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Digestive characteristics, rumen ammonia nitrogen and volatile fatty acids levels in sheep fed commercial pellets supplemented with grimmett barley grain or freeze-dried or fresh barley sprouts

Dachung D. Dung[1,2], Ian R. Godwin[1] & John V. Nolan[1]

ABSTRACT

Commercial concentrate pellets for ruminants were fed to sheep, supplemented with four different treatments of barley as control, barley grain, freeze-dried barley sprouts and fresh barley sprouts in a 4 x 4 Latin Square design. The study was conducted to compare the effect of barley grain and sprouts on production parameters. Results showed no difference ($P>0.05$) in average daily DM intake due to the feeding of sprouts supplements in comparison to the control. Supplementing with fresh barley sprouts also did not differ in average daily DM intake from barley grain. Supplementation with barley grain gave a higher ($P<0.01$) total VFA concentration than the fresh barley sprouts but not different from freeze-dried barley sprouts. Barley grain and freeze-dried barley sprouts supplementation gave a higher ($P<0.01$) lipogenic to glucogenic ratio than the fresh barley sprouts supplementation. The pH values recorded did not differ ($P>0.05$) among treatments. Rumen ammonia concentration also did not differ ($P>0.05$) among treatments in the current study. It can be concluded from this study that when diets high in nutrients are fed to livestock, there is no advantage of supplementing with hydroponic barley sprouts. There were no clear performance benefits from the hydroponic barley sprouts supplementation.

Key words: Pellets, barley, sprouts, rumen, digestive characteristics.

INTRODUCTION

Sprouting of grain brings about enzymatic activities that lead to inter-conversions of the stored nutrients in the endosperm of seeds as well as the release of simpler compounds from the breakdown of the stored compounds (Chavan & Kadam, 1989). Starch is broken down to sugars, proteins to amino acids and lipids to free fatty acids. The inter-conversions normally lead to increases in the concentrations of some vitamins to levels higher than prior to sprouting (Chavan & Kadam, 1989; Cuddeford, 1989).

The quality of proteins especially in cereals is known to improve with sprouting. The conversion of lysine deficient proteins like prolamins into albumins and globulins usually increases the lysine content and hence quality of the proteins (Chavan & Kadam, 1989).

Dung *et al.* (2010) reported a significant increase in voluntary intake (TDMI), nitrogen balance, mean rumen ammonia concentration and total VFA concentration with inclusion of sprouted barley treatments in a basal diet of oaten chaff. These increases were recorded on a low protein basal diet (8.1 % CP). Reports in the literature (Thomas & Reddy, 1962; Tudor *et al.,* 2003) have indicated that when adequate nutrition is provided, the effect of sprouts supplementation does not elicit any improvement in performance due to the fact that the animal requirements would have been met already. A report in favour of noticeable improvement in yield parameters as a result of feeding hydroponic barley sprouts (Grigor'ev *et al.,* 1986) indicated an increase in milk yield due to feeding of hydroponic barley sprouts as a supplement.

The current study was designed to feed a diet high in nutrients (commercial pellets) to the sheep with the view of observing any improvement in parameters associated with the supplementation of hydroponic barley sprouts purported to give increased performance.

MATERIALS AND METHODS

Animals and housing

Four Merino sheep (initial weight of 49.6 ± 7.4 kg) were housed in individual pens in an animal house. Each was fitted with a permanent rumen cannula.

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Diets and feeding

The four fistulated sheep above were given commercial pellets *ad libitum,* daily, and the voluntary intake determined over a period of 14 days in individual pens. After this period, the sheep were subjected to four different treatments in a Latin Square design. During the treatment phase there was a 7-day total urine and faecal collection (in metabolism cages) and also sampling of rumen fluid. Between treatment phases, there was an adjustment period of 14 days before collection of samples. The apparent digestibility of DM, OM, and N retention were determined. The rumen fluid profile of VFA (molar proportions and total concentration), and rumen ammonia in the four treatments were determined.

Analytical methods and calculations

(a) Estimation of microbial N supply

Purine derivative (allantoin) conversion to microbial outflow was determined as follows:

Microbial N supply for sheep was calculated based on the equation by Chen & Gomes (1995), briefly described below.

$$Y = (0.150\ ^{W0.75}\ e^{-0.25X}) + 0.84X$$

Where:
Y = Purine derivative excretion in the urine;
X = Exogenous purines

(b) Dry matter, organic matter and ash

The DM content of feed, refusals and faeces was estimated by drying samples in triplicate from each animal in each period in a forced draught oven at 60 ^{0}C for a minimum of 72 h, or until constant weight was achieved. Thereafter, the samples were bulked and milled in a Wiley Mill to pass through 1 mm screen, and dried overnight in crucibles at 105 ^{0}C to determine the final DM content. The DM was then combusted in a muffle furnace at 600 ^{0}C for 4 h to determine both the organic matter and ash content (AOAC, 1990).

(c) Total N

The total N content in the feed ingredients, feed refusals, faeces and urine was determined using the automated semi MicroKjeldahl system (AOAC, 1990).

(d) Ammonia N

The concentration of ammonia N in the rumen fluid supernatant was estimated using an autoanalyser (Technicon) according to the method described by Beitz (1974).

The proportion of un-ionised ammonia in the total ammonia concentration was calculated using the Henderson-Hasselbalch equation (Siddons *et al*., 1985) taking into account total ammonia concentration and rumen fluid pH.

(e) Volatile fatty acids.

The total molar concentration (mmol/l) of all VFAs, and molar percentages of major

Un-ionised [NH3] = 1-(1/ (1 + antilog [pH-pK'a]
Where: pK'a = 9.02

VFA (acetic, propionic and butyric) and minor VFA (iso-butyric, iso-valeric and valeric) were estimated in the rumen fluid supernatants by methods of Erwin *et al*. (1961), using gas liquid chromatography (GLC) (Model CP 3800GC), and iso-caproic acid as an internal standard. The ratio of lipogenic to glucogenic VFA were determined as described by Maas *et al*. (2001).

Experimental design and statistical analysis

Four Merino sheep fitted with permanent rumen cannulae were used for a 4 x 4 Latin Square design. The Latin Square design (Steel & Torrie, 1980) of four treatments and four periods was used for the assessment of the three barley treatments (grain, freeze-dried and fresh hydroponic barley sprouts) and a control. The data were analysed using the analysis of variance (ANOVA) and treatment means compared using pair-wise comparisons at 5 % level of probability (Duncan's LSD).

Minitab 12.1 software was used for data analyses. Intake and digestibility data were analysed using the one-way analysis of variance while the general linear model (GLM) was used in repeated measures analysis for data repeated over time (ruminal pH, ammonia and VFA concentrations).

RESULTS

Feed DM intake, apparent DM and OM digestibility and nitrogen retention

The mean daily DMI, DM and OM digestibility and N retention are presented in Table 1. The pattern of feed DMI did not follow an expected trend based on supplements' CP content and supplementation of barley grain or sprouts. The commercial feed pellets given were high in nutrients.

The treatment supplemented with barley grain had the highest DMI, followed by the fresh barley sprouts supplementation, and

Table 1. Total DMI, DM and OM digestibility, nitrogen balance and microbial outflow in sheep fed concentrate pellets (T1), T1 + barley grain (T2), T1 + freeze-dried barley sprouts (T3), T1 + fresh barley sprouts (T4).

Component	T1	T2	T3	T4	Significance
Total DMI g/d	1297.0[a]	1401.8[b]	1276.7[a]	1340.3[ab]	**
Total DMI g/kg $W^{0.75}d^{-1}$	67.2[a]	73.0[b]	66.8[a]	71.7[b]	**
DM digestibility, %	56.5	60.1	58.4	58.5	NS
OM digestibility, %	54.3	58.1	55.5	55.9	NS
Total N intake, g/d	25	28.2	27.3	27.3	NS
Fecal N, g/d	10.3	10.7	10.4	10.5	NS
Urine N, g/d	7.6	7.5	8.3	7.2	NS
Nitrogen balance, g/d	7	10	9.1	9.6	NS
Microbial outflow, g/d	7.8	8.1	8.9	8.3	NS

** ($P<0.01$), NS = not significantly different.
Means with different superscripts, a, b, c within the same row differ significantly ($P<0.01$).

then the unsupplemented treatment and finally the freeze-dried hydroponic barley sprout supplementation. The barley grain supplementation gave a higher ($P<0.01$) DMI than both the unsupplemented treatment and the supplementation using freeze-dried barley sprouts. Barley grain supplementation, however, did not give a higher ($P>0.05$) DMI than the fresh barley sprouts supplementation, though the values tended to be higher. Generally, the intake values were higher than reported by the current authors (Dung *et al.,* 2010), when the basal diet was oaten chaff.

A similar pattern of intake occurred when DMI was considered on the basis of metabolic weights of the sheep used in the trial.

The DM and OM digestibility did not differ among the four treatments, so also the N balance. The DM digestibility varied from 56.5 % for the pellets only diet to 60.1 % for the barley grain supplemented treatment. The OM digestibility varied from 54.3 % to 58.1 % for unsupplemented pellets and barley grain supplementation, respectively. The N balance varied from 7.0 g/d for the unsupplemented pellets to 10.0 g/d for the barley grain supplementation.

In all the parameters listed in Table 1, the treatment supplemented with barley grain had the highest values recorded for both the significant and non-significant means, except for microbial outflow.

Total VFA concentrations, VFA proportions and pH in rumen fluid

There was no observed time x treatment interaction among treatments for total VFA concentration as well as VFA proportions due to type of supplements given. Total VFA concentrations were different ($P<0.01$) due to supplementation of different types of barley to the pellet diet as shown in Table 2 and Figure 1. The highest total VFA concentration was recorded for the barley grain supplementation which was higher ($P<0.01$) than the unsupplemented pellets (control) and the fresh hydroponic barley sprouts supplementation. The barley grain supplementation, however, did not differ ($P>0.05$) from the freeze-dried hydroponic sprouts supplementation in total VFA production. It is likely that the barley grain supplementation encouraged the amylolytic bacterial population noted for fermentation of high grain concentrates.

The mean acetic acid proportion did not differ ($P<0.01$) due to supplementation type imposed on the basal diet of commercial pellets used in the trial. This is presented in Table 2. The molar proportions of acetic acid varied from 57.5 % for the barley grain supplemented treatment to 63.1 % for the fresh hydroponic sprouts supplementation.

The molar proportions of propionic acid differed ($P<0.001$) as a response to the different supplementations given (Table 2). The highest propionate proportion was recorded for freeze-dried barley sprouts supplementation which was higher ($P<0.001$) than the fresh hydroponic barley-supplemented treatment. The freeze-dried barley supplemented treatment was however not higher ($P>0.05$) than the control or the barley grain-supplemented diets. The fresh barley sprouts-supplemented diet had the lowest figure for propionic acid proportion in the rumen fluid.

Table 2. Concentrations of rumen fluid ammonia and VFA, molar proportions of VFA and rumen pH of sheep fed concentrate pellets (T1), T1 + barley grain (T2), T1 + freeze-dried barley sprouts (T3), T1 + fresh barley sprouts (T4).

Components	T1	T2	T3	T4	SEM	Significance
Ammonia concentration (mg N/L)	77.0^{a}	87.1^{a}	86.6^{a}	119.1^{b}	28.2	**
Non-ionised NH3-N (mg N/L)	0.13	0.29	0.09	0.13	0.39	NS
Total VFA concentration (m mol/L)	105.9^{a}	125.6^{b}	119^{ab}	105^{a}	17.5	**
Acetic, %	61.4^{ab}	57.5^{a}	59.3^{ab}	63.1^{b}	4.0	**
Propionic, %	23.2^{ab}	26.4^{bc}	28.9^{c}	20.4^{a}	3.4	***
Butyric, %	11.8^{b}	12.2^{b}	8.6^{a}	12.3^{b}	2.9	**
Minor VFA, %$^{+}$	3.6^{ab}	3.8^{ab}	3.1^{a}	4.2^{b}	0.96	*
Glucogenic VFA, %$^{++}$	26.8^{a}	30.3^{b}	32.0^{b}	24.6^{a}	3.6	**
Lipogenic VFA,%$^{+++}$	73.2^{b}	69.7^{a}	68.0^{a}	75.4^{b}	3.6	**
Glucogenic:Lipogenic VFA	0.4^{b}	0.5^{c}	0.5^{c}	0.3^{a}	0.08	**
pH	5.8	5.6	5.7	5.7	0.2	NS

$^{+}$Sum of isobutyric, isovaleric and valeric
$^{++}$Sum of propionic, isobutyric, isovaleric and valeric
$^{+++}$Sum of acetic and butyric
*(P,0.05), **(P<0.01), ***(P<0.001), NS = Not significantly different (P>0.05)
Means with different superscripts, a, b, c within the same row differ significantly

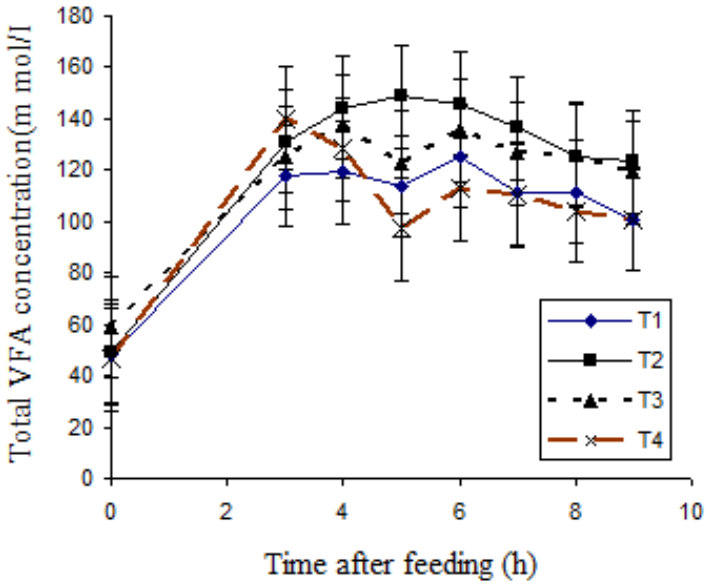

Figure 1. Total VFA concentration in rumen fluid of sheep fed concentrate pellets (T1), concentrate pellets + barley grain (T2), concentrate pellets + freeze-dried barley sprouts (T3), and concentrate pellets + fresh barley sprouts (T4).

Butyric acid proportion differed (P<0.01) among the treatments (Table 2). The freeze-dried hydroponic barley produced the least proportion of butyric acid and this was different (P<0.01) from the other three treatments in the trial (pellets only, pellets + barley grain, and pellets + fresh hydroponic barley sprouts); these three, however, did not differ from one another.

The proportion of minor VFA (isobutyric, isovaleric and valeric) in the rumen fluid of sheep fed the four treatments in Table 2 differed (P<0.05). The highest proportion of minor VFA was recorded for the fresh hydroponic barley sprouts supplementation and this differed (P<0.05) from the freeze-dried hydroponic barley treatment but did not differ for the control, or barley grain supplementation to pellets diets.

The mean concentration of glucogenic VFA differed (P<0.01) among the four treatments (Table 2). The lowest concentration of 24.6 % was recorded for pellets supplemented with fresh hydroponic barley sprouts

and this was lower (P<0.01) than the values for the diet supplemented with freeze-dried barley sprouts. The mean values for glucogenic VFA for pellets only and barley grain supplementation of pellets were, however, not different from the fresh barley sprouts supplementation although the latter two treatments tended to be higher. Treatments that give a good supply of glucogenic VFA are desirable because of the higher efficiency of energy supply associated with it.

Lipogenic VFA concentration differed (P<0.01) among the four treatments (Table 2). The fresh barley sprouts supplementation of pellets gave rise to a higher (P<0.01) concentration of lipogenic VFA above the other treatments; the three treatments did not differ from one another.

The ratio of glucogenic to lipogenic VFA differed (P<0.01) among the treatments (Table 2). The fresh barley sprouts supplement brought about the least ratio of glucogenic to lipogenic VFA and was lower (P<0.01) than the freeze-dried barley and barley grain supplementation. It was, however, not different from the control diet treatment.

The pH values shown in Table 2 did not differ (P>0.05) due to the different treatments, though the treatment with the highest pellets intake tended to be slightly more acidic. Generally, the pH values were considered extremely low. They were at the lower end of the range conducive for rumen microbes (pH 5.5 to 7.5).

Ammonia concentration in rumen fluid

There was no time x treatment interaction for ruminal ammonia concentration. The mean rumen fluid ammonia concentration due to supplementation of barley grain, freeze-dried barley sprouts, and fresh hydroponic barley sprouts are presented in Table 2 while the profile of ammonia concentration in the rumen fluid is presented in Figure 2.

