999) compared different mulch materials on newly planted pine seedlings for three growing season and found that mulching eliminated the established vegetation and weeds. In pot and field experiments, Patterson (1998) found that translucent polyethylene film mulch, similar to that used in the present study, reduced emergence and growth of purple nutsedge (Cyperus spp) 65–88% compared to opaque mulch.

As in the experiment reported here, Bunnaa *et al.* (2011) found that mulching of rice straw at 1.5 t/ha in Cambodia increased mungbean crop establishment, reduced weed

Table 4 Economic analysis of watermelon production under different mulch treatments

Treatment	Yield t/ha	Gross income	Treatment cost	Weeding cost	Net profit	Incremental profit
		T$/ha				
Control	58.6	70 320	0	5000	63 320	0
Plastic	62.9	75 480	4200	0	71 280	5960
Coconut frond	63.6	76 320	5000	0	71 320	6000
Coconut sawdust	69.2	83 040	6500	0	76 540	11 220
Guinea grass	68.0	81 600	6200	0	75 400	10 080

NB: 2016 market price of watermelon is T$1.20/kg, sawdust $12/t, tractor service $100/h and labour $6/h.

biomass and increased yield. Mulch was also effective in conserving soil moisture which was 1.5% higher in the mulched than unmulched treatments at maturity.

Soil nitrogen and carbon

The diverse range and different application rates of vegetative mulch had no significant effect on soil N reflecting the rapid turnover rate of N under these tropical conditions. The high rate of nutrients applied to the first crop (watermelon), including 138 kg N/ha, was applied to mask any N effects resulting from the mulch additions. No fertilizer additions were applied to last the two crops.

Assuming a C concentration of 50% in each mulch, the 200 mm thickness of mulch applied was equivalent to 80 t/ha for sawdust mulch, 45 t ha for mature coconut fronds mulch and 37.5 t/ha for guinea grass. The soil TC increased significantly under the sawdust mulch 1 yr after application reflecting the close contact between this particulate mulch and soil. The significantly lower δ^{13}C for the sawdust mulch, together with the higher soil LC, indicates that the sawdust mulch had decomposed to a great extent and that it had become integrated into the soil C. In the guinea grass treatment, LC was increased but not TC indicating that as the grass C entered the soil it decomposed faster.

Nill & Nill (1993) found that mulching with 13 t/ha of guinea grass provided 100% cover, and after 1 yr, the guinea grass had decomposed to 50% cover. Tian *et al.* (1993) reported that 2 yr mulching with high-quality plant residues (low C/N ratio and low lignin) enhanced maize yield through direct nutritional contributions, whereas low-quality residues do so through mulching effects on the microclimate.

Economics of mulch

Rudimentary economic analysis of mulch treatments input cost and crop yields showed a higher net profit compared to the control. The net profit in the guinea grass and coconut sawdust treatments was some T$17 000 more than the nonmulched control for watermelon based on a watermelon price of T$1.20/kg. Should the price of watermelon fall to T$1.04, there would have been no economic advantage in grass mulching in this crop. The longer-term benefits of mulch on crop yield and soil C were not the subject of this research but this is now being studied. Considering the accessibility and availability of guinea grass mulch to farmers in Tonga, it is recommended as a sustainable practice for crop production in Tonga.

The rate of guinea grass mulch in this experiment was 65 t DM/ha, which would require a harvest of at least 3 ha of guinea grass biomass of 15–25 t DM/ha. In a similar warm, wet climate to that in Tonga Kwakye *et al.* (1995) has shown that 5 t/ha grass mulch sustained higher crop yields in a 30 yr continuously cropped Ultisol forest soil in Ghana. Therefore, the recommendation of using grass mulch would be to harvest the accumulated biomass within the cropped area followed by cultivation and planting of the crops and then reapplying the biomass as mulch. The overall recommendation for Tonga from this research is a crop/fallow system with natural guinea grass vegetation used as mulch and a fallow period of, at most, 3 yr.

The results of this study are applicable to many areas of the developing world where crop/fallow systems are practiced. Careful management of fallow vegetation for use on subsequent crops can have considerable benefits in both crop production and soil conservation. In many areas, labour constraints at, and after, harvesting limit this possibility, but in other areas, where machines are increasingly being introduced, the possibilities are greater.

Conclusion

Addition of vegetative mulches at the planting of the first crop in the three crop rotations was found to have a positive impact on the yield and profitability of all three crops which could largely be attributed to the mulches modifying soil temperature and moisture and in controlling weeds. In area where fallow or waste product vegetative materials are available, consideration should be given to utilizing them in crop production.

In selecting vegetative materials to be used as mulches, a balance needs to be struck between soil surface condition modification and soil carbon accumulation. Materials with fast breakdown rate could enhance short-term soil C status but not provide sufficient soil cover to modify soil surface temperature and moisture and control weeds.

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