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Effects of vegetative mulches on growth of indigenous crops in the Kingdom of Tonga

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Abstract

As in many areas of the developing world, intensification of agriculture in Tonga, and other Pacific Islands, has put increased pressure on the soil resource. Two experiments were conducted to evaluate the effect of mulch on the growth and yield of two important food and fibre crops. The first was conducted on sloping land to evaluate the effect of guinea grass (*Megathyrsus maximus*) mulch and hedgerows on taro [*Colocasia esculenta* (L.) Schott] yield, and in controlling soil erosion. The second compared the response of paper mulberry [*Broussonetia papyrifera* (L) Ventenot] to different management regimes of a grass fallow. Thick vegetative mulch increased taro corm yield by 81% and reduced soil loss by 50% compared to local farmer practice, and the soil loss from taro with mulch was comparable to the perennial cash hedgerow treatment. Mulch increased paper mulberry bark yield by 30% compared to the non-mulch control. Comparative economic analysis showed that increased net profit in the mulched treatments compared to the non-mulched control was T$2660/ha for taro and T$12 108/ha for paper mulberry. Considering that mulch is readily available to many farmers throughout the Pacific Islands and elsewhere in the tropics, it is recommended as a sustainable practice for crop production.

Keywords: Land use, mulching, soil erosion, land use, soil use and management

Introduction

As world population increases without a concomitant expansion of productive agricultural land, farmers are forced to cultivate erosion-prone marginal lands. Such areas initially have relatively fertile topsoils because of surface cover, but are prone to erosion and productivity loss after this has been cleared (Smith *et al*., 2015). This leads to a decrease in the sustainability of the whole catchment soil resource (Keesstra *et al*., 2016). This situation is particularly so in many Pacific Islands and in developing tropical countries.

In their review of mulching and soil erosion, Prosdocimi *et al*. (2016) state "there are still some uncertainties about how to maximize the effectiveness of mulching in the reduction of soil and water loss rates. First, the type of choice of the vegetative residues is fundamental and drives the application rate, cost, and consequently, its effectiveness. Second, it is important to assess application rates suitable for site-specific soil and environment conditions. The percentage of area covered by mulch is another important aspect to take into account, because it has proven to influence the reduction of soil loss". This study addresses the first of these issues.

Taro is an important food for Pacific Islanders both in a nutritional and cultural sense (Akwee *et al*., 2015). World production of taro was estimated at 11.8 million tonnes in 2012 (Vishnu *et al*., 2012). Singh *et al*. (2012) estimated global production came from about 2 million hectares in Africa, Asia and the Pacific Islands with an average yield of 6 t/ha. Most of the global production comes from developing countries characterised by small holder production systems relying on minimum external resource input (Singh *et al*., 2012).

The migration of significant numbers of Pacific Islanders to Australia, New Zealand and western North America, who have taken their desire for taro with them, has resulted in significant local markets for the commodity, which are largely imported from Pacific Islands (FAO, 1999). This, together with increased local demand from the increasing population has increased local production, often from

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erosion-prone marginal lands that could benefit from mulching.

Production of tapa cloth, which is made from the paper mulberry, is a traditional home industry of economic importance to Tonga and with increased tourism, demand is increasing. All this intensification has increased pressures on land, and Manu *et al*. (2014) have shown that intensification resulted in a marked decline in soil carbon (C), wet aggregate stability and nutrient status.

Considerable research has been undertaken on mulching, particularly in temperate agriculture. Qin *et al*. (2015) examined the results from 74 experiments conducted in 19 countries and found that mulching increased average yields, water use efficiency and nitrogen (N) use efficiency by up to 60%, and that plastic mulch was more effective than straw mulch. In tropical areas, plastic mulch has not been so successful because of elevated soil temperatures (Manu *et al*., 2014).