The mean rumen fluid ammonia concentration in Table 2 differed (P<0.01) due to type of supplementation given on the pellets used in the current study. The fresh barley sprouts supplementation gave the highest (119 mmol/l) mean ammonia concentration in the rumen fluid of sheep used in the current study; this value was higher (P<0.01) than the control diet but not different from the supplementation using barley grain or freeze-dried hydroponic barley sprouts.

The trend of rumen fluid ammonia concentration as shown in Figure 2 portrays a similar trend for three of the treatments (pellets only, freeze-dried barley and barley grain supplementation) which differed from the fresh barley sprouts supplementation. The fresh barley sprouts supplementation gave rise to a sharp increase in rumen ammonia concentration from 3 – 5 h after feeding then

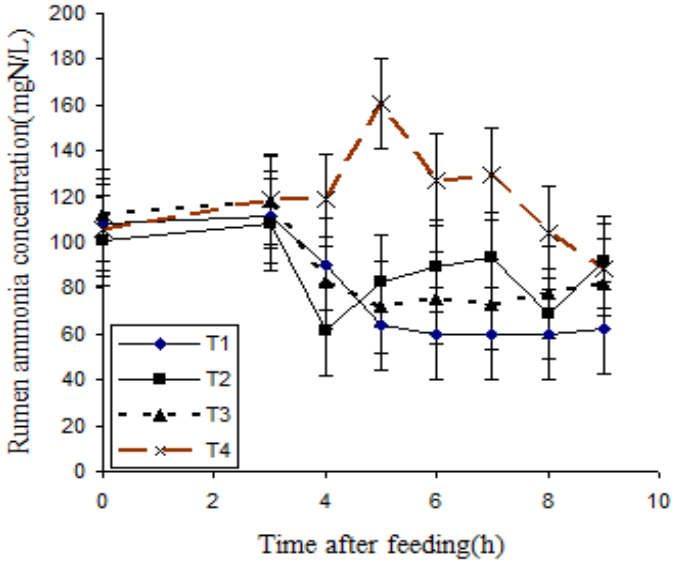

Figure 2. Total ammonia concentration in rumen fluid of sheep fed concentrate pellets (T1), concentrate pellets + barley grain (T2), concentrate pellets + freeze-dried barley sprouts (T3), and concentrate pellets + fresh barley sprouts (T4).

dropping sharply from 5 – 6 h after feeding before ending in a gradual decline till 9 h post feeding. The other treatments with a similar trend had a rapid decline in rumen fluid ammonia concentration between 3 – 5 h post feeding then stabilised to near constant levels from about 5 – 9 h post feeding.

Rumen bacterial outflow

The rumen bacterial outflow did not differ as a result of supplementation given to the sheep in this study. The treatments with sprouts supplementation were numerically higher than the treatments without sprouts, albeit not significantly so. The microbial outflow values in the current study were generally higher than the study by the authors using oaten chaff as basal diet (Dung *et al.,* 2010).

DISCUSSION

Feed DM intake, apparent DM and OM digestibility and nitrogen retention

There was no definite pattern of feed intake as a response to supplementation given to the sheep used in the current study. Only the grain supplemented sheep had a higher ($P<0.01$) average daily DMI than the control (pellets only), (Table 1). The treatments with supplementation using a higher CP content (sprouts supplementation) did not generate a better response than the control.

Intake of low-quality forage increases with protein supplementation (McCollum & Galyean, 1985; Beaty *et al.,* 1994; Krehbiel *et al.,* 1998). However, others (Ferrell *et al.,* 1999; Swanson *et al.,* 2000; Bohnert *et al.,* 2002) have reported no difference in forage intake when ruminants fed low-quality forages were supplemented with protein. Swanson *et al*. (2000) reported that forage intake by mature ewes fed a forage containing 6.7 % CP did not increase in response to supplemental protein. They were of the view that the 49 g/d digestible intake protein from the forage offered the control ewes might have been adequate for maintaining ruminal fermentation and therefore no DM intake resulted from additional CP. A similar result was obtained with lambs when CP supplementation was given to a forage diet containing 7.5 % CP (Salisbury *et al.,* 2004).

The CP content in the commercial pellets fed to the sheep in the current study was higher (12 % CP) than those in the preceding reports, and therefore would have supported adequate ruminal fermentation by the microbes.

The barley grain supplementation tended to give a numerically higher DM intake than the fresh barley sprouts supplementation which was however, not significant. The fresh sprouts supplementation likely gave more gut fill due to the fluid enclosed in the cells of the sprouts making it take more volume of rumen space. Each animal fed fresh barley sprouts in the current study had 500 g fresh sprouts daily. The time taken to ferment the sprouts and clear that space in the rumen needs to be considered compared to the time taken to clear the barley grain. The pellets used in the current study had a high grain component that favoured rapid fermentation in the rumen. The barley grain supplement likely encouraged rapid fermentation and greater intakes comparatively.

When the supplements used in this study were compared on the basis of metabolic weight of animal, the barley grain supplement gave the highest intake.

The DM and OM digestibility did not differ ($P>0.05$) among the treatment means of the supplements offered in this study, although barley grain supplementation tended to be higher numerically. The composition of the total feed ingested which were about 90 % pellets for all the treatments would not have varied enough to cause a noticeable difference in digestibility of OM and DM.

Total VFA concentrations, VFA proportions and pH in rumen fluid

The values of VFA reported in this study are similar to those of Susin *et al*., (1995) on a high-grain diet fed to ewes. The results in the current study showed differences in mean VFA concentrations among treatment means due to supplementation, but the interaction of time x treatment was not noticed for any of the rumen fluid parameters measured.

Barley grain supplementation gave the highest total VFA concentration among the treatments. It was higher ($P<0.01$) than the fresh barley sprouts supplementation and the control but not different from the freeze-dried barley sprouts supplementation. More degradable starch tends to decrease rumen pH, increase rumen VFA production and decrease rumen ammonia concentration (Cabrita *et al.*, 2006).The commercial pellets used in this study were high in grain concentrate, therefore addition of barley grain supplement would

have given rise to greater VFA production. Barley grain is noted for high rates of DM and starch degradabilities in the rumen (Herrera-Saldana *et al.,* 1990; Zinn, 1993) and diets based on barley grain increase microbial protein synthesis (Zinn, 1993) and produce a high level of fermentation and lower pH in the rumen immediately after feeding (McAllister *et al.,* 1990; Yang *et al.,* 1997). The high mean daily DMI recorded for the barley grain supplementation (Table 1) would have favoured greater VFA production above the other treatments under the conducive pH mentioned earlier. From Figure 2, the sharp decrease in rumen ammonia levels is likely a result of its usage in protein synthesis stimulated by the presence of a high VFA level. This corroborates the report by Cabrita *et al*. (2006).

The fresh sprouts supplements which had a higher CP content than the barley grain also had readily available sugars, but this did not favour as much VFA production as the barley grain supplement. The likely reason being the time taken to dislodge the cell contents in the sprouts and also the time taken for degradation and outflow of the whole sprouts to create space in the rumen for more intake of the commercial pellets.

The proportion of acetic acid (percentage of total VFA) differed ($P<0.01$) among the treatment means as a result of the supplementation given. Acetic acid constituted the largest molar proportion VFA in the rumen fluid. Acetic acid is lipogenic and formation of lipogenic VFA in large concentrations is mainly from high fibre diets with slow rates of fermentation. Sutton *et al.* (2003) reported a shift in fermentation pattern from high acetate to high propionate on low roughage rations. In the current study, the fresh sprouts supplement had the highest acetate proportion albeit only different ($P<0.01$) from barley grain supplementation.

Propionic acid differed ($P<0.01$) among treatment means due to type of supplementation. Rumen propionate levels increase rapidly on a high grain diet (Susin *et al.,* 1995; Russell, 1998) as was the case in this study. The freeze-dried barley supplement gave the highest propionate proportion although it differed ($P<0.01$) only from the fresh barley sprout supplementation. An inter-play of intake, diet and microbial population as affected by pH would likely have caused the variation. It is believed the high intake rates of the pellets (high in grain) gave rise to proportionately higher levels of readily fermentable carbohydrates which favoured higher levels of incorporation into microbial protein, in the presence of the adequate ammonia N (Stern & Hoover, 1979). Rapid fermentation rates are usually associated with high propionate production.

Butyric acid proportions differed ($P<0.01$) among treatment means due to effect of supplementation. The freeze-dried barley supplement gave the lowest which differed ($P>0.05$) from all the other treatments. Butyric acid is lipogenic but the diet in this study favoured glucogenic precursors because of the high grain nature. High ruminal concentration of butyrate is known to have an adverse effect on glucose production and lactate synthesis (Miettinen & Huhtanen, 1996), so the treatment that favours that is likely to bring about low efficiency of production. It appears the interaction of microbial type, pH and diet intake did have a strong bearing on butyrate concentration as to bring much difference due to supplementation.

The minor VFA (isobutyric, isovaleric and valeric) differed ($P<0.05$) in response to supplementation given. The freeze-dried sprout supplement had the lowest mean value for minor VFA concentration which was different from fresh barley sprouts supplementation but not different from the other treatments. The minor VFA are glucogenic and high levels are encouraged except for isovaleric and valeric VFA. These can be formed from protein fermentation (Davidson *et al.,* 2003) and could be an inefficient way of energy supply.

Glucogenic VFA normally increase in concentration when a high concentration of grains are fed with an accompanying high bacterial population and activity (Cheng & Hironaka, 1973; Jouany *et al.,* 1998; Hristov *et al.,* 2001). In the current study, the freeze-dried barley sprouts supplementation had the highest glucogenic VFA concentration in the rumen fluid. It was higher ($P<0.05$) than the fresh barley sprouts supplementation only. The barley grain supplementation tended to be higher than the fresh barley sprouts and the control treatments but the differences were not significant. Production of high levels of glucogenic VFA is desirable because of their higher energy efficiency (Preston & Leng, 1987). *In vivo*, the flow of total and bacterial protein to the intestines has been correlated

with the molar percentage of propionic acid in the rumen fluid (Ishaque *et al.,* 1971; Jackson *et al.,* 1971).

There were differences in the concentration of lipogenic VFA in the current study, due to the different supplements used. The fresh barley sprouts supplements gave the highest lipogenic VFA concentration which differed ($P<0.05$) from all the other treatments. Lipogenic VFA production can have adverse effects on the more energy-efficient glucogenic VFA; reports by Miettinen & Huhtanen (1996) showed that high ruminal butyrate production can have adverse effects on glucose production and lactose synthesis. The glucogenic VFA is usually encouraged especially in high-yielding dairy cows by manipulation of fermentation characteristics (Vanhatalo *et al.,* 2003).

The lipogenic to glucogenic ratio differed ($P<0.01$) among the means of the treatments in the current study. The barley grain and freeze-dried barley sprouts supplements had the best lipogenic to glucogenic VFA ratio and both were higher ($P<0.01$) than the fresh barley sprouts supplement. They were, however, not higher ($P<0.01$) than the control. The treatments with the best glucogenic to lipogenic ratios are desirable due to the better energy efficiency of glucogenic VFA (Preston & Leng, 1987; Vanhatalo *et al.,* 2003).

The pH values in the current study did not vary ($P>0.05$) among the means of all the treatments due to supplement type given. The mean pH values did not drop below pH 5.5 in any of the treatments giving the impression that it was not too acidic for the rumen microbes to flourish.

Ammonia concentration in rumen fluid

The mean rumen ammonia N concentration differed ($P<0.01$) among treatments due to supplementation types administered. The control had the lowest concentration of rumen ammonia N which differed ($P<0.01$) only from the fresh barley sprouts supplementation. All the supplemented treatments did not differ ($P>0.05$) from one another although the fresh barley sprouts supplement tended to be higher than the others.

The barley grain supplementation which had the highest value for rumen fluid total VFA concentration showed a drastic response (decline) in rumen ammonia levels probably due to the increase in the VFA levels (Figures 1 and 2). This shows an interaction between VFA levels and rumen ammonia N concentration. More degradable starch tends to decrease rumen pH, increase rumen VFA and decrease rumen ammonia concentration (Plascencia & Zinn, 1996; Yang *et al*., 1997). When the basal diets are high in forage, however, the increase in VFA can decrease roughage degradation due to lowering of the rumen pH and its effects on roughage degrading microbes (Cabrita *et al.,* 2006). The diet in the current study being a high grain diet would, therefore, not be adversely affected by the rapid fermentation of grain in the presence of adequate ammonia levels.

The decreased ammonia concentration levels observed with high concentrate diets likely stem from a higher level of utilization of ammonia as a result of more readily available carbohydrate and increased ammonia assimilation (Hristov *et al.,* 2001).

The un-ionised ammonia did not differ in concentration among the different treatments. The pH and total ammonia concentrations determine the non-ionised ammonia N concentration (Abdoun *et al.,* 2006).

Rumen bacterial outflow

The rumen microbial outflow did not differ among treatments. Efficient microbial protein synthesis depends on supply of adequate N and readily fermentable carbohydrates as well as other nutrients for uptake and utilisation by microbes. The high level of nutrients in the pellets used in this study provided the required levels for all the treatments.

CONCLUSION

Results of the current study suggest that sprouting did not bring about an increase in DMI when compared to barley grain supplementation. Barley grain supplementation of high grain concentrate pellets in this study gave the highest DMI which was better than all other treatments except the fresh barley sprouts supplement. Apart from DMI, other digestibility parameters did not differ among the four treatments, suggesting that supplementing high nutrient diets with sprouts was of no advantage. The increase in performance alluded to the presence of a "grass juice factor" was therefore not noticed in the current study.

Supplementing concentrate pellets with freeze-dried sprouts did not give a higher concentration of rumen ammonia N above treatments without sprouts, although fresh

barley sprouts gave the highest rumen ammonia concentration. The total VFA concentrations in the four treatments did not show an advantage of supplementing with hydroponic barley sprouts.

Other rumen fluid parameters (proportions of VFA) did not show a clear advantage of feeding sprouts supplements to sheep on high concentrate pellet diet.

It can be concluded that when diets high in nutrients are fed, there is no advantage of supplementing with hydroponic barley sprouts and there was no clear indication of a "grass juice factor" giving improved performance. The current study does not suggest any likely performance benefits from using sprouted grain for livestock feed supplementation even when the basal feed has a high level of nutrients; a similar performance trend was reported using a low quality basal feed by the current authors (Dung *et al.,* 2010). Sprouting in a situation like this would amount to spending time and money for no special advantage.

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Strengthening governance of agriculture to enhance competitiveness of farmers in Pacific Islands Countries

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ABSTRACT

Effectiveness of governance and its regulatory quality matter for agricultural development in Pacific islands countries. Agriculture in these countries is important but is poorly developed and suffers due to weak agricultural institutions and governance issues. A stronger performing agriculture is crucial, but its development depends on the enabling environment. There is need to facilitate the farmers by enhancing their competitiveness and bargaining power. Needed actions for strengthening the governance in Pacific islands countries are: investment in rural and market infrastructures and services, ensuring quality of farm enterprises, strengthening the extension capabilities, and promotion of regional brand for niche products.

Key words: Strengthening governance, competitiveness, competitive advantages, Pacific islands.

INTRODUCTION

Governance refers to the manner in which public officials and institutions acquire and exercise the authority to shape public policy and provide goods and services (World Bank, 2007). This includes the capacity of the government to effectively manage its resources (AusAID, 2008a) and implement sound policies (Foukona, 2006). Governance includes both the 'enabling conditions' for enforcing law, as well as the capacity to manage broader economic and social factors (Magrath, 2010). For agriculture, good governance is important to formulate a conducive policy environment and for effective implementation of policy agendas. Effectiveness of government and its regulatory quality, therefore, matter for agricultural development (World Bank, 2008).

In developing countries, particularly the small islands countries of the Pacific region, problems of market failure are more serious. In the region, agriculture suffers due to weak agricultural institutions relative to the institutions governing other sectors and the governance problems. Effectiveness of government, defined in terms of quality and capacity of public services, and the quality of policy formulation (Commonwealth, 2009) and trade liberalization are crucial for economic growth. For the flow of benefits of trade, however, the liberalization process, which has been initiated in the nineties in different Pacific islands countries (PICs), must be accompanied by efforts to improve the competitiveness of farmers. This would require the development and effective dissemination of appropriate crop technologies, and strengthening the bargaining power of farmers by investing in post-harvest facilities and marketing infras-tructures and thus creating a business-enabling environment (Singh *et al.*, 2010).

Agricultural sector in PICs continues to be the linchpin of their national economies and serves as the main source of livelihood for poor rural households, but is, in general, poorly developed. Over the last two decades, the level of food self-sufficiency of these countries has been declining and presently the region is perennially in food deficit (Singh *et al*., 2010, Esera, 2012). Lack of economic growth experienced by these countries (see Appendix I) is contributing to rising unemployment and hardship to their people. With scarcity of arable land in the region, with the exception of Papua New Guinea (PNG), the task of increasing food production may be accomplished by getting higher crop productivity which cannot be realized by farmers alone. However, through partnership with governments, their development partners,

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research institutions and extension agencies, farmers' associations, the civil society and private sector working together, the needed task of increasing food production can be done. But the question is not only of producing additional food; there is an important issue of enabling different players particularly the farmers, a big majority of whom are smallholders, to get their due share. These small scale producers can be helped to realize better returns from their farm produce by formulating right kind of policies, arrangements, technologies and approaches helpful in increasing productivity, lowering unit costs of production, strengthening producers' competitiveness and bargaining power, and promoting private investment in agriculture (Singh *et al.*, 2010; Singh & Bhati, 2012).

In this paper we want to highlight options that are available to strengthen the governance of agriculture to enhance the competitiveness of farmers in PICs. The study may be helpful to government agencies to learn about approaches and strategies to stimulate political and economic development and work in partnership with NGOs, farmers' organizations, civil society and the private sector. The paper is organized in five parts. Next part defines the salient features of agricultural sector in PICs, their agricultural marketing situation, competitive advantages, opportunities available and challenges faced by them. The third part discusses the strategies for enhancing the performance of farmers. The fourth part highlights ways and means for strengthening the governance to help farmers improve their competitiveness. Conclusions and recommendations are presented in the final part.

FEATURES OF AGRICULTURAL SECTOR IN PICs

General overview

The PICs is a group of small islands countries scattered over vast areas in the Pacific region. The group includes a mix of continental and volcanic islands, and low and raised coral atolls. These island states have small populations - totalling 9.5 million scattered across an ocean area of approximately 30 million square kilometres of which less than two percent area is land (Secretariat of the Pacific Community - SPC, 2004). Over 70 percent of the population of PICs is predominantly rural (Food and Agriculture Organisation - FAO, 2009). These countries display an amazing combination of geographical, ecological, sociological and economic characteristics (Table 1). The diverse groups of indigenous peoples and cultures of the region are recognized with three common sub-regions - Melanesia[1], Polynesia[2], and Micronesia[3].

The Pacific region is unique and diverse and the PICs have diverse resource endowments, economies, and political situations with varying agricultural conditions which vary both among and within countries. Notwithstanding this diversity, these nations experience a number of common development challenges, not only due to their geographic dispersion, limited size, ecosystem fragility and isolation from external markets and related high transportation costs, but because of governance issues as well (International Fund for Agricultural Development - IFAD, 2004). Their poor access to commercial and capital markets, poorly developed infrastructure and limited institutional capacity hinder their economic development. Their economic growth, in general, has been well below the global average for developing countries (World Bank, 2012). The challenges shared by them are compounded by weak policy and regulatory frameworks. Agriculture is important to many of these countries from subsistence security and livelihood option viewpoints. As land is the most important factor of production, system of its governance, the land tenure, is crucial for the development of agriculture.

Land tenure systems in the region, though very diverse, have several common features. Most of the land is held under customary authority also known as traditional, customary or communal tenure. In most of the countries, it accounts for more than 80 percent of the land area (see Appendix II). Approxima-

[1]Melanesia: It comprises of Fiji, New Caledonia, PNG, Solomon Is., and Vanuatu. These are relatively larger countries with best natural resources and most of the land and population of the region.
[2]Polynesia: The sub-region comprises of Cook Is., Niue, Samoa, Tokelau, Tonga, and Tuvalu. Samoa and Tonga have modest land resources. In Tokelau and Tuvalu, the scarcity of land and water are the limiting factors.
[3]Micronesia: Countries of the sub-region are Federated States of Micronesia, Kiribati, Marshal Is., Nauru, and Palau. These tiny nations are resource-poor, small, and predominantly atoll states, and unsuitable for agriculture. But they are spread over vast area of Pacific Ocean and possess vast marine resources.

Table 1. Profile and summary of selected PICs (basic indicators).

Country	Land area (km^2)	Sea area (,000 km^2)	Population (,000)	Land form	Agricultural exports as % of total exports	Contribution of agriculture to GDP (%)
Fiji	18 376	1290	779	Volcanic Is. & minor atolls	43	16
FS Micronesia (FSM)	701	2780	119	Volcanic Is. & atolls	--	--
Kiribati	726	3550	83	Predominantly atolls	40	17
PNG	461690	3120	4312	Volcanic Is. & few small atolls	17	26
Samoa	2 934	120	177	Volcanic Is.	16	14
Solomon Is.	29 785	1340	432	Volcanic Is. & few atolls	8	40
Tonga	696	700	100	Volcanic Is. & few small atolls	75	28
Vanuatu	12189	680	177	Volcanic Is. & few small atolls	70	20

Source: FAO, Support to the Regional Programme for Food Security in Pacific, 2003.

tely 79 percent of all farmers are small-holders and operate on an average up to two hectares of land. The average size of holding is, thus, small. Though most islanders have some land they can call their own, few can use it fully and freely without fear of dispute, constraint, or claim on the crop or its proceeds by kin or community (Crocombe, 1974). The land, therefore, is being used less efficiently. Such system produces many problems and keeps farm productivity low. It also leads to lack of individual responsibility and incentive for land improvement and conservation, no security of tenure, restricted scale of operation and problems in getting credit (Johnson, 1990). As getting land rights beyond the subsistence needs is hard the system is an obstacle to commercialization. Relationship between land tenure, crop productivity and investment shows that access to land is crucial to escape poverty (Prasad, 1998; Prowese & Chimhowu, 2007). Uncertainty of property rights in land affects the level of production and investment (Prasad, 1998). Most of the governments of PICs have tended to avoid interfering with customary tenure system in terms of allocation, management and record keeping rights (AusAID, 2008b). However, recognising the intertwined dimensions of the issue of improving land-based economic development, the (Pacific) Forum Regional Security Committee had endorsed a Land Management and Conflict Minimisation Project in 2006. In addition, periodic efforts have also been made in some parts of the region to improve land administration by addressing specific aspects of introduced administration system with the aim of facilitating access to customary land. Such efforts have been met with limited success (SPC, 2008). As countries are experiencing the problems of unemployment, poverty, food security and low economic growth, a stronger performing agricultural sector is crucial.

Production and productivity of farm enterprises meant for commercial purposes are related to prices and, therefore, subject to fluctuations. Given the functions of agricultural prices, the implications of wide fluctuations in them are that the incomes of farmers fluctuate more than the fluctuations in output. In the short-run, a fall in prices dampens the enthusiasm of producers to invest. Consequently, in the long-run, the production may dampen. On the other hand, an unrestrained rise in agricultural prices would affect the levels of living of population in other sectors of the economy. Because of such

behaviour of prices and their importance, different governments in the region, in the past, have taken different measures to regulate/ stabilize prices for their export commodities (notably tree crops) and/or improve the bargaining position of the farmers. In the development plans of most of the PICs also, government-led agricultural development projects have featured prominently. Such projects involved the establishment of marketing boards and agencies. Few examples of these projects included Fiji's National Marketing Authority (NMA), the Tonga Commodities Board (TCB), Samoa Produce Marketing Division and the cocoa and copra boards, Solomon Islands Commodity Export Marketing Authority (CEMA), Vanuatu's Commodities Export Marketing Authority (VCMB), etc. In some countries, agricultural sector was also protected and subsidized and public sector bodies were involved in processing and marketing of chosen goods. However, evidences show that many of the projects/programmes were not sustained and have failed (Commonwealth, 2006). Despite the intentions to support farmers, such interventions proved to be detrimental to them and the development of many crop based industries (FAO, 1999a; FAO, 1999b; FAO, 2002; Singh & Bhati, 2012).

Farmers, including the semi-subsistence farmers, in the region, are becoming increasingly market oriented and are supplying the domestic markets with roots and tubers, horticultural produce and other foods. However, it is being widely recognized that production is a major constraint. As stated above, the issue of improved marketing of agricultural produce and market development is not new to the region. There are some improvements in infrastructures including communications. Fiji, PNG, Samoa, Solomon Is., Tonga, and Vanuatu have joined the WTO. Many other governments are also reducing barriers to imports and exports. Gradual shift in the role of governments from administration to development is also being observed, but a lot more needs to be done. As part of growth policy, the role of government is to accelerate the growth of agriculture output. Large parts of farm produce are retained for home consumption; favourable policies, therefore, may ensure adequate increase in market supplies of farm commodities.

Agricultural marketing situation

Crop sub-sector of agriculture in the region is undergoing changes both in production and marketing technologies. Supplying affordable foodstuffs for growing urban populations is a challenge. As stated earlier, slow growth of these economies, particularly the agricultural sector (Appendix III), has created socio-economic problems. In spite of government efforts to produce more food, PICs still import substantial amounts of foodstuffs. The farming sector has the potential to provide the growing population with employment opportunities and food supplies, but for farmers to produce more, they need a secure source of income from marketing of excess production. As subsistence production is important and the domestic markets have limited capacity due to small size of most island economies, the concern is to promote supplies for export markets by providing incentive to farmers through better returns. Farmers produce and sell small quantities of produce which involve diseconomies in its assembling at different locations. There are additional constraints of infrequent and expensive sea transport from smaller and isolated islands. Accumulation of sufficient produce at individual export ports is difficult and costly as small surpluses of producers need to be transferred from small ports to major export ports. Even larger and more populated islands experience communication-transport bottlenecks. Due to small domestic demand and few processing ventures, the export markets offer potential for fresh vegetables and fruits. But there are concerns of wide price fluctuations in international markets. Main recipient of crop produce from PICs is New Zealand which itself is of relatively small size. Together with this other problems being experienced by these nations are: quarantine requirements, competition from outside the region, difficulties of irregular and unreliable supplies both in terms of quantity and quality, lack of storage and freezer facilities at collection centres, and the inability to comply with international trade obligations under WTO. Basic agricultural statistics on crop production, number of farm operations, market information, etc., is weak and understanding of market variables is poor and a constraint to development. PICs have, also, to put in more efforts in market research to determine the processing and export potential of different commodities.

Due to weak linkages and coordination between the ministries/departments of agricul-

ture, trade, commerce, tourism and industries, the strategies and programmes are often contradictory and confusing. Agricultural marketing is mainly in the hands of private sector, except for few commodities' boards which are responsible for domestic purchase and sales and/or are engaged in policy and regulatory functions. Many of these boards could be regarded as monopoly traders or monopsonist in trade practices (FAO, 1999a; FAO, 1999b; FAO, 2002; Singh & Bhati, 2012). There is need to have a change in the development strategy, and focus should be on the diversification of crop sub-sector from predominantly subsistence entity to a semi-subsistence and commercial entity. Presently, the farmers and traders in PICs lack the ability to meet the WTO's Agreements on Sanitary and Phytosanitary (SPS) Measures and Technical Barriers to Trade (TBT) and are at a disadvantageous position compared to the multinationals which are entering the region.

Competitive advantages, opportunities and challenges

Agricultural sector in PICs presents many opportunities. Taking advantage of such opportunities is important both to lift aggregate growth and to enhance rural incomes. During the last few years, these countries have been experiencing rapid rates of urban population growth. One domestic opportunity stems from the rapid rates of urban population growth, which have created a domestic market for traditional staples and other food products in urban areas. There is also potential to target the tourism market more effectively. Presently in Pacific islands, most food consumed by tourists is imported. Significant tourism sectors offer a substantial market for locally grown produce and packaged value-added products. In terms of export opportunities, countries of Melanesia remain internationally competitive in producing traditional tree crops. In Fiji, smallholder horticulture is now the fastest growing part of its agricultural sector (Singh & Bhati, 2012). There is also scope to expand export markets by effectively targeting the Asian and Pacific island communities in New Zealand, Australia and the west coast of the United States, which offer a significant market for various horticultural products. Fiji and the Polynesian countries are in a position to take advantage of such opportunities. The rest of Melanesia is in a disadvantageous position due to limited airfreight capacity, unfavourable fruitfly status, and the absence of their own people living in target markets. But indigenous tree nuts, for example '*nangai*' or '*ngalinut*' (*Canarium* sp.) have potential for Melanesia. In Vanuatu where only estimated five percent of the nuts are harvested, a limited value addition can help to realize a price of AU$ 17,000 per tonne (Commonwealth, 2006). Solomon Is. also has a thriving domestic market for both natural and processed *nangai* and has now started exporting its products. There are other promising nut species, e.g. 'cut nut' (*Barringtonia* spp.), 'okari' (*Terminalia* spp.), etc., which need assistance for development, value addition and marketing. In PNG, despite the constraints of poor governance, weak infrastructure and customary land tenure, the palm oil industry is thriving because of natural comparative advantage and market-driven approach. Many PICs have comparative advantage in the production of many tropical fruits, root crops and off season vegetables. They have the advantage of location and a relatively pest free unpolluted environment for producing niche organic fruits and vegetables having export demand. Few countries are promoting the production and marketing of high value products. Overall, their agricultural sector has performed poorly. Available agricultural statistics suggest low and variable agricultural growth across the region (Appendix III). Their traditional farming systems are under increasing pressure, particularly in Melanesia and East Timor.

ENHANCING PERFORMANCE OF FARMERS

Issues identified above need action. Infrastructure is an important constraint for the development of agriculture, but land tenure, policies and governance are also inhibiting factors in the region and need emphasis. Improved profitability of farm sector is crucial for enhancing the performance of farmers, which in turn will accelerate agricultural growth. Farmers can be helped to get better returns from their produce by lifting productivity and lowering unit costs of production for which the needed actions are: improving farmers' access to technology and information; removing distortions against agriculture; and facilitating market access.

Limited access to appropriate technology and market information constrains the abilities

of farmers and marketers to make informed farming and business related decisions. Research needs of farm enterprises in general are not catered for due to funding constraints in many countries unlike in Fiji, for sugar, and PNG, for larger tree crop enterprises. But there are opportunities to establish twinning relationships and links with neighbouring countries, donors and international research institutions. Presently, these countries operate diffuse and often ineffective extension services with weak links to research. Their research and extension capabilities are weakest in areas of subsistence and domestically marketed food products (Commonwealth, 2006). An improved cooperation between research and extension wings can improve the effectiveness of extension services. Paucity of agricultural statistics constrains the assessments of the sustainability of different farming systems. There are inter-country variations and available observations are for short periods. These countries are feeling the pain of declining crop yields in the face of increasing population pressure and inadequate land conservation measures. To fund agricultural research and extension, they may pursue alternative approaches with greater involvement of private sector, commodity industries and NGOs. Regional bodies with agricultural programs, like the SPC, can be approached to get technology and market information to farming communities (Commonwealth, 2006).

Development of agricultural sector depends heavily on an enabling environment and trade policies. Farmers should have a choice in who they sell to. In Fiji, Samoa and Vanuatu, cocoa boards have monopoly powers but their export industries are performing below the potential or barely exist. However, in PNG, the coffee and cocoa boards never had monopoly on marketing and had focused on improving quality standards, price stability and funding and directing research. Such a competing marketing structure has served PNG farmers well despite the decline in efficiency and performance of the boards. Here it is important to understand that future expansion of demand for domestically produced food is likely to remain limited, even including the demand for tourists, unless agricultural raw material contributes a substantial proportion of total value added in food industry. In the absence of such a structural shift, most additional spending on food will go to overseas food processors. Consequently, the focus of agricultural marketing development should be on expanding value in export marketing channels. Governments should also understand that there are not enough roles for the public sector as marketing participants. Most of the farmers are village-based, small, sell their output independently and have limited bargaining power. Marketing channels for different commodities are also underdeveloped. There is lack of market information and farmers have to contend with poorly developed infrastructure. Therefore, the temptation for government intervention is always there. Yet, it would be inappropriate for governments to intervene as direct participants in marketing or processing. Statutory authority like commodity boards is not a good vehicle for innovation and productivity gains necessary to compete in the competitive agricultural markets. Appropriate role for the governments is to aid the development of contractual system in agricultural marketing. Contractual farming is not new to PICs. Examples of agro-industries having formal contractual relations between crop producers and processors are sugar industry of Fiji, and oil palm industry in PNG and Vanuatu. Development of producer groups, successful producer cooperatives, and NGOs could form an integral part of development and evolution of contractual system. Governments through policies, infrastructure and services can also play other facilitating roles to nurture value-adding ventures.

Quality and safety standards - SPS measures, are a weak link in the export marketing chains of PICs. As exporter, they have to ensure that their products meet the quarantine safety standards of export markets. As importer they have to ensure that their own quarantine systems are adequate to prevent the entry of pests. As many countries are not in position to develop the critical mass of required expertise, they may take a regional approach to provide such specialized functions. More work is also needed to resolve non-SPS market access barriers, such as securing import approval for new or specialized products. 'Noni' (*Morinda citrifolia*), 'kava' (*Piper methysticum*) and various indigenous nuts produced in the region have considerable export potential.