Manu *et al*. (2017) found that a single application of 20 cm thick vegetative mulch was effective in increasing yields over three successive crops and suggested that addition of mulches could be a way to increase agricultural production and arrest the decline in the resource base.

Alley cropping has been attempted in many regions as a means of alleviating some of the negative pressures of land use intensification (Lefroy *et al*., 1994). Considerable research and extension activity has been devoted to the introduction of tree legumes in the alleys and using the tree loppings for animal feed or as a green manure. In some areas, such as the Pacific Islands, cash crops are used in the alley. One major disadvantage of alley cropping is that land is lost from food production both by the land taken up by the alley and through competition for light, water and nutrients (Paul *et al*., 2017).

There is still uncertainty about the type of mulch to use to reduce soil and water loss, and at the same time maintain or enhance crop yield. This will be influenced by soil type, slope, rainfall intensity, the materials available locally for use and their management.

Two experiments were conducted to evaluate the effect of mulch on the growth and yield of different types of indigenous and exotic crops of importance in Tongan agriculture. The first was conducted on sloping land to evaluate the effect of guinea grass mulch and hedgerows on taro (*Colocasia esculenta* (L.) Schott) yield, and in controlling soil erosion. The second compared the response of paper mulberry [*Broussonetia papyrifera* (L) Ventenot] to different management regimes of a grass fallow.

Materials and methods

Experiment 1

The experiment was carried out with taro (*C. esculenta* var Lau'ila) in the hill slope land area of Tele'a'uta (latitude $21^0 12.5'$ S, longitude $175^0 11.7'$ W, altitude 199 m) on the island of 'Eua. The soil is a Fa'itoka clay loam hill soil (*Typic Tropudalf*, halloysitic, isohyperthermic). The site had previously been under root crops for 3 yrs before it was fallowed for 3 yrs with mixed-grass vegetation. The soil pH was near neutral (6.8, 1:5 water), with 4.0% total C and 0.38% total N, 12 mg/kg 0.01 M H_2SO_4 extractable phosphorus (P which is locally classed as low and 16 mg/kg) KCl-40-extractable sulphur (S) (Blair *et al*., 1991) which is considered high.

The experiment consisted of three replications of four erosion control treatments: local farmer practice (control); 20 cm deep guinea grass, *Megathyrsus maximus* (grass mulch); perennial cash crop hedgerow (cash hedgerow); perennial leguminous hedgerow (legume hedgerow). The treatments were laid out in a randomised block design. The upper two replications were situated on a 9–10^0 slope while the third replication had a 13^0 slope. The 12 experimental plots, each 10 m wide and 20 m long, were marked out in June. The plots were manually weeded and the top and sides protected from water ingress by galvanised iron sheets 30 cm tall. A 10-m-long collection trough was cemented at the bottom of each plot, and a tipping bucket was installed at the centre of the trough with sampler tubes installed both sides of the tipping buckets to collect run-off and to measure soil loss. The soil in the collection trough and the volume of run-off were recorded weekly throughout the trial unless there was a major rainfall event when it was collected immediately afterwards.

Three 10 m wide and 1 m deep rows of the hedgerow treatments were planted across the slope above the relevant plots in December. A similar area above the control and grass mulch plots was kept bare. The four treatments were randomised across the slope. For the cash hedgerow treatment, single rows of sugar cane (*Saccharum officinarum* Linn. var Tohina), vanilla (*Vanilla fragrans* Andrews) and pineapple (*Ananas comosus* (L. Merill) var Fainatonga) were sown. For the legume hedgerow treatment, single rows of pitpit (*Stenolobium stans* L.), *Leucaena leucocephala* (Lam.) DeWit var Siale Mohe and *Flemingia macrophylla* were sown. The grass mulch was applied to a thickness of 20 cm on the whole of the relevant plots after planting and the control plots kept bare of mulch.