STRENGTHENING GOVERNANCE

Historically, public sector interventions in agricultural markets in PICs were often ill

informed, poorly implemented (FAO, 1999a; FAO, 1999b; FAO 2002; Singh & Bhati, 2012), and corrupt leading to poor overall governance. However, the scales of interventions were reduced during the nineties when structural adjustments were initiated by many PICs. This had positive impact on the private and agriculture sectors, but has left many unresolved issues particularly those of market failures since their private sector, in general, is weak. They now have to enhance their investment in public goods like agricultural research, extension, transport and rural market infrastructure, and agricultural statistics. After structural adjustments, in many countries the ministries of agriculture have to redefine their roles and develop new capabilities. The 'Agreement on Agriculture' (AoA) has made the agricultural sector very sensitive to trade related issues. Efforts to increase production for global markets means that the sector is not isolated and rather increasingly linked with other sectors within the economy, and with other economies at global level. It is advisable to develop regional trade agreements/be member of such agreements to supplement their supplies (i) for potential export markets or (ii) if local-domestic production capacity is limited. Governments should develop regional quality-safety standards and certification mechanism and position their niche products having comparative advantage under a common brand name. They should focus on agribusiness, marketing and trade to strengthen the capability of their farmers. For the development of a competitive agribusiness sector, a positive rural investment environment is needed, which can be created by financial sector reforms. In PICs, the farmers' organizations and NGOs have potential to overcome the market failures. This third sector can facilitate the input supply, extension and marketing activities successfully as has been demonstrated in many other developing countries. Development partners can also pool their expertise and resources to support the governance reforms.

Presently, countries in the region have underdeveloped capacity for policy analysis and formulation. Their systems of collection, analysis and management of agricultural statistics are weak. Strengthening of these systems is needed to enhance their capacity of policy analysis. They find it difficult to meet food quality and regulate safety standards due to weak capacity. Competitiveness of niche, traditional crop and livestock products is also weak due to their limited grading, standardization, processing and other value adding facilities. Many PICs do not have facilities for slaughtering the meat animals under good and hygienic conditions. Construction of abattoirs and improved meat handling facilities, etc., will mean more income to farmers and better supply of food to the consumers. Improved infrastructural facilities, therefore, will improve the competetiveness of farmers. These countries must also develop effective farm support services including the market driven research and extension to promote improved technology and farmers' access to such technologies. By encouraging the application of improved husbandry practices, more particularly the tropical fruits and vegetables' agronomic practices and livestock husbandry, the productivity will improve which, will lead to affordable costs of safe and nutritious food to the islanders. A thriving agriculture underpinned by improved productivity will expand the rural economy. The development partners of PICs can help in strengthening the needed capacities. Land reforms are important but sensitive and political issues. However, they are on the agenda of many countries. PNG and Vanuatu have taken a holistic approach to address the issues based on national land forum approach of the Land Resources Division of SPC. On the other hand, Samoa has adopted the approach of consultation as part of ADB funded land development project (SPC, 2008). Likewise, Solomon Is., Marshal Is. and Tonga are also considering to bring some sort of land policy reforms to ensure that land contributes to community and national development. The challenge is to develop new modalities for land use agreements which are consistent with traditional/customary arrangements.

CONCLUSIONS AND RECOMMENDATIONS

Governance is the exercise of economic, political, and administrative authority to manage a country's affairs at all levels. Good governance is important for formulating conducive policy environment and effectively implementing agendas that make it possible to use agriculture for development. The PICs have varying geographical, social, political and agricultural conditions. Notwithstanding

this diversity, these countries experience many common development challenges and governance issues. Agriculture is important to the economies of many of these countries from subsistence and livelihood option viewpoints, but poorly developed. In the region, farmers mainly practice semi-subsistence farming under customary tenure system. As private sector is poorly developed, a stronger performing agricultural sector is crucial for addressing food security, poverty and economic growth. Farmers mainly grow wide variety of tropical fruits and vegetables, roots and tubers, spices and medicinal plants.

In the development plans of PICs, government-led agricultural development projects feature prominently, which involve the establishment of marketing boards and agencies. But the evidences show that many of these projects/programmes have been detrimental to the farmers and the development of crop-based industries. Farmers in the region are becoming market-oriented and there are improvements in infrastructure. Gradual shift in the role of governments from administration to development is also being observed. But still, there are many gaps and obstacles which create market imperfections. Role of state is to create favourable environment to accelerate the growth of output and increase in market supplies. As has been stated, supplying affordable foodstuffs to the rising populations, particularly the urban populations, is a challenge. In all the countries, reliance on cheap imported food is increasing. The farming sector has the potential to meet food supplies, but to produce more, farmers need a secure source of income from the marketing of excess production. Concern is to provide incentive to producers through better returns from their produce. Profitability of farm enterprises can be improved if producers are able to produce more at lower unit costs. With the development of appropriate production technologies, effective extension services, and by improving the market infrastructure the competitiveness and the bargaining power of farmers may be strengthened, which will help them in realizing better returns and remunerative prices. Most of the countries follow customary land systems where there is lack of clarity in property rights. It constrains the development, conservation and use of arable land for commercial crop production. Security of land tenure, when implemented properly, provides incentives to farmers for long-term investment. Therefore, land reforms supported by rural reconstruction programmes are important.

Agricultural development depends on the enabling environment and trade policy. Infrastructure in PICs is an important constraint for the growth of farm sector and agribusiness. For improving the productivity, farmers need access to technology and information. Limited access to appropriate crop production and post-harvest technology and market information constrains the abilities of farmers and marketers to make well informed decisions. Due to funding constraints, research needs of many enterprises are not catered for. But opportunities are there for the governments to establish twinning relationships and links with their neighbours, development partners, donors and international research institutions. Extension services and links between research and extension departments of these countries are also weak. Farmers need improved technical knowhow and better inputs which, presently, are being provided for few crops and by few countries only. Alternative approaches may be pursued with greater involvement of private sector, commodity industries and NGOs. Regional bodies like SPC can also be helpful. Quality and food safety standards-SPS are weak in the export marketing chain of these countries. The PICs have also to work to resolve many non-SPS market access barriers like securing import approvals for new and specialized niche products, for example, 'noni' juice, kava, various indigenous nuts, etc.

In the region, there is need to have a government drive to revitalise the agricultural sector and give a much needed boost to production through higher productivities. It requires a strong private sector to lead the increase in farm productivity guided by the market driven approach. The agricultural sector has been under-performing due to the constraints of institutional factors which are impeding the productive potential of farmers and agribusiness. These countries must, therefore, develop effective farm support services to boost productivities. A thriving agriculture in PICs will expand the rural economy. In light of the above discussion, focus areas for better governance, government interventions and priority outcomes can be summarized as follows. The development structure of PICs has common elements which inter alia include: strengthening policy,

regulatory frameworks, increased agricultural productivity and food self-sufficiency, improving marketing and export performance. Government has to facilitate farmers to enhance their bargaining power and competitiveness. Needed medium- and long-term actions which would be helpful to farmers may be highlighted as: investment in rural and market infrastructure and services, ensuring the quality of farm produce both for home and export markets, strengthening the extension and research capabilities, and promotion of regional brand for niche products.

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Appendix I. Annual GDP growth rates (%) of selected countries: 2001, 2005, 2008 to 2011.

Country	2001	2005	2008	2009	2010	2011
FSM	0.9	3.0	-2.4	0.7	3.1	1.4
Fiji	1.9	-1.3	1.0	-1.3	-0.2	2.0
Kiribati	-3.1	0.3	-1.1	-0.7	1.8	1.8
PNG	-0.0	3.9	6.7	5.5	8.0	9.0
Samoa	8.1	5.2	-3.2	-1.7	1.7	2.1
Solomon Is.	-8.0	5	7.3	-1.2	7.0	9.0
Tonga	3.5	-1.0	2.0	-0.1	-0.5	1.2
Tuvalu	13.2	-4.1	1.3	-1.7	-5.0	1.0
Vanuatu	4.5	7.1	9.0	3.5	3.0	4.3

Note: FSM - Federated States of Micronesia, PNG - Papua New Guinea.
Sources: 1. ADB, Key Indicators for Asia & the Pacific 2010.
2. World Bank Data: http://www.worldbank.org/en/country/pacificislands [Accessed 5 Dec. 2012]

Appendix II. Distribution of land by systems of tenure in selected PICs, in per cent.

Country	Public land[a]	Freehold land[b]	Customary tenure
Fiji	4	8	88
FS Micronesia	35	< 1	65
Kiribati	50	< 5	>45
Nauru	< 10	0	>90
Niue	1.5	0	98.5
Palau	Most	Some	Some
Papua New Guinea	2.5	0.5	97
Samoa	1.5	4	81
Solomon Islands	8	5	87
Tokelau	1	1	98
Tonga	100	0	0
Tuvalu	5	< 0.1	95
Vanuatu	2	0	98

Note: a. Includes Crown land and land owned by provincial and local governments.
b. Includes land that is not strictly freehold, but similar in characteristics, such as the 'perpetual estates found in Solomon Islands.'
Source: Commonwealth of Australia, 2008. Making Land Work, Vol. One, Reconciling Customary Land and Development in the Pacific, Table 2.1.

Appendix III. Annual growth in agricultural output in selected PICs during 2000, 2005, 2008 and 2009, in percent.

Sub-region & country	**Annual growth rate**			
	2000	2005	2008	2009
Melanesian sub-region:				
Fiji	-1.3	0.9	2.1	na
PNG	2.1	5.6	4.3	2.3
Solomon Islands	-17.1	5.2	6.6	-7.3
Vanuatu	3.2	5.6	6	na
Polynesian sub-region:				
Cook Islands	0.1	-3.5	-3.7	na
Samoa	0.1	4.8	-8.6	0.7
Tonga	7.0	-4.8	0.6	-1.3
Tuvalu	-2	0.9	3	0.4
Micronesian sub-region:				
Kiribati	-6.1	-5.7	1.8	1.4

Note: na- Data not available.
Source: ADB, Key Indicators for Asia & the Pacific 2010.

Micropropagation of baobab (*Adansonia digitata* Linn.), an economic plant

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ABSTRACT

Adansonia digitata Linn. has been repeatedly reported to have ethno-medicinal uses such as food and fodder, fibre in clothing and ropes, ethno-veterinary medicine and other herbal applications. Currently, it is widely used in the many traditional systems of medicine, and yet detailed report of its mass propagation is lacking. This study was, therefore, conducted to initiate multiple formation of shoot and buds of *Adansonia digitata* using embryos as starting material. Matured embryos of baobab plant were inoculated on two basal media namely: Murashige and Skoog (MS), and Woody Plant Medium (WPM). Nodal explants excised from the regenerated plantlets were cultured on MS basal medium supplemented with various concentrations of cytokinin (BAP and KIN), auxin (NAA) and additive (coconut water). The effects of growth hormones and additive (coconut water) on *in vitro* propagated plantlets were evaluated. In embryo regeneration, both basal media could be used, though MS basal medium proved to be better with the highest number of nodes coupled with the maximum length of roots and shoots. However, in shoot multiplication, MS basal medium with or without KIN and NAA performed better. The sufficiently rooted plants were then transferred for acclimatization and later taken to screen house for hardening.

Key words: Propagation, growth hormones, plantlet, baobab, useful plant.

INTRODUCTION

Adansonia digitata Linn., commonly called baobab, belongs to the family Bombacaceae. It is important for the livelihood of the people in the arid zones (Becker, 1983). Monkey bread is one of the common English names derived from the fact that monkeys eat the baobab's fruit (Rashford, 1994). Baobabs are often the most prominent tree species wherever they occur because of their great size and bizarre shapes. They are widespread throughout the hot and the drier regions of tropical Africa. It has an extensive root system, a high water holding capacity and is resistant to fire. This adaptation allows it to grow in zones with 100mm-1000mm annual rainfall. Baobab was found to be among the most effective at controlling its water loss (Abdalla *et al.,* 2010).

Among many plant species that have been reported to have ethno-medicinal uses, *Adansonia digitata* has been widely used in the traditional systems of medicine. According to the United Nations (2005), the fruit pulp of *A. digitata* is traditionally used for the treatment of fever, diarrhoea, dysentery, haemoptysis, and smallpox in humans. Leaf infusions are used as treatment for diarrhoea, fever, kidney and bladder diseases, blood cleansing, and asthma in humans. The bark is used for treatment of fever caused by malaria. As far as ethno-veterinary medicine is concerned, reports indicated that the bark of *A. digitata* is used for the treatment of diarrhoea in poultry (Guèye, 1999). Fruits are used for treatment of Newcastle diseases in poultry (Gebauer *et al.,* 2002; Wynn & Fougère, 2006).

The fibrous bark of *A. digitata* is used to make ropes, mats, fishing nets, fishing lines, sacks, as well as clothing. The tree provides food, shelter and material for hunting and fishing (Venter & Venter, 1996). Review through literature showed that the only work published on *Adansonia digitata* micro-propagation was by Ishii & Kambou (2007), where four different basal media were used. The four basal media were half strength of Quoirin and Lepoivre (LP), half strength of Murashige and Skoog (MS), half strength of

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Gamborg's (B5) and half strength of Woody Plant Medium. These four basal media were used at different stages of propagation of the plant. In any case, this study is the first in which a single basal medium was used to complete the different stages of the propagation.

Considering the above mentioned facts, this study was conducted to standardize the *in vitro* protocol for regeneration of *Adansonia digitata.* This was done to evaluate a reliable and prolific shoot multiplication procedure using mature embryo explants as starting material. Also, to evaluate and compare the effect(s) of cytokinin, auxin and coconut water on *in vitro* propagated plantlets.

MATERIALS AND METHODS

Matured fruits of *Adansonia digitata* were collected from fruiting stand in the nursery located at the Department of Botany, University of Ibadan, Ibadan, Nigeria. Seeds were collected from dry fruits by cracking the fruit open and washing away the dry, powdery coating. The dark brown to black, kidney-shaped seeds were soaked in a container of hot water and allowed to cool after soaking for 24 hours. The seeds were disinfected, embryo excised out and inoculated on prepared media

The experiment was conducted at the Biotechnology laboratory of the National Centre for Genetic Resources and Biotechnology (NACGRAB), Moor plantation, Ibadan, Oyo state, Nigeria.

Media for Micropropagation

MS (Murashige & Skoog, 1962) and Woody Plant Medium (Lloyd & McCown, 1981) media supplemented with different concentrations and combinations of growth regulator and additive (coconut water) were prepared as media for micropropagation. For embryo regeneration, embryos were cultured on MS and WPM basal media supplemented along with various concentrations of cytokinins (BAP and KIN) ranging from 0.01-0.05 mg/L and 0.01-0.5 mg/L, respectively, with 0.01 mg/1 of auxin (NAA). For shoot proliferation, Nodal explants were cultured on MS basal medium supplemented with various concentrations of cytokinin (BAP and KIN), auxin (NAA) and additives (coconut water). The BAP concentrations used were 0.02 and 0.1 mg/L, and KIN concentrations used were 0.02 - 0.03 and 0.1 mg/L, respectively, with 0.01 and 0.02 mg/L of auxin and 0.01 mg/L of coconut water.

Transfer to the soil

Rooted plantlets were taken out from culture tubes and washed thoroughly with tap water to remove the culture medium from the roots. Washed plantlets were planted in normal and sterilized soil in small perforated polythene bags. After 7 days the hardened plantlets were taken to the screen house for hardening. The hardened plants were transferred to the nursery before establishing on the field.

Data collection and statistical analysis

Weekly visual observation of culture was made and frequency of culture showing plantlet, shoot and root formation and multiplication was recorded. Data was subjected to analysis of variance (ANOVA) and mean separation were also carried out using the Duncan's multiple range test. The level of significance was determined at 5 %.

RESULTS AND DISCUSSION

An efficient and reliable system for *in vitro* propagation of *Adansonia digitata* has been optimized. Two basal salt mixtures Woody Plant Media (Lloyd & McCown, 1980) and MS Media (Murashige & Skoog Media, 1962) were used initially to study the effect of basal media on embryo regeneration. In the light of the study, MS media proved to be better than WPM media since they showed highest number of nodes, maximum length of shoots and roots with or without growth regulators (Tables 1 & 2). The woody plant medium was basically designed to overcome the chloride ion susceptibility of the woody plants (George, 1993). Since the best results were obtained from MS media, prediction can be made. Unlike most woody plants, *Adansonia digitata* is not susceptible to chloride ion in terms of embryonic regeneration.

The results on regeneration showed that excised embryo of *Adansonia digitata* culture on treatment composition of 0.02 mg/L BAP and 0.03 mg/L KIN promoted more nodes than did the control and other ranges of cytokinin. Treatments containing 0.04 mg/L BAP gave the highest shoot length while treatments with 0.03 mg/L KIN gave the highest root length as shown in Table 1. The different concentrations of BAP and KIN used proved successful for the germination of embryos in *Adansonia digitata,* and this is in

accordance with Sebastian *et al.* (2005) who reported a satisfactory germination of embryos of *Phyllanthus emblica* L. and *Hevea brasiliensis* on the same media. Benzyl amino purine (BAP) in combination with NAA gave the optimal result in embryo culture of *Adansonia digitata*. MS without growth regulator regenerated the culture embryo of *Adansonia digitata*. However, KIN gave the best root length for *Adansonia digitata.*

Shoot multiplication of was achieved through the plantlet generated from the embryo of *Adansonia digitata.* Nodal explants excised from the regenerated plantlets were cultured on MS basal medium supplemented with various concentrations of cytokinin (BAP and KIN), auxin (NAA) and additives (coconut water). The result showed that micro shoots (single nodes) excised from *in vitro* grown seedlings of *Adansonia digitata* sub-cultured, induced shoot regeneration from the axillary buds which is in accordance with McCartan & Crouch (1998), who developed a micropropagation protocol for *Mondia whitei* using single-node explants from *in vitro* grown seedlings. Shoot regeneration was obtained on all the concentrations of cytokinins (BAP and KIN) and coconut water used in combination with the different auxin (NAA and IAA) as shown in Table 3.

The optimal growth of the micro shoots was on MS only, which gave the optimal shooting, number of nodes without root initiation. BAP gave the best result on shoot length while the optimum root length was obtained from KIN with increased NAA. This disagrees with the report of Tetyana & van Staden (2001) on the *in vitro* culture of *Cussonia paniculata* that showed the best growth regulator for shoot initiation and number of shoots with kinetin. It is important to note from Table 3 that low concentrations of auxin (NAA and IAA) could not initiate root formation. Coconut water also initiated shooting and rooting which is in conformity with several reports on the beneficial effects of coconut water for micropropagation (Brain & Richard, 1993; Sajina *et al*., 1997; Wondyifraw & Surawit, 2004). Plantlets with well developed root systems were transferred for acclimatization (Figures 1 and 2).

CONCLUSION

The protocol reported here could be used for the conservation of this valuable medicinal and economic tree plant. On the basis of this experiment, mature embryo is a good starting explant material for micro-propagation of *Adansonia digitata.* In the light

Table 1. Effect of BAP, KIN and 0.01 mg/L NAA on the growth of the embryo of *Adansonia digitata* on MS medium after 3 weeks.

Code	Concentration (mg/L)		Number of nodes	Shoot length (cm)	Root length (cm)
A	0.00		3.33 ± 0.33^a	3.87 ± 0.54^a	6.23 ± 2.38^a
B1	0.01	BAP	3.00 ± 0.00^a	6.20 ± 1.60^a	14.50 ± 2.00^b
B2	0.02	,,	4.00 ± 0.00^a	5.67 ± 1.28^a	11.23 ± 2.41^b
B3	0.03	,,	3.67 ± 0.33^a	5.57 ± 0.92^a	6.43 ± 3.48^a
B4	0.04	,,	3.67 ± 0.88^a	8.07 ± 2.53^a	14.07 ± 2.70^b
B5	0.05	,,	3.00 ± 0.58^a	5.07 ± 0.27^a	8.33 ± 0.90^a
K1	0.01	KIN	3.67 ± 0.33^a	7.03 ± 1.24^a	13.63 ± 1.73^b
K2	0.02	,,	3.00 ± 0.00^a	4.87 ± 1.37^a	5.90 ± 4.31^a
K3	0.03	,,	4.00 ± 0.00^a	6.00 ± 0.70^a	14.63 ± 2.82^b
K4	0.04	,,	2.67 ± 0.33^a	5.37 ± 1.32^a	4.93 ± 2.66^a
K5	0.05	,,	3.33 ± 0.88^a	6.07 ± 1.65^a	10.03 ± 3.41^b

Values are mean of three determinations. Data with the same superscript along each column are not significantly different from each other according to Duncan's multiple range test ($P<0.05$).

Key
A: Control experiment
B: 6- Benzyl-amino purine (BAP)
K: 6- Furfuryl amino purine (KIN)
NAA: Naphthalene acetic acid
MS: Murashige and Skoog media (1962)

Table 2. Effect of BAP, KIN and 0.01 mg/L NAA on the growth of the embryo of *Adansonia digitata* on WPM medium after 3 weeks.

Code	Concentration (mg/L)	Number of nodes	Shoot length (cm)	Root length (cm)
A	0.00	3.00 ± 0.00[a]	4.50 ± 0.25[a]	8.07 ± 1.21[a]
B1	0.01 BAP	3.67± 0.33[a]	5.70 ± 0.78[a]	11.13 ± 0.68[b]
B2	0.02 ,,	3.33 ± 0.33[a]	6.90 ± 0.86[a]	13.33 ± 0.68[b]
B3	0.03 ,,	3.00 ± 0.00[a]	4.93 ± 0.56[a]	9.80 ± 1.83[a]
B4	0.04 ,,	3.67 ± 1.20[a]	4.37 ± 0.43[a]	7.37 ± 0.70[a]
B5	0.05 ,,	4.00 ± 0.00[a]	5.30 ± 0.51[a]	10.53 ± 1.45[b]
K1	0.01 KIN	3.33 ± 0.33[a]	4.97 ± 0.46[a]	7.90 ± 0.65[a]
K2	0.02 ,,	2.00 ± 0.00[a]	4.13 ± 4.13[a]	5.90 ± 1.46[a]
K3	0.03 ,,	2.67 ± 0.33[a]	5.33 ± 1.05[a]	8.2 ± 1.86[a]
K4	0.04 ,,	3.67 ± 0.33[a]	6.10 ± 0.31[a]	11.23 ± 0.83[b]
K5	0.05 ,,	3.33 ± 0.33[a]	5.97 ± 1.23[a]	7.60 ± 2.43[a]

Values are mean of three determinations. Data with the same letter along each column are not significantly different from each other according to Duncan's multiple range test (P< 0.05).

Key
A: Control experiment
B: 6- Benzyl-amino purine (BAP)
K: 6- Furfuryl amino purine (KIN)
NAA: Naphthalene acetic acid
WPM: Woody Plant Media

Table 3. The growth of sub-cultured micro shoots of *Adansonia digitata.*

Code	Concentration (mg/L)	Number of nodes	Shoot length (cm)	Root length (cm)
A	0.00	3.33 ± 1.86[a]	0.93 ± 0.74[a]	--
B	0.02 KIN + 0.01 NAA	2.33 ± 0.33[a]	0.57 ± 0.13[a]	--
C	0.02 KIN + 0.02 NAA	3.00 ± 1.00[a]	0.73 ± 034[a]	1.87 ± 1.87[a]
D	0.03 KIN + 0.02 NAA	1.33 ± 0.33[a]	0.20 ± 0.10[a]	3.47 ± 1.87[a]
E	0.02 KIN + 0.01 IAA	1.33 ± 0.33[a]	0.13 ± 0.03[a]	--
F	0.02 KIN + 0.02 IAA	2.67 ± 1.20[a]	0.93 ± 0.74[a]	1.53 ± 1.53[a]
G	0.01 Coconut	0.67 ± 0.07[a]	0.40 ± 0.00[a]	1.60 ± 0.60[a]
H	0.02 BAP + 0.01 NAA	2.67 ± 1.20[a]	0.60 ± 0.45[a]	2.13 ± 2.13[a]
I	0.02BAP+0.01NAA+C.NUT	0.67 ± 0.33[a]	0.10 ± 0.06[a]	--
J	0.1 BAP	1.33 ± 1.33[a]	1.10 ± 0.00[a]	1.53 ± 1.53[a]
K	0.1 KIN	0.67 ± 0.07[a]	0.20 ± 0.00[a]	--

Values are mean of three determinations. Data with the same superscript along each column are not significantly different from each other according to Duncan's multiple range test (P<0.05).

Key
A: Control experiment
B-F: MS + KIN + NAA
G: MS + Coconut water
H: MS + BAP + NAA
I: MS + BAP + NAA + Coconut water
J: MS + BAP
K: MS + KIN
KIN: 6- Furfuryl amino purine
NAA: Naphthalene acetic acid
BAP: 6- Benzyl-amino purine
MS: Murashige and Skoog media

A

B

Figure 1. (A) Showing *in vitro* regenerated plantlets of *Adansonia digitata* in MS. (B) Showing *in vitro* regenerated *Adansonia digitata* plantlet in WPM.

A

B

Figure 2. (A) Showing subcultured micro shoots of *Adansonia digitata.* (B) Showing acclamatized plantlet of *Adansonia digitata.*

of the results, it is established that enhanced shoot and bud formation can be achieved by using MS and WPM for the embryo growth. However, for shoot multiplication, MS in combination with cytokinins, auxins and additives (coconut water) can be used.

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Soil quality, management practices and sustainability of pineapple farms in Cavite, Philippines: Part 1. Soil quality

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ABSTRACT

Composite surface soil samples (0-10 and 10-20 cm depths) were collected from forty farms within four pineapple growing municipalities of Cavite, Philippines namely Indang, Alfonso, Tagaytay and Silang, in order to (1) diagnose and evaluate any soil nutritional and physical problems that may affect the productivity of pineapple farms in Cavite, and (2) recommend appropriate fertiliser application practices to alleviate any soil fertility constraints. Soils were analyzed for bulk density, aggregate stability, moisture content at saturation, field capacity, pH, total nitrogen (N), mineralizable N, organic C, extractable phosphorus, cation exchange capacity, exchangeable K, Ca, Mg and the micronutrients Cu, Fe, Mn and Zn. The topsoils contain little organic matter and have low levels of total N and extractable P but more than adequate levels of exchangeable K. Micronutrient levels of soils are sufficient in all of the pineapple farms. Most pineapple soils are already extremely acidic (pH below 4.5) as a result of long-term application of ammonium-based fertilizers. Soil qualities of relatively undisturbed sites are often better than those of soils long cropped to pineapple, implying the importance of fallowing. A trend towards declining topsoil pH was noted the longer the time farms were cropped to pineapple.

Key words: Soil quality, soil health, pineapple farming.

INTRODUCTION

Growing pineapple (*Ananas comosus* L.) is an important source of income for Cavite farmers in the Philippines. It is a cash crop of choice in the uplands because it tolerates acidic soils within the range of 4.5-6.5, has low phosphorus and calcium requirements, and is relatively drought-tolerant. However, the current status of soil fertility related problems of pineapple farms in the province is not known. Many pineapple farmers in Cavite are reportedly applying excessive amounts of nitrogen (Labios, 1999) way above the recommended rate for the crop (Cosico, 1991). This could result in higher production cost, soil acidification and potential environmental pollution. In the long-term, possible yield declines may be observed due to deficiency of some plant nutrients brought about by nutrient imbalances in the soil or due to deterioration of soil quality of the pineapple farms. Sadly, there had been no local study conducted about soil fertility related problems in these pineapple farms. Thus, it is important to diagnose any soil fertility or other soil management problems in pineapple production so that productivity can be raised and further sustained for this cash crop. A survey of soil qualities and soil management practices in Cavite pineapple farms is one important requirement in formulating a balanced fertilisation strategy.

Soil quality is the capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality and support human health and habitation. The term is often used interchangeably with soil health. Changes in the capacity of soil to function are reflected in soil properties that change in response to management or climate (USDA, 2001). Soil quality indicators are important in focusing conservation efforts or maintaining and improving the condition of the soil and in evaluating soil management practices and techniques. Indicators are also important to relate soil quality to that of the other resources. It helps to determine trends in the health of soils and it can also serve as a guide in land

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management decisions (USDA, 2001). This study was conducted to assess the soil qualities of pineapple farms in four upland municipalities of Cavite namely Indang, Alfonso, Tagaytay City and Silang. Specifically, the study aimed to (1) diagnose and evaluate soil nutritional problems that may affect the productivity of pineapple farms in Cavite; (2) document and assess the fertilisation and soil management practices of pineapple farmers; and (3) recommend appropriate fertiliser management practices to alleviate any soil fertility constraints.

MATERIALS AND METHODS

Selection of farms

Topsoil samples (0-10 and 10-20 cm depths) from forty pineapple farms in upland Cavite (10 farms per municipality) were collected using an auger and composited into one sample per depth per farm. The farms are a subset of the sample farms studied by Dr. Alice T. Valerio of the College of Economics, Management and Development Studies (CEMDS), Cavite State University, Philippines (Valerio, 2002). Each farm selected has an area of at least 1000 m^2 devoted wholly to pineapple or where pineapple is an important crop in the farming system. Farmers who are engaged in planting pineapple for at least two years were the ones selected. Farmers were also asked about their current yields and the number of years they cropped their soil with pineapple. Where possible, composited topsoil samples were collected in nearby "undisturbed" sites. The undisturbed sites are those areas where soils are not cultivated and fertilized for a long period of time or a minimum of two years. These sites are usually woodlands, grasslands, abandoned coffee fields or vacant lots supporting a variety of weeds. Undisturbed sites were sampled as reference sites to compare soil qualities there with soil qualities in the cropped soils.

Collection and analyses of soil samples

Horticulturally important physical and chemical soil properties were measured using standard methods of analyses (Bureau of Soil and Water Management, 1988). Physical properties include bulk density by the core method, aggregate stability by the wet-sieving technique, field capacity, and moisture content at saturation. Chemical properties include total Kjeldahl N, potentially mineralizable N by anaerobic incubation (Anderson & Ingram, 1993), Bray-extractable P, exchangeable Ca and Mg by EDTA titration, exchangeable K by flame photometry, pH by the electrometric method, organic carbon by the modified Walkley-Black method and the micronutrients Cu, Fe, Mn and Zn by DTPA extraction. A Perkin Elmer A Analyst 100 atomic absorption spectrophotometer housed at the Laboratory Services Division of the Bureau of Soils and Water Management, Quezon City, Philippines, was used to measure the concentrations of micronutrients.

Slope steepness was measured in the field using an Abney hand level and clinometer, and the measurement expressed in percentage.

Data analysis

Means and the standard errors of soil properties were computed for the 0-10 cm and 10-20 cm depths. The weighted average values of soil properties for the 0-20 cm depth were also computed. To compare the soil quality status of the four towns, one-way analysis of variance was used. Mean separation was done using Duncan's Multiple Range Test (DMRT). A paired t-test was used to compare soil qualities in sites cropped to pineapple and in relatively undisturbed sites. Regression analysis was performed using the soil qualities in the cropped soils as predictors of yield. SPSS for Windows software was employed in all statistical analyses.

RESULTS AND DISCUSSION

Soil/land quality status of pineapple farms

Table 1 shows the mean soil physical qualities of the farms cropped to pineapple. Bulk density, aggregate stability, moisture content at saturation and field capacity were all within the range of values for normal soil physical properties (Hansen *et al.*, 1980). Almost all of the soil samples had stable aggregates when passed through a 0.25 mm sieve. More than 50 % of the soil weight was left after sieving under water. All soil samples are able to hold moisture greater than 50 % under saturated conditions. Field capacity of samples ranged from 15.1 %, where only a small amount of water in the soil can be available for plant use, to 56.7 %, where adequate amount of moisture can be used by the plants.

The slopes of the pineapple farms averaged 5 %. Slopes ranged from nearly level

(3 %) to steep (28 %). In nearly level farms, soil erosion is negligible but on steep slopes it is significant. The plow layer depth ranged from 15 to 33 cm. In general, a thick plow layer implies a good store of water and nutrients. However, in some sloping farms, the plow layer is no longer the topsoil or the A horizon but the subsoil or exposed volcanic tuff parent material which cannot store significant amounts of water and nutrients. Elevation of the farms ranged from 210 m above sea level (masl) in Silang to 615 masl in Tagaytay.

Table 2 shows the mean soil chemical qualities of the farms cropped to pineapple. The data indicate that the average values of soil properties are within the range of values normally encountered in soil analysis. Most values of soil chemical properties in the 0-10 cm depth are higher than in the 10-20 cm depth. What is striking in the pineapple soils is that they have pH already below what is considered to be extremely acidic (pH less than 4.5). This could be a result of the long-term use of ammonium-based fertilizers. These fertilizers are applied on the soil surface; thus, pH is lower in the topsoil. The topsoils contain little organic matter and have low levels of total N and extractable P but more than adequate levels of exchangeable K.

While total N is low, potentially mineralizable N is high, which implies that the soils are able to release inorganic N rather quickly. This characteristic is important in pineapple growing because fertiliser N applied is rapidly absorbed by the plant during the early growth stages (Kelly, 1993).

Micronutrient levels in the soils are also within the normal range. Micronutrients are usually higher in the 10-20 cm depth implying that these nutrients are taken up by plants in large quantity in the topsoil.