Mixed crops of taro and kava (*Piper methysticum* Forster f. var Kavakula) were planted into these plots between March and April. Taro headsets were manually planted into holes of 20 cm deep at a spacing of 100 cm between plants and 150 cm between rows. Kava was interplanted with three one-node basal stem cuttings between the taro plants.

All plots were manually weeded every 2 weeks and the legume hedgerows cut at 8–12 weekly intervals with the cuttings applied as mulch to the respective plot. A subsample of the soil in the collection trough and a 1 L subsample of run-off water was oven-dried at 105 °C. The combined amount of sediment and suspended soil loss was determined from the dry weight of soil from the trough and in the run-off samples multiplied by the volume of run-off.

The weather data were recorded at 15-min intervals and downloaded from the automatic weather station on a monthly basis. Rainfall varied considerably throughout both experimental periods and ranged from monthly totals of 12–483 mm (Figure 1).

The taro crop matured in May approximately 30 months after planting; 84 plants per plot were harvested and the number and weight of corms recorded. The kava crop continued to grow after the taro harvest and was not harvested until after this study had been completed.

Experiment 2

The experiment was conducted with paper mulberry (*Broussonetia papyrifera* var Laumahaehae) on a Vaini clay loam soil (*Typic Argiudolls*, very-fine, halloysitic, isohyperthermic) in paddock 47 in the Vaini Research Station of MAF Research and Extension Division on Tongatapu Island. The site had been under guinea grass for more than 10 yrs with occasional grazing by livestock. The site was still under mature guinea grass vegetation when the experiment commenced. The soil pH was near neutral (6.7, 1:5 H_2O) with 5.6% total C and 0.63% total N, 64 mg/kg 0.1 M H_2SO_4-extractable P which is locally classed as high and 11 mg/kg KCl-40-extractable S which is considered low.

The experiment consisted of four different management treatments of guinea grass fallow vegetation prior to cropping, namely bare soil control; surface mulching with the grass (mulch); burning of the grass with ash retained on the surface (grass ash); incorporation of grass into the surface soil (grass incorporated). The four treatments were replicated five times and arranged in a randomised block design. The control and grass incorporated treatments were disc ploughed three times before sowing within a 5-week period.

Root cuttings of paper mulberry were used as planting material. They were dug 1 day before planting and stored under shade. The mulberry root cuttings were planted in May, at a spacing of 140 cm between rows and 100 cm between plants. In each plot, there were six rows of 12 plants per row. The experiment was manually weeded every 20 days. The mulberry plants were pruned weekly by removing the young side shoots from the stems so that when the crop matured, it consisted of long-stemmed plants about 2–4 m high with uniform continuous bark. The experiment was harvested after growing for 30 months when 40 plants per plot were cut, and the number of large and small stems recorded. The bark was stripped from the plant and the outer skin layer of the bark was also removed. The length and the width at both ends of the bark strip were measured, and the area of the bark strip was estimated using equation (1). The sum of the bark area per plot was evaluated by multiplying the number of stems harvested with the area of bark strip harvested.

$$\text{Bark strip area} = a(b + c)/2 \tag{1}$$

where, a = length and b, c = width of the bark strip at the ends

Large strips are those larger than 0.10 m^2 and small <0.10 m^2. The average area of large bark strips harvested was 0.1191 ± 0.002 m^2 and small 0.0745 ± 0.0018 m^2.

Comparative economic analysis

In all experiments, the costs used to calculate net profit were: compost T$1.20/kg, tractor service T$100.00/h and labour T$6.00/h (Currency Tongan Pa'anga, T$ = US$0.44).

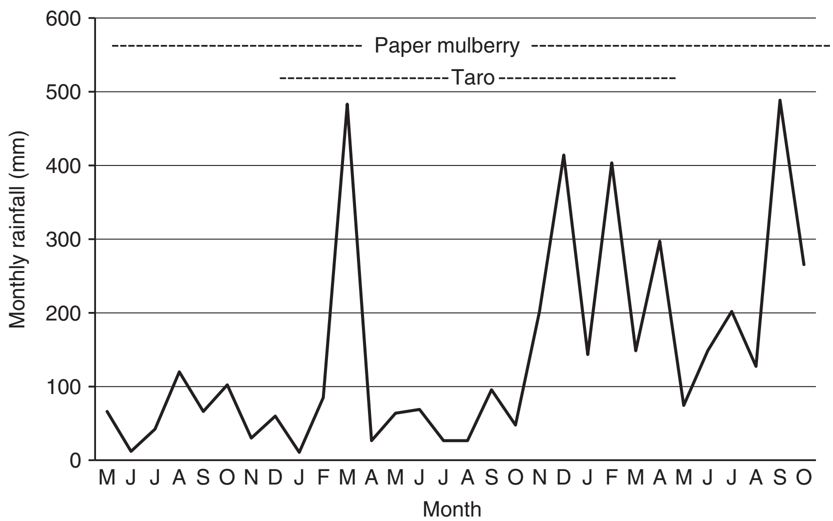

Figure 1 Monthly rainfall totals received and crop growing times throughout the experimental period.

Market prices used were: taro T$1.50/kg, and T$4.00/kg and T$1.00/kg for large and small mulberry bark strip, respectively. Common costs across treatments were not taken into account as comparisons were relative to the control treatment.

Statistical analysis

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

Results

Experiment 1

Crop yield. The climate during the experiment was very dry with low rainfall from April to October. The mean fresh corm yield of taro was significantly higher, by 1.4–3.5 times, in the mulch treatment than in the control and both hedgerow treatments (Table 1).

The corm yield in the control was also significantly higher than the yield in the hedgerow treatments. The mean taro corm weight in the mulch treatment was approximately twice as heavy as that in the two hedgerow treatments. There was no significant difference in taro yield between the two hedgerow treatments. The mean corm weight in the control treatment was not significantly different from the mulch treatment or the hedgerow treatments (Table 1).

Run-off and soil loss. The total amount of soil loss in the farmer practice control treatment was significantly higher by 24–54%, than in the grass mulch and the two hedgerow treatments (Table 2). The amount of soil loss in the legume hedgerow treatment was significantly higher than in both the grass mulch and the cash hedgerow treatments. There was no significant difference between the treatments in the volume of surface run-off (Table 1).

Table 1 Fresh corm yield of taro, soil loss and run-off and comparative economic analysis from plots intercropped with kava grown on the hillslopes on ‘Eua Island. Numbers within a column followed by the same letter are not significantly different according to Duncan’s Multiple Range Test (DMRT) at $P = 0.05$

	Treatment			
Parameter	Control	Grass mulch	Cash hedgerow	Legume hedgerow
Corm yield (t/ha)	5.53 b	7.97 a	2.33 c	2.95 c
Corm weight (g/corm)	848 ab	1150 a	518 b	577 b
Gross income (T$/ha)	8295	11 955	3495	4425
Hedgerow income (T$/ha)	0	6000	4000	4000
Treatment costs (T$/ha)	0	6000	4000	4000
Weeding cost (T$/ha)	5000	0	4000	4000
Net profit (T$/ha)	3295	5955	910	−2075
Soil loss (t/ha/yr)	1.43 a	0.71 c	0.65 c	1.09 b
Surface water run-off (L/ha/yr)	432 ns	524	376	494

Market price taro = T$1.50/kg, tractor service T$100/h and labour T$6/h.

Comparative economic analysis. The comparative economic analysis of the input costs and returns of treatments resulted in higher net profit for the grass mulch treatment. The treatment cost was highest for the mulch treatments, but the weeding cost was very much reduced. As a result, the net profit for the mulch treatment was 81% higher than the farmer practice control and three to five times the profit of the hedgerow treatments. Both the hedgerow treatments had low gross income and a high treatment cost, which resulted in a net loss.

Experiment 2

Crop yield. The growth of the paper mulberry plants during the 30 months of the experiment was limited by the low rainfall periods in the first year and by excessive rainfall in the second. The effect of the treatments on bark yield was highly significant (Table 2) with the yield 15–31% higher in

Table 2 The effect of management of the grass fallow on the bark yield and net profit of paper mulberry. Numbers within a column followed by the same letter are not significantly different according to Duncan’s Multiple Range Test (DMRT) at $P = 0.05$

Treatment	Bark yield (m^2/ha)	Bark size ratio (large/small)	Stem number/plant	Gross income (T$/ha)	Treatment cost (T$/ha)	Weeding cost (T$/ha)	Net profit (T$/ha)
Bare soil control	2209	1.88 a	3.44 bc	45 892	0	5000	40 892
Grass mulch	2817	2.07 a	4.43 a	60 000	6000	1000	53 000
Grass ash	2441	1.97 a	3.81 b	51 132	0	5000	46 132
Grass incorporated	2135	1.45 b	3.22 c	47 024	800	5000	41 224

Market price bark strip = T$4.00 for large bark and T$1.00 for small bark, labour T$6/h, disc plough = T$100/h.

the grass mulch treatment compared to the other treatments. The bark yield in the grass ash treatment was significantly higher than the grass incorporated treatment and the bare soil control treatment. The ratio of the number of large/small bark strips was significantly smaller in the grass incorporated treatment than the other treatments. This is important because the market price for the large bark strip is four times the price for the small ones.

The number of stems harvested per plant in the grass mulch treatment was also significantly higher ($P < 0.05$) than in the other treatments indicating that the increased bark yield of paper mulberry in this treatment was largely due to production of a higher numbers of stems per plant.

Comparative economic analysis. The comparative economic analysis of the input costs and return of the treatments showed a higher net profit for the grass mulch treatment (Table 2). The treatment cost was highest for the grass mulch treatment, but the weeding cost during the first 18 months was very much reduced. As a result, the net profit for the grass mulch treatment was 30% higher (T$12 108/ha) than the bare soil control.

Discussion

Crop yields

This research has shown that thick vegetative mulch increased yields and profitability of two diverse crops whose growth periods ranged from 18 months (taro) to 30 months (paper mulberry). Thick vegetative mulch increased taro corm yield by 44% despite the dry climate, and it also increased the paper mulberry bark yield by 28%, despite two dry periods in the 30 months of the experiment.

This is in contrast to the results of Rogers *et al*. (1992) who found no significant difference in taro corm yield following mulching with 30 t/ha of *Calliandra calothyrsus* applied three times throughout the growth of the crop. The Rogers *et al*. (1992) experiment was conducted at the beginning of the rainy season (3000 mm/yr), and soil moisture was not limiting. The split application of the fast decomposing *Calliandra* they used maintained surface cover which would not have happened with a single application. Tian *et al*. (1993) reported that in Nigeria, only slow decomposing plant residues had a lasting effect, which resulted in enhanced crop yields through their effect on soil microclimate. In the Philippines, Escalada & Ratilla (1998) found that 7.3 t/ha of *Leucaena* biomass supplemented with P and potassium (K) fertilisers increased taro corm yields in three consecutive crops. The guinea grass mulch used in the present study maintained cover throughout the experimental period.

The smaller taro corm yield in both the hedgerow treatments measured in the present study is consistent with other agroforestry research results in the South Pacific region reviewed by Manu & Halavatau (1995). Various reasons postulated for the lower crop yield in the hedgerow alley are shading effects and competition between the crops with the hedgerow for nutrients and water, which was exacerbated in drier seasons.

Soil erosion and surface run-off

In the present study, the 20 cm thick grass mulch reduced soil loss 50% compared to local farmer practice, and the soil loss from the mulched treatments was comparable to that from the hedgerow treatments. No effect of mulch on the volume of surface run-off was measured. This was mainly due to the erroneous and highly variable number of tips (10 L/tip) of the tipping bucket recorded during hurricanes or near hurricane strong winds. Although the tipping bucket had a protective wall on three sides, strong winds still managed to tip the bucket without run-off. However, as the raindrops during these hurricanes were the most erosive due to their high impact kinetic energy, it is difficult to correct or to ignore these recorded tipping buckets counts. Because of this, the volume of run-off recorded did not correlate with soil loss or rainfall.

The results in the present study are similar to those in several previous studies. Nill & Nill (1993) found mulching with 13 t/ha of guinea grass providing 100% cover resulted in no run-off and no soil loss, and after 1 yr, the guinea grass decomposed to 50% cover. Kukal *et al*. (1993) reported that with 4 t/ha mulch, maize yield increased, run-off was reduced by 58% and soil loss reduced by 72%. By contrast, *Leucaena* hedgerows decreased maize yield, but also reduced run-off and soil loss. Barton *et al*. (1998) found mulching with 4 t/ha rice straw resulted in 19.2–71.4% less soil loss in maize plots relative to the conventionally tilled control and inter-row plastic mulch plots. Paningbatan (1987) reported results from the Philippines showing that mulching with 5 t/ha of dry *Leucaena* loppings reduced soil loss and run-off by 39–93%, and with retention of crop residues, losses were reduced by 68–98%. Maize yield was increased by 42–284%. Shock *et al*. (1997) reported that 0.9 t straw/ha applied to irrigation furrows substantially reduced soil erosion by 95%, run-off by 43%, N losses by at least 50% and 15-fold for P losses in sediment.

The results of the present study show that maintaining the vegetative mulch on the surface, rather than burning or incorporating, it has the greatest benefit. The importance of choosing the correct mulch is demonstrated by the results of Sutrisno *et al*. (1994) in Indonesia who found that run-off was reduced from 13% of incident rainfall without mulch to 3% where *Flemingia macrophylla* mulch was applied at 2 t/ha and soil loss was reduced from 15.8 to 1.0 t/ha. By contrast, rice straw mulch increased infiltration under low-intensity rainfall but increased run-off above the no mulch control under high-intensity rainfall because the straw acted as a water-shedding thatch.

Whitbread *et al*. (2017) reported that in terms of rice grain production and nutrient use efficiency, leaf litter quality was an important driver. In the initial years of the trial, grain yield was increased in the range of 364–670 kg/ha relative to the no leaf litter control in treatments with higher quality leaf litters; however, this effect decreased with each successive season until the 6th season, where all leaf litter treatments yielded similarly and significantly more than the no leaf litter control.

Comparative economics of mulch

Rarely are the benefit/cost relationships considered in publications relating to mulch. The comparative economic analysis undertaken in this study showed a higher net profit with mulch than the non-mulched controls of T$ 1400/ha for taro and T$ 7054/ha for paper mulberry. They also showed that incorporating or burning the grass mulch decreased net profitability. The results also highlighted the lower net profit when alleys were established.

A similar increase in net income was found in a study undertaken in Himalaya, India, by Mishra & Rai (2014) where the net benefit from vegetative barriers was US$ 627 compared to US$2113 with vegetative mulch.

Considering the accessibility and availability of guinea grass mulch to farmers in Tonga, it is recommended as a sustainable practice for local crop production. In other parts of the world, where excess vegetative material is available, similar results would be expected.

Conclusions

In agricultural areas of the world where excess vegetation accumulates in fallows, or in the non-cropping season, utilising this material or cuttings from alley crops as surface mulch offers crop production gains and erosion management.

The experiments reported here have shown increased crop yields and profitability from the use of grass mulch in two diverse crops. Its use has also been shown to reduce soil loss from sloping land to approximately half that from the non-mulched plots.

With increased mechanisation that is occurring throughout the developing world, the collection and management of residues become more feasible and such practices should be promoted in vulnerable areas.

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