Critical values of selected soil parameters are given in Table 3. It shows that 77.5 % of the soil samples from the 0-10 cm depth are extremely acidic (below 4.5), while it is 62.5 % from the 10-20 cm depth, and 70 % from the weighted 0-20 cm depth. Pineapple can tolerate acidic soils, but as noted earlier, the low pH may lead to nutrient imbalances and poor nutrient absorption by plants that could result in poor yields in the long-term. One very important implication of this result is that if the farmer is thinking of shifting to other crops or would like to practice intercropping, the farmer's choice of crops will be limited to those species or varieties which are acid-tolerant (e.g. sugarcane, tea plant). Thus, some lime may need to be applied to the soil to allow other crops to grow successfully under the extremely acidic soil conditions. Regardless of depth, at least 70 % of the soils are deficient in nitrogen (<0.10 % N) due to low organic matter levels. This implies that since soil is deficient in N, high levels of N fertilizers will need to be applied to sustain production.

Due to extreme acidity, most of the soils (>90 %) have low levels of extractable P but pineapple has a very low requirement for this nutrient. However, just like pH, low P values may not be tolerated by other crops in the farming system and P fertilisation and liming may also need to be practiced later on.

Despite the low pH level of pineapple soils, exchangeable Ca, Mg and K remain

Table 1. Status of soil/land physical qualities of 40 pineapple farms in upland Cavite.

Soil/land quality indicator	Minimum	Maximum	Mean	Standard deviation
Bulk density (g/cm^3)				
0-10 cm	0.87	1.42	1.16	0.16
10-20 cm	0.79	1.45	1.14	0.18
0-20 cm	0.85	1.15	1.15	0.15
Aggregate stability (%)				
0-20 cm	44.39	95.22	76.93	11.30
Saturation moisture content (%)				
0-20 cm	51.65	97.88	67.92	9.77
Field capacity moisture content (%)				
0-20 cm	15.23	56.72	38.01	8.32
Slope (%)	3	42	5.95	7.33
Plow layer (cm)	15	33	19.3	4.6
Elevation (m above sea level)	210	615	408	127

above the critical values considered low for these nutrients probably due to high cation exchange capacity of the soils (BSWM, 1990). With sufficient calcium, appearance of fruit abnormalities such as severe fasciations, joined multiple fruit and rounded (cannon balls) fruits are prevented. Adequate magnesium can prevent the occurrence of sun-bleached coloured leaves in pineapple crop. Soils with sufficient potassium can produce fruits with high sugar content and acid levels and with bright yellow flesh (Kelly, 1993).

Table 2. Status of soil chemical qualities of pineapple farms in upland Cavite.

Soil quality indicator	Minimum	Maximum	Mean	Standard deviation
pH				
0-10 cm	3.81	5.45	4.31	0.37
10-20 cm	3.91	5.43	4.41	0.35
0-20 cm*	3.86	5.44	4.37	0.36
Exchangeable K (cmol+/kg)				
0-10 cm	0.33	0.75	0.55	0.12
10-20 cm	0.39	0.75	0.58	0.11
0-20 cm	0.36	0.75	0.56	0.10
Exchangeable Ca (cmol+/kg)				
0-10 cm	12.10	18.50	15.06	1.60
10-20 cm	11.00	19.10	14.25	2.07
0-20 cm	11.60	18.00	14.66	1.62
Exchangeable Mg (cmol+/kg)				
0-10 cm	1.60	6.50	3.54	0.98
10-20 cm	1.80	5.80	3.64	1.05
0-20 cm	1.70	6.20	3.59	0.87
Extractable P (mg/kg)				
0-10 cm	1.0	26.6	6.1	4.8
10-20 cm	<0.1	10.3	4.4	2.7
0-20 cm	1.4	15.4	5.2	3.0
Organic Carbon (%)				
0-10 cm	<0.01	1.20	0.74	0.26
10-20 cm	0.37	3.19	0.82	0.44
0-20 cm	0.18	2.19	0.78	0.35
Total Nitrogen (%)				
0-10 cm	0.075	0.121	0.094	0.012
10-20 cm	0.069	0.180	0.089	0.018
0-20 cm	0.072	0.138	0.092	0.012
Mineralizable N (mg/kg)				
0-10 cm	5.48	82.47	38.90	16.34
10-20 cm	<0.01	56.31	29.91	11.37
0-20 cm	10.61	59.20	34.37	11.41
DTPA-extractable Cu (mg/kg)				
0-10 cm	0.09	9.38	2.89	2.24
10-20 cm	0.02	8.65	3.53	2.49
0-20 cm	0.07	9.02	3.21	2.25
DTPA-extractable Zn (mg/kg)				
0-10 cm	0.16	4.23	1.68	1.03
10-20 cm	0.35	4.88	1.84	1.06
0-20 cm	0.26	4.56	1.76	1.00
DTPA-extractable Mn (mg/kg)				
0-10 cm	14.12	118.42	49.45	26.92
10-20 cm	14.45	112.84	45.73	24.71
0-20 cm	14.29	114.83	47.59	24.72
DTPA-extractable Fe (mg/kg)				
0-10 cm	3.13	391.79	69.47	66.42
10-20 cm	4.61	361.06	74.58	66.54
0-20 cm	3.87	376.43	72.03	62.94

*Values for the 0-20 cm depth are averages of the 0-10 cm and 10-20 cm depths.

Most of the soils have sufficient levels of micronutrients. For copper, only 10 % of the soils in the 0-10 cm depth are below the critical value for Cu (0.2 mg/kg), and only 7.5 % in the 10-20 cm depth.

As regards zinc (Zn), 10 % of the soil samples, regardless of depth, are below the critical value of 0.5 mg/kg. Manganese (Mn) is sufficient since all of the soils are above the critical value (10 mg/kg). For iron (Fe), only

Table 3. Selected soil quality indicators, their critical values, number and frequency of farms below the critical values.

Soil quality	Number of samples	Critical value[1]	Number of farms below critical value	%
pH				
0-10 cm	40	4.5	31	77.5
10-20 cm	40		25	62.5
0-20 cm	40		28	70.0
Exchangeable K (cmol+/kg)				
0-10 cm	40	0.4	3	7.5
10-20 cm	40		3	7.5
0-20 cm	40		0	0
Exchangeable Ca (cmol+/kg)				
0-10 cm	40	0.5	0	0
10-20 cm	40		0	0
0-20 cm	40		0	0
Exchangeable Mg (cmol+/kg)				
0-10 cm	40	0.4	0	0
10-20 cm	40		0	0
0-20 cm	40		0	0
Extractable P (mg/kg)				
0-10 cm	40	10.0	37	92.5
10-20 cm	40		39	97.5
0-20 cm	40		37	92.5
Total N (%)				
0-10 cm	40	0.10	28	70
10-20 cm	40		36	90
0-20 cm	40		30	75
Potentially mineralizable N (mg/kg)				
0-10 cm	40	25.0	5	12.5
10-20 cm	40		6	15
0-20 cm	40		6	15
DTPA-extractable Cu (mg/kg)				
0-10 cm	40	0.2	4	10
10-20 cm	40		3	7.5
0-20 cm	40		4	10
DTPA-extractable Zn (mg/kg)				
0-10 cm	40	0.5	4	10
10-20 cm	40		4	10
0-20 cm	40		4	10
DTPA-extractable Mn (mg/kg)				
0-10 cm	40	10.0	0	0
10-20 cm	40		0	0
0-20 cm	40		0	0
DTPA-extractable Fe (mg/kg)				
0-10 cm	40	4.5	1	2.5
10-20 cm	40		0	0
0-20 cm	40		1	2.5

[1]Critical values of soil parameters except micronutrients were taken from Kelly (1993). Critical values for micronutrients were taken from BSWM (1988).

2.5 % of the soils (0-10 cm depth) are below the critical limit (4.5 mg/kg). Sufficient extractable Fe exists in the 10-20 cm depth.

Comparison of soil qualities in the four pineapple-growing towns

Table 4 shows the comparison of soil physical quality indicators in the four pineapple growing towns of Cavite. All soils have a bulk density within the range of 0.79 to 1.45 g/cm^3, which is below the critical value 1.5 g/cm^3. Soils with bulk density above this critical value can already restrict root growth (Donahue *et al.*, 1977). Bulk density of Indang soils is significantly lower than that of Alfonso soils. Lower bulk density can promote good aeration, drainage and root growth as pineapple cannot tolerate poorly drained soils. Tagaytay and Silang soils have bulk density comparable with the two towns. Moisture content at saturation and aggregate stability of soil samples from four towns did not differ significantly. Field capacity of Alfonso soils is significantly higher than the field capacity of the Indang, Tagaytay and Silang soils. Having a high field capacity is advantageous not only for pineapple crops but also to other rain-fed crops since the soil's water storage capacity is greater. There were no significant differences in the slopes of farms and the depth of the plow layer among all four towns. Tagaytay farms are located in the highest elevation, followed by Alfonso farms. Indang and Silang farms are located in relatively lower topographic positions.

Table 5 shows the comparison of soil chemical quality indicators in the four pineapple growing towns of Cavite. Topsoil (0 -10 cm) total N differed significantly between towns. Total nitrogen of soils in Alfonso and Silang are significantly higher than in Indang and Tagaytay. Significant differences were also observed in the potassium content of topsoil in cultivated areas. Indang soils have significantly lower exchangeable K than the Alfonso, Tagaytay, and Silang soils. In the 10-20 cm and 0-20 cm depths, Indang and Alfonso soils have significantly lower exchangeable K compared with Tagaytay and Silang soils.

In the 10-20 cm depth and 0-20 cm depth, exchangeable Ca is lowest in Silang soils compared with the other three towns where exchangeable Ca levels are comparable. Exchangeable Mg of Tagaytay and Silang soils (10-20 cm depth) are significantly higher than the exchangeable Mg of Indang and Alfonso soils. In the 0-20 cm depth, Silang soils have higher exchangeable Mg than Indang and Alfonso soils.

There were no significant differences in organic C, pH, extractable P and potentially mineralizable N in soils of the four towns.

Regardless of depth, levels of Fe, Cu, and Zn did not differ significantly among towns. The Mn levels of Alfonso and Tagaytay soils are significantly higher than the Mn levels of Indang and Silang soils.

Fertilizer recommendations for the four towns

Ammonium sulfate and urea are nitro-

Table 4. Mean soil physical quality indicators in the four pineapple growing municipalities of Cavite.

Soil quality indicator[1]	Indang	Alfonso	Tagaytay	Silang
Bulk density (g/cm^3)				
0-10 cm	1.05b	1.24a	1.14ab	1.17ab
10-20 cm	1.01b	1.20a	1.16ab	1.17ab
0-20 cm	1.03b	1.22a	1.15ab	1.17a
Aggregate stability (%)				
0-20 cm	79.52a	74.83a	75.87a	77.50a
Moisture content at saturation (%)				
0-20 cm	66.78a	73.76a	65.51a	65.64a
Field capacity moisture content (%)				
0-20 cm	34.21b	48.07a	35.47b	34.29b
Slope (%)	3.80a	4.40a	8.30a	7.30a
Depth of Plow Layer (cm)	17..2a	19.0a	19.9a	21.12a
Elevation (masl)	300.5c	490.5b	562.5a	329.5c

[1]Within a row, means with a common letter are not significantly different at the 5% level by DMRT.

Table 5. Mean soil chemical quality indicators in the four pineapple growing municipalities of Cavite.

Soil quality indicator[1]	Indang	Alfonso	Tagaytay	Silang
pH				
0-10 cm	4.36a	4.28a	4.40a	4.24a
10-20 cm	4.40a	4.27a	4.50a	4.34a
0-20 cm	4.38a	4.28a	4.46a	4.05a
Exchangeable K (cmol+/kg)				
0-10 cm	0.45b	0.51ab	0.60a	0.59a
10-20 cm	0.58ab	0.51b	0.64a	0.61ab
0-20 cm	0.51b	0.51b	0.63a	0.60a
Exchangeable Ca (cmol+/kg)				
0-10 cm	15.88a	15.21a	14.73a	14.44a
10-20 cm	15.66a	14.58a	14.50a	12.25b
0-20 cm	15.77a	14.89a	14.61ab	13.35b
Magnesium (cmol+/kg)				
0-10 cm	3.24a	3.19a	3.68a	4.07a
10-20 cm	3.15b	2.86b	4.03a	4.51a
0-20 cm	3.19bc	3.02c	3.85ab	4.29a
Extractable P (mg/kg)				
0-10 cm	6.63a	6.13a	5.52a	6.46a
10-20 cm	4.13a	4.16a	4.29a	4.83a
0-20 cm	5.38a	5.15a	4.81a	5.65a
Organic Carbon (%)				
0-10 cm	0.67a	1.00a	0.66a	0.76a
10-20 cm	0.71a	0.70a	0.89a	0.77a
0-20 cm	0.87a	0.70a	0.75a	0.85a
Total N (%)				
0-10 cm	0.084b	0.100a	0.091b	0.104a
10-20 cm	0.089a	0.091a	0.086a	0.090a
0-20 cm	0.087a	0.096a	0.092a	0.096a
Potentially mineralizable N (mg/kg)				
0-10 cm	36.87a	39.94a	40.29a	38.51a
10-20 cm	28.39a	33.86a	26.48a	30.59a
0-20 cm	32.63a	36.90a	38.53a	34.55a
DTPA-extractable Cu (mg/kg)				
0-10 cm	3.42a	2.69a	1.92a	3.52a
10-20 cm	4.01a	3.45a	2.81a	3.85a
0-20 cm	3.71a	3.06a	2.36a	3.68a
DTPA-extractable Zn (mg/kg)				
0-10 cm	1.64a	1.73a	1.30a	2.04a
10-20 cm	1.89a	1.78a	1.78a	1.92a
0-20 cm	4.31a	5.14a	5.68a	5.04a
DTPA-extractable Mn (mg/kg)				
0-10 cm	67.21a	34.62b	33.13b	62.35a
10-20 cm	62.37a	29.57b	31.69b	59.27a
0-20 cm	63.59a	32.09b	32.40b	62.36a
DTPA-extractable Fe (mg/kg)				
0-10 cm	59.49a	61.34a	56.33a	100.73a
10-20 cm	66.34a	56.24a	59.40a	116.36a
0-20 cm	62.91a	58.79a	57.86a	108.54a

[1]Within a row, means with a common letter are not significantly different at the 5% level by DMRT.

gen-based fertilizers which are commonly used by pineapple farmers. The survey indicated that 63 % of the farmers are applying fertilizers way beyond the recommended rate of 250 kg N/ha or 24 sacks/ha for ammonium sulfate or 10 sacks/ha for urea. Twenty-one percent of the farmers are under-fertilizing and only 16 % of them are fertilizing close to the recommended amount.

All soil samples are low in nitrogen so that fertiliser recommendations focused on this nutrient. The recommendation is based on the

planting density of each farm. Ammonium sulfate application is recommended as g/plant (Table 6a).

The soils contain low levels of P but as stated earlier, pineapple requires little P. Nevertheless, some phosphate fertiliser (90 kg P_2O_5/ha) was recommended to avoid long-term P depletion. Since all soils have sufficient potassium, fertilisation with this nutrient was not recommended (Table 6b).

Comparison of soils grown to pineapple and soils in relatively undisturbed sites

Soil quality indicators are often better in undisturbed soils relative to cultivated soils, reflecting some decline in soil fertility due to long-term cropping (Table 7). Bulk densities of undisturbed soils are slightly higher than bulk density of cultivated soils reflecting the influence of cultivation in the latter. Total nitrogen content of undisturbed soils is significantly higher than in the cropped soils for the 0-10 cm and 0-20 cm depths. On the other hand, exchangeable K in the 10-20 cm layer is significantly higher in the cultivated soils. The pH of soils in the undisturbed sites is significantly higher than in the cultivated sites.

Exchangeable Ca in the 10-20 cm depth is significantly better in the undisturbed sites. Organic carbon and extractable P values are also higher for the undisturbed sites compared with the cultivated sites but the differences were not statistically significant.

Micronutrients Cu and Zn levels of the uncropped sites (0-10 cm and 10-20 cm depths) are significantly higher than those of the cropped sites. Manganese and Fe levels of the soils cropped to pineapple did not differ statistically to levels in the uncropped sites.

The amount of mineralizable N in uncropped soils is significantly higher than the mineralizable N of the cropped soils.

These results imply that if soils are allowed some rest or fallow period, some replenishment of nutrients lost through plant uptake may be expected.

Relationship between soil qualities and pineapple productivity

Average fruit yield based on interviews with the farmers was 21.1 t/ha with a minimum value of 7.5 t/ha and a maximum of 44 t/ha. This average value is very close to the 21 t/ha provincial average fruit yield reported by the Bureau of Agricultural Statistics (BAS, 2003). Table 8 shows the average fruit yield of the four towns. Tagaytay has the highest recorded average yield followed by Silang, then Indang and lastly Alfonso. Analysis of variance, however, revealed no significant yield differences between towns.

Table 9 shows the linear correlation coefficients between selected soil quality indicators and fruit yield reported by the farmers. Exchangeable Mg and organic C are closely positively related to yield. Magnesium is a component of chlorophyll, the green pigment in leaves that uses sunlight energy to convert carbon dioxide to carbohydrates. Decrease of this nutrient in soil below 10 mg/ kg can affect plant metabolism (Kelly, 1993). Organic matter acts as a source and sink of nutrients in soils and it appears that it is also a sensitive indicator for crop yield. Thus, any changes in these variables are likely to be good predictors of pineapple productivity. Other soil quality indicators were not significantly correlated with fruit yield.

Decline of soil pH with time

Figure 1 shows that the longer the soils are cropped to pineapple, there is a trend towards declining topsoil (0-10 cm) pH. This is the soil layer where nitrogenous fertiliser application and incorporation occur. If a line is fitted through these points, the regression line is not statistically significant at the 5 % level but significant at the 7.5 % level [Fitted line: Soil pH=4.47 – 0.01 (Yrs Under Pineapple Cultivation), P=0.063]. This indicates that, with time, more significant decline in soil pH is inevitable if farmers continue applying ammonium-based fertilizers without employing any soil amelioration measures such as liming.

CONCLUSIONS AND RECOMMENDATIONS

Soil quality indicators are often better in non-cultivated sites compared to the sites cropped to pineapple. Thus, it is important to allow fallow period to rest the soil in order to replenish lost nutrients. More significant decline in soil pH is anticipated if farmers do not employ any soil amelioration measures such as liming. Farms with soils having low pH value should employ liming. A long-term research programme on monitoring of pineapple soil quality (e.g. every five years or so) should be initiated.

Analysis of nutrient elements in pineapple tissues should be done to get an

Table 6a. Fertilizer recommendations for nitrogen for each pineapple farm.

	Farm of:	Total N in 0-20 cm depth (%)	Rating	Number of plants/ha	Ammonium sulfate (g/plant)
1.	David Cabral	0.079	Low	10000	114.4
2.	Angeles Vicedo	0.138	Low	20000	57.1
3.	Leonardo Matel	0.079	Low	20000	57.1
4.	Nicolas Silan	0.079	Low	20000	57.1
5.	Simon Avilla	0.08	Low	20000	57.1
6.	Aniceto Pejana	0.075	Low	12000	95.2
7.	Cenon Rodil	0.084	Low	30000	38.1
8.	Carding Herrera	0.081	Low	20000	57.1
9.	Domingo Ruiz	0.079	Low	45000	25.4
10.	Eusebio Mojica	0.091	Low	25000	45.7
11.	Cerio Cumprada	0.102	Low	20000	57.1
12.	Narciso Resurrecion	0.076	Low	10000	114.4
13.	Elpidio del Mundo	0.097	Low	10000	114.4
14.	Marciano Vislenio	0.102	Low	30000	38.1
15.	Catalino Vislenio	0.1	Low	20000	57.1
16.	Nestor Morales	0.091	Low	25000	45.7
17.	Eufronio Mendoza	0.102	Low	20000	57.1
18.	Rizal Alano	0.088	Low	25000	45.7
19.	Rizal Ortega	0.102	Low	20000	57.1
20.	Cesar Degrano	0.097	Low	25000	45.7
21.	Antonio Umali	0.80	Low	30000	38.1
22.	Roberto Ferma	0.091	Low	20000	57.1
23.	Fermin Joya	0.092	Low	12000	95.2
24.	Mario Humarang	0.086	Low	20000	57.1
25.	Carmen Dimapilis	0.093	Low	20000	57.1
26.	Vivencio Daño	0.085	Low	30000	38.1
27.	Raymundo de Guzman	0.098	Low	20000	57.1
28.	Elejio Pia	0.085	Low	30000	38.1
29.	Benedicto Rodriguez	0.087	Low	30000	38.1
30.	Pedring de Leon	0.087	Low	25000	45.7
31.	Lisa Layaban	0.093	Low	10000	114.2
32.	Leonardo Mendoza	0.1	Low	20000	57.1
33.	Willy Cortez	0.113	Low	20000	57.1
34.	Nicanor Miranda	0.094	Low	25000	45.7
35.	Florante Belen	0.107	Low	30000	38.1
36.	Librado Toledo	0.094	Low	22000	51.9
37.	Daniel Tumbo	0.102	Low	28000	40.7
38.	Lito Mendoza	0.091	Low	25000	45.7
39.	Savino Baysa	0.085	Low	25000	45.7
40.	Irenea Zacharias	0.091	Low	25000	45.7

Critical Value = 0.10%

estimate of nutrient balance and nutrient depletion in soils. Further studies should be done to measure nitrate pollution via leaching in soil and sediment runoff in adjacent rivers and creeks of pineapple farms receiving heavy inputs of nitrogen fertilizers.

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Table 6b. Fertilizer recommendation for phosphorus for each pineapple farm.

	Farm of:	Phosphorus in 0-20 cm depth (mg/kg)	Rating	Number of plants/ha	Solophos P_2O_5 [0-18-0] (g/plant)
1.	David Cabral	6.7	Low	10000	50
2.	Angeles Vicedo	3.35	Low	20000	25
3.	Leonardo Matel	4.8	Low	20000	25
4.	Nicolas Silan	9.45	Low	20000	25
5.	Simon Avilla	4.4	Low	20000	25
6.	Aniceto Pejana	2.2	Low	12000	42.7
7.	Cenon Rodil	8.3	Low	30000	16.7
8.	Carding Herrera	2.55	Low	20000	25
9.	Domingo Ruiz	6.35	Low	45000	11.11
10.	Eusebio Mojica	5.7	Low	25000	20
11.	Cerio Cumprada	4.4	Low	20000	25
12.	Narciso Resurrecion	15.4	Low	10000	50
13.	Elpidio del Mundo	1.9	Low	10000	50
14.	Marciano Vislenio	3.9	Low	30000	16.7
15.	Catalino Vislenio	2.2	Low	20000	25
16.	Nestor Morales	3.6	Low	25000	20
17.	Eufronio Mendoza	2.75	Low	20000	25
18.	Rizal Alano	4.65	Low	25000	20
19.	Rizal Ortega	9.6	Low	20000	25
20.	Cesar Degrano	3.05	Low	25000	20
21.	Antonio Umali	4	Low	30000	16.7
22.	Roberto Ferma	4.9	Low	20000	25
23.	Fermin Joya	6.35	Low	12000	42.7
24.	Mario Humarang	5.75	Low	20000	25
25.	Carmen Dimapilis	3.2	Low	20000	25
26.	Vivencio Daño	5.95	Low	30000	16.7
27.	Raymundo de Guzman	7.7	Low	20000	25
28.	Elejio Pia	4.95	Low	30000	16.7
29.	Benedicto Rodriguez	1.9	Low	30000	16.7
30.	Pedring de Leon	3.35	Low	25000	20
31.	Lisa Layaban	4.5	Low	10000	50
32.	Leonardo Mendoza	2.2	Low	20000	25
33.	Willy Cortez	10.05	Low	20000	25
34.	Nicanor Miranda	6.4	Low	25000	20
35.	Florante Belen	2.75	Low	30000	16.7
36.	Librado Toledo	6.55	Low	22000	22.7
37.	Daniel Tumbo	9.45	Low	28000	17.8
38.	Lito Mendoza	1.35	Low	25000	20
39.	Savino Baysa	2.75	Low	25000	20
40.	Irenea Zacharias	10.45	Low	25000	20

Critical Value = 10 ppm

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Table 7. Comparison of soil quality indicators in cropped and undisturbed soils.

Soil quality indicator	Cropped	Undisturbed
Bulk density (g/cm^3)		
0-10 cm	1.16	1.17
10-20 cm	1.14	1.16
0-20 cm	1.15	1.17
pH		
0-10 cm	4.31	4.63**
10-20 cm	4.41	4.69**
0-20 cm	4.37	4.66**
Exchangeable K (cmol+/kg)		
0-10 cm	0.54	0.58
10-20 cm	0.58	0.51*
0-20 cm	0.57	0.55
Exchangeable Ca (cmol+/kg)		
0-10 cm	15.03	16.21
10-20 cm	14.25	14.87*
0-20 cm	14.66	15.70*
Magnesium (cmol+/kg)		
0-10 cm	3.55	3.54
10-20 cm	3.64	3.52
0-20 cm	3.59	3.53
Extractable P (mg/kg)		
0-10 cm	6.1	8.5
10-20 cm	4.4	5.8
0-20 cm	5.2	7.2
Organic Carbon (%)		
0-10 cm	0.74	0.81
10-20 cm	0.82	0.74
0-20 cm	0.79	0.78

*Statistically significant at the 5% level of significance by a paired t-test.
** Statistically significant at the 1% level of significance by a paired t-test.

Table 8. Average fruit yields in the four pineapple growing municipalities of Cavite.

Reported fruit yield (t/ha)			
Indang	Alfonso	Tagaytay	Silang
21.0	18.2	22.8	22.0

Table 9. Soil quality indicators significantly correlated with yield.

Soil quality indicator	Correlation coefficient
Exchangeable Mg (cmol+/kg)	
0-10 cm	0.461**
10-20 cm	0.333*
Organic carbon (%)	
10-20 cm	0.602**
0-20 cm	0.557**

*Significant at the 5% level
** Significant at the 1% level

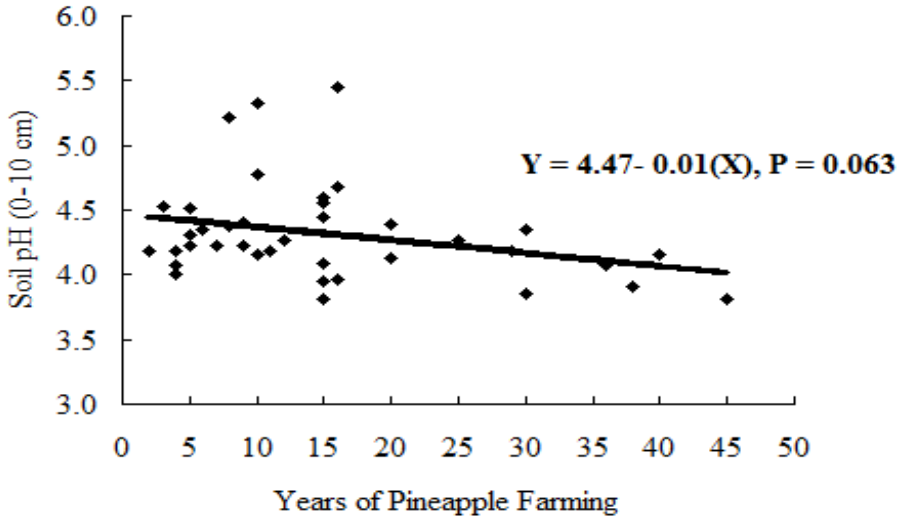

Figure 1. Declining trend of soil pH (0-10 cm) with time.

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Soil quality, management practices and sustainability of pineapple farms in Cavite, Philippines: Part 2. Management practices and sustainability assessment

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ABSTRACT

The management practices and sustainability of pineapple farms in Cavite, Philippines, were assessed. Most farmers are plowing and harrowing their land 3-4 times a year. Single row planting is predominant (95 %) as well as pineapple monocropping (67 %). Only 7.5 % of the farmers are practicing any soil and water conservation measures. More than half of the farmers are applying nitrogen fertiliser above the recommended rate, representing a waste of valuable farm resource that could also lead to nutrient pollution problems. The Framework for Evaluating Sustainable Land Management was used to assess the sustainability of each farm in terms of productivity, security, protection, economic viability, and social acceptability. Results showed that the pineapple farming systems are weak with respect to the security and protection pillars of sustainability due to the lack of long-term incorporation of crop residues and the general absence of on-farm soil and water conservation measures. These are the issues which should be addressed by agricultural extension programs to ensure the environmental sustainability of pineapple farming in the province.

Key words: Sustainability assessment, pineapple farming.

INTRODUCTION

In a preceding paper, soil quality indicators of selected pineapple farms in Cavite were measured and evaluated with respect to soil quality standards, and fertiliser recommendations were tailored to suit each farm (Guinto & Inciong, submitted). In this paper, we attempt to use soil quality indicators and soil management practices as components of farming systems sustainability coupled with farm-level socio-economic data as exemplified in the Framework for Evaluating Suitable Land Management (FESLM) approach where soil qualities and other factors affecting productivity, economic viability, social acceptability, security and protection are used to predict the sustainability of farming (Smyth & Dumanski, 1993). The FESLM is based on the definition of sustainable land management as a system that combines technologies, policies, and activities aimed at integrating socio-economic principles with environmental concerns so as to maintain or enhance production and services simultaneously; reduce the level of production risk; protect the potential of natural resources; be economically viable, and be socially acceptable (Dumanski & Smyth, 1994). The FESLM approach consists of a logical analysis procedure for guiding the evaluation of land use sustainability. The three main stages are: (1) identification of the purpose of evaluation, specifically land use systems and management practices; (2) definition of the analysis process which consists of evaluation factors, diagnostic criteria, indicators and thresholds to be utilized; and (3) an assessment endpoint that identifies the sustainability status of the land use system under evaluation. Learning about these parameters can help us maintain and/or improve farming systems sustainability. It is important to note, however, that soil qualities are only one component of the many factors affecting productivity and, subsequently, sustainability (Ringrose-Voase *et al.*, 1997). The objectives of this paper were to: (1) document and assess the fertilisation and soil management practices of pineapple farmers in Cavite; and (2) assess sustainability of the pineapple farms using the FESLM approach of the International Board for Soil Resources and Management (IBSRAM).

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MATERIALS AND METHODS

Data on socio-economics and management technologies of farmers were obtained from a Bureau of Agricultural Research, Department of Agriculture-funded research project on the socio-economic impact assessment of pineapple technology in Southern Tagalog and Bicol Regions by Dr. Alice T. Valerio of the College of Economics and Development Studies, Cavite State University (Valerio, 2002). During the interviews, a survey questionnaire was used to ask farmers about their farm management practices (including soil management practices) and to obtain socio-economic data (e.g. land tenure, years engaged in farming, etc.). Details of the survey questionnaire are provided in Inciong (2004). A total of 38 pineapple farmers from Indang, Silang, Alfonso and Tagaytay City participated in the interview.

Sustainability of pineapple farms was assessed using the Decision Support System for Evaluating Sustainable Land Management in Sloping Lands of South-East Asia Version 1.1 (Alpha-Test Version) Software (Rais *et al*., 1997; IBSRAM, 2000). In this software, the five pillars of the international Framework for Evaluating Sustainable Land Management (FESLM) (Smyth & Dumanski, 1993) were used. These include productivity (e.g. yield, soil organic matter and nutrients), security (e.g. long-term trends in rainfall and variability), protection (e.g. soil erosion), economic viability (e.g. benefit-cost ratio, on-farm and off-farm income, labor availability), and social acceptability (e.g. land tenure, access to extension services). The SLM indicators along five FESLM pillars have been transformed into several user-friendly questions. For each question, one of the multiple choice answers can be selected. Some examples of the questions pertain to land holding size (less, than 1 ha, 1 to 2 ha, more than 2 ha); annual cropping intensity (2 to 3 crops with conservation measures, 2 to 3 crops without conservation measures, one crop with conservation measures, one crop without conservation measures); land tenure (full ownership, long term user rights, no official land title). The relevant answers for the farm being evaluated were input into the DSS-SLM system. Based on the information for a specific farm, DSS-SLM provides an assessment of the sustainability status of the farm as influenced by land management practices by the farmer. The sustainability status for each of the FESLM pillars namely productivity, security, protection, economic viability and social acceptability is provided as one of the four following possible scenarios: Score=1: land management practices meet sustainability requirements; Score=2: land management practices are marginally above the threshold for sustainability; Score=3: land management practices are marginally below the threshold for sustainability; and Score=4: land management practices do not meet sustainability requirements. Full details of the assessment technique are provided in Rais *et al.* (1997, 2000).

RESULTS AND DISCUSSION

Management practices of pineapple farmers

The management practices of the pineapple farmers in the four municipalities of Cavite are shown in Table 1. Most of the farmers are plowing and harrowing their land 3-4 times a year. Single row planting is predominant (95 %). Multi-cropping is practiced by the farmers although mono-cropping is more dominant (67 %). Only 7.5 percent of the farmers are practicing any form of soil and water conservation measures. This is most likely because majority of the farmers (65 %) are tenants while the rest (35 %) are owners. Lack of awareness on the importance of conserving valuable topsoil could also be one reason. Soil and water conservation measures practiced by those few farmers include mulching using coconut fronds and pineapple residues, and planting strips of Napier grass (*Pennisetum purpureum)* at the edges of their farms.

Fifty-five percent of the farmers are applying nitrogen fertiliser above 300 kg N/ha, which is well above the recommended rate of 250 kg N/ha. Only 1 farmer (3 %) applies phosphorus fertiliser on his farm. Application of fertiliser nitrogen above the recommended rate is counter-productive because excessive nitrogen does not benefit the plant at all, represents a waste of valuable farm resource, and could cause nutrient pollution via nitrate leaching or sediment runoff leading to eutrophication of streams and rivers.

Correlations between management practices and soil quality were computed but no significant relationships were found (data not presented). Similar results were obtained by Ringrose-Voase *et al.* (1997) who indicated that the reason for the low correlations is that

Table 1. Management practices of pineapple farmers in upland Cavite.

Management practice	Frequency	Number of farmers	Percentage
Plowing			
	1-2	11	29
	3-4	20	53
	5-6	7	18
Harrowing	0	1	3
	1-2	15	39
	3-4	18	47
	5-6	4	11
Planting system	Single row	38	95
	Double row	2	5
Cropping system	Mono-cropping	27	67
	Multi-cropping	13	33
Soil and water conservation techniques	Presence	3	8
	Absence	37	92
Planting density (plants per hectare)	10000-20000	21	55
	21000-30000	16	42
	>30000	1	3
Kg N/ha applied	<100 kg	1	3
	100-300 kg	16	42
	>300 kg	21	55
Kg P_2O_5/ha applied	None	37	97
	100-200 kg	1	3

soil qualities and management practices are only one component of the many factors affecting productivity.

Sustainability assessment of the pineapple farms

Sustainability of farms was assessed using the five pillars of the Framework for Evaluating Sustainable Land Management (FESLM) using IBSRAM's DSS-SLM software. These include: productivity, economic viability, social acceptability, security, and protection. It should be noted that the version of DSS-SLM software used in this research contains only a diagnostic module which identify sustainability status of the farm for each FESLM pillar. The prognosis or prediction aspect of DSS-SLM is still under development (IBSRAM, 2000). Nevertheless, the diagnostic module in itself is already useful in highlighting the weak spots of a particular farm in order to improve its sustainability in the future.

Regardless of town, all of the farms are marginally above the threshold for sustainability using the productivity criterion (Score=2, see Table 2). Productivity rating was not affected by the low value of N, since farmers are applying nitrogen fertilizers to boost their yield. The average yield of most of the farms is less than 25 percent of the average yield of the community (21 t/ha according to the Bureau of Agricultural Statistics (BAS), 2003).

Using the economic viability criterion, 82 % of the farms are marginally above the threshold for sustainability and only 16 % met the sustainability criterion.

All of the farms have direct access to main roads, making transportation of harvested pineapple fruits easy, and agricultural inputs are available as required. Farmers are either owners or tenants with long-term user rights. Also, health and educational facilities are adequate, making pineapple farming socially acceptable. Thus, about 60 % of the farms are marginally above the threshold while near 40 % of the sites met the sustainability threshold.

The security criterion has three indicators: average annual rainfall, drought frequency and the amount of biomass or crop residues plowed back to the land. All farms have sufficient rainfall and drought occurrence

Table 2. Number and percentage of farms belonging to a particular sustainability score by FESLM pillar category.

FESLM pillar	Score*	Number of farms	Percentage
Productivity	1	0	0
	2	38	100
	3	0	0
	4	0	0
Economic viability	1	6	16
	2	31	82
	3	0	0
	4	1	2
Social acceptability	1	15	39.5
	2	23	60.5
	3	0	0
	4	0	0
Security	1	0	0
	2	0	0
	3	0	0
	4	38	100
Protection	1	3	7.9
	2	14	36.8
	3	18	47.4
	4	3	7.9

*1 = meets sustainability; 2 = marginally above the threshold for sustainability; 3 = marginally below the threshold for sustainability; 4 = does not meet sustainability criterion

is not frequent, but the amount of crop residues incorporated back to the soil on a long -term basis is low. This is regarded as critical by DSS-SLM making all of the farms not sustainable using the security criterion of the FESLM (Score=4).

Almost half of the farms (47 %) are marginally below the protection criterion. Most farmers are not doing any erosion control practices and most of them are engaged in monocropping which makes the soil more prone to erosion and nutrient loss. About 37 % of the farms, however, are marginally above the protection criterion.

Table 3 shows the mean sustainability assessment scores of the four pineapple growing municipalities of Cavite by FESLM pillar. For productivity and economic viability, all of the municipalities were marginally above the sustainability threshold. For social acceptability, Silang met the sustainability threshold while the rest of the municipalities were marginally above the sustainability threshold. As explained earlier, all municipalities scored poorly with respect to the security pillar. For the protection pillar, Alfonso and Silang fared better than Indang and Tagaytay (Score of 2 vs. 3).

Table 3. Mean sustainability assessment scores of the four pineapple growing municipalities of Cavite using the five pillars of FESLM.

Town	Number of farms	FESLM Pillar				
		Productivity	Economic viability	Social acceptability	Security	Protection
Indang	9	2*	2	2	4	3
Alfonso	9	2	2	2	4	2
Tagaytay	10	2	2	2	4	3
Silang	10	2	2	1	4	2
All farms**	38	2	2	1.7	4	2.8

*1= meets sustainability; 2 = marginally above the threshold for sustainability; 3 = marginally below the threshold for sustainability; 4 = does not meet sustainability criterion
**For all farms, the value of each FESLM pillar is a weighted average.

CONCLUSION

The use of soil quality indicators and soil management practices together with socio-economic data using the FESLM approach is useful in assessing the sustainability of pineapple farms in Cavite. The evaluation revealed that pineapple farming systems of the province are weak with respect to the security and protection pillars of sustainability due to the lack of long-term incorporation of crop residues and the general absence of on-farm soil and water conservation measures. Extension efforts by the Department of Agriculture and Cavite State University need to raise farmers' awareness on these issues to ensure that pineapple crops are grown in an environmentally sustainable manner into the future.

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An overview of crops experimental designs: Comparing their layout arrangements, merits and limitations

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ABSTRACT

The reliability and applicability of agricultural information rests on its validity. The validity of research information depends on the process through which it is generated. Hence, designing of experiments forms the backbone of any research endeavor in the discipline of agriculture and allied sciences. Therefore, it is very important to select the right kind of experimental design for generating relevant agricultural technology and innovations. This paper provides a comparative review of systematic and randomised arrangements in layouts of agricultural crop experiments. It compares unique characteristics, advantages and limitations of layout designs of major agricultural field experiments. The aim is to help enhance the knowledge, confidence and capabilities of the young agricultural researchers to critically evaluate and decide as to which type of field experimental design is more suitable for their particular location and agro-climatic condition.

Key words: Crop experimental layouts, merits of experimental layouts, experimental designs.

INTRODUCTION

The main reason for dismal success rate of agricultural development projects in developing countries like Pacific island countries (PICs) is that most of the projects were not based on research-evidence. The limited adoption of the recommended agri-cultural production techniques by farmers also reflects weaknesses of the new agricultural production methods suggested that do not compete favourably with ones farmers already use.

In the field of agriculture, an experi-mental research is conducted to answer a particular question or solve a particular problem. Agricultural research seeks to increase production by improving the yield of crops per unit area or by growing extra crop during the year by searching high yielding crop varieties, crop planting techniques, fertilisation and pest management methods that allow the formulation of new crop sequences and combinations that are managed differently from the existing ones. The reliability and applicability of agricultural research information is affected by the process through which it is generated. Selecting an appropriate type of experimental design is an important component of research process. Agricultural research is conducted to obtain data in stricter control under carefully specified conditions. This requires scientific designing of research experiments, partly to eliminate various disturbing effects that might creep in and partly to ensure that maximum precision is achieved for the amount of effort expended (Cox, 1958; Mead, 1990; Atkinson, *et al.,* 2007). Designing is done to increase the precision of the experiment by reducing the experimental error by various techniques (Cochran, 1957; Federer, 1967; Hicks, 1973; Fisher, 1990; Atkinson & Bailey, 2001). Experimental design is the conceptual structure within which research is conducted. It shows the layout arrangement of an experiment. It is the arrangement of conditions for data-gathering exercises where variation is present (Atkinson & Bailey, 2001; Hinkelmann & Kempthorne, 2008).

A range of experimental designs are available to suit a wide variety of agricultural circumstances (Little & hills, 1978; Peterson, 1994; Quinn & Keough, 2002; Hoshmand, 2006). A correct choice of experimental design depends partly on knowledge of the experimental material and partly on the kind of questions one wishes to tackle (Bailey, 2008). It is, therefore, extremely important that alternative designs be carefully considered before embarking on the actual procedure of

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experimentation (Cox, 1958). If the research design is badly chosen, the data analysis may be unduly laborious, and it may even turn out that certain important questions regarding the research problem studied cannot be answered at all (Montgomery, 1991; Ghosh & Rao, 1996; Clewer & Scarisbrick, 2001; Bailey, 2008). Therefore, selecting a right type of experimental design for studying a particular agricultural problem is very important.

The root cause of inadequate agricultural research output in PICs is that there is a dearth of adequately trained staff to undertake scientific agricultural research. To overcome this handicap, it is important to build research capabilities of agricultural research staff. The first step in this direction would be to make them aware about the various types of layout arrangements for agricultural experimentation. This paper is an effort in this direction. The paper provides an overview of various agricultural experimental designs and their unique characteristics, comparative advantages and limitations. The two main questions discussed in the paper are: (1) What are the main research designs available to agricultural researchers? (2) Which design is most suitable for which type of research? The intention is to help enhance research skills of agricultural students and other potential researchers and to inspire self-confidence of young agricultural researchers in developing countries like PICs, thereby encouraging their overall research efforts and initiatives. This paper may also be of use to those active in management and funding of agricultural research and training of the agricultural research and extension staff. Boosting of agricultural research capabilities of the existing and potential agricultural research staff of PICs will accelerate output of location-specific agricultural technologies and innovations suitable for adoption on smallholder farms under varied resource constraints and agro-climate conditions in the South Pacific region.

The paper is organized in six sections, starting with an introduction. The next section provides definition of some basic terms and concepts used in agricultural research discussions. The third section describes broad classes of agricultural experimental layouts. In the fourth section, various types of single factor designs are discussed. Multi-factor experiment -tal designs are discussed in the fifth section. Finally, summary and conclusions are presented.

SOME BASIC TERMS AND CONCEPTS

Research: Research means systematic investigation to establish facts. It is systematic because all the activities are planned and executed based on rules so everything can be repeated.

Data: These are the information collected about various variables of experiment in which a researcher is interested. Data are collected by experimentation, sampling or routine observations.

***Variable*:** A variable/factor denotes a feature of an item that we measure. It denotes a situation, number or quantity that can vary (change) or be varied. Some important variables related to agriculture experiments include: (i) *Agronomic variables* - germination and survival percentages, plant height and growth, stem form, biomass weight, crop yield, etc.; (ii) *Soil chemical variables* - soil fertility (nutrients type and level); (iii) *Plant chemical variables* - levels of essential elements (N, P, K, etc.); (iv) *Socio-economic variables* perceived to be of importance to the farmers (farmers' views of the importance of a particular treatment, costs and benefits of improved techniques, adoption rates); and (v) *Derived variables*, e.g., differences in response of control and introduced treatments.

***Experiment*:** An experiment is the act of conducting a controlled test or investigation. Most of, if not all, the conditions that happened or were used in the experiment are known or regulated. In experimental research, different kinds or levels of a particular factor or several factors are evaluated. Thus, experiment is a research situation in which at least one independent variable, called the experimental variable, is deliberately manipulated or varied by the researcher. Most agricultural field experiments are based on the concepts of replication, local control (blocking) and randomisation (Atkinson & Bailey, 2001; Hinkelmann & Kempthorne, 2008).

Design: Design means arrangement. It is the conceptual structure which shows the layout arrangement of an experiment with respect to the number of treatments and replications and the spatial relations to one another. In agricultural research, proper design is important because we want to establish or find the true results without any doubt in mind. With improper or wrong design, results may

not be convincing or reliable. We need experimental design to control variability so that treatment effects can be identified.

***Treatments*:** They denote different conditions, processes or interventions under which experimental and control groups are put in the experimental design. These are materials being forced on the subject (experimental unit) and whose effect is to be monitored. A treatment can be either qualitative (e.g. species, fertiliser types) or quantitative (e.g. quantified levels of a particular fertiliser type).

Replication: It denotes the repetition of a test or complete experiment. Treatments are repeated to help identify the sources of variation and to better estimate the true effects of treatments. Replication allows for estimation of the experimental error by applying treatments to different plots under the same experimental conditions (Fisher, 1990; Ghosh & Rao, 1996). Sufficient replication is needed to distinguish treatments from background variability (Fisher, 1990; Atkinson *et al.*, 2007).

Local-control (or Blocking): A process of research design which minimizes the influence or effect of extraneous variables that are not related to the purpose of study but may affect the dependent variables. For example, the soils generally constitute a continuum with variability at different scales. Thus, the structure of soil variability in the experimental area has important implications for the design of experiments (Fagroud & van Meirvenne, 2002). Local-control by blocking is the arrangement of grouping experimental units into homogeneous groups (blocks) consisting of units that are similar to one another. A block is a relatively large area or several identical units receiving all or most of the treatments. Blocking is used in agricultural field experiments to control the adverse effects of soil heterogeneity (Martin, 1986; Calinski & Kageyama, 2000).

***Randomisation*:** It is the process of making allocation of treatments to experimental units by means of some appropriate random method. Random is the process in which each item has an equal chance of being chosen. Basic purpose of randomisation is to remove bias from the estimation of treatment effects (Atkinson & Bailey, 2001), and to equalize the error over all treatment differences (Fagroud & van Meirvenne, 2002).

***Experimental units*:** The pre-determined smallest units (e.g. plots) where different treatments are used. The information (data) for comparison is collected from such single units.

***Hypothesis*:** It is a statement that has to be verified or disproved through experimentation. It is based on the researcher's past experiences, observations and/or theoretical considerations.

TYPES OF AGRICULTURAL EXPERIMENTAL LAYOUTS

Paper describes the most common layout arrangements of crop experiments that arise in practice and point out the advantages and weaknesses of each experimental design.

A range of experimental designs are available to suit a wide variety of agricultural circumstances. Experiments can be classified into two broad categories, namely, single-factor experiments and multifactor experiments. In the single-factor experiment, only one factor is varied while all others are kept constant. In such experiments, the treatments consist solely of the different levels of the single variable factor, while all other factors are applied uniformly to all plots at a constant prescribed level (Cochran, 1957; Federer, 1967: Mead, 1990). Examples are: fertiliser trials (where several rates of a single fertiliser element are tested); insecticide trials (where different concentration levels of a chemical are used); plant-population trials (where several plant densities of a crop are tested). In fertiliser trials, several rates of single fertiliser element, say nitrogen, may be tested. All other factors such as agronomic practices, irrigation, and insect control are kept at uniform level.

When response to the factor of interest is expected to differ under different levels of the other factors, the use of those experimental designs which can handle simultaneously two or more variable factors are considered (Cochran, 1957; Cox, 1958; Hicks, 1973, Mead, 1990). Such experiments are known as multi-factor experiments. These experiments help evaluate the individual effects of each factor as well as their interaction, if the effect of one factor changes as the level of other factor changes (Little & Hills, 1978; Kuehl, 2000; Hosmand, 2006)

A correct choice of experimental design depends partly on the experimental material studied and partly on the kind of research problem one wishes to tackle (Bailey, 2008). It is, therefore, extremely important to

carefully consider the unique characteristics of alternative designs before selecting any one for the actual procedure of experimentation (Cox, 1958).

Most agricultural research is of comparative nature concerned with comparing effects of different factors or treatments. Hence, the majority of research needs can be met sufficiently well by a fairly small number of experimental designs (Hinkelmann & Kempthorne, 2008). Most commonly used experimental designs are listed in Table 1.

Three most commonly used single factor experimental designs are: (i) completely randomised design (CRD), (ii) randomised complete block design (RCBD), and (iii) Latin square design (LS design). Under the multi-factor experimental designs the two most commonly used arrangements are: (i) Factorial experiments, and (ii) the Split-plot design. The term "factorial" describes a specific way in which the treatments are formed. A Factorial experiment can be laid out using randomised arrangement of treatments to plots in a CRD, RCBD or LS design. Split-plot experiment is laid out by using random arrangements separately for main-plot treatments and split plot treatments. In the following section, the layout arrangements for various types of single -factor experiments are compared.

SINGLE-FACTOR EXPERIMENTAL DESIGNS

In single factor experimental designs, levels of **one** factor (e.g. varieties of a crop, fertiliser levels) with several replications in each are tested while all other factors (such as agronomic practices, insect control, irrigation, weeding, etc.) are kept at uniform level. The three most commonly used single-factor experimental designs are: (i) completely randomised design, (ii) randomised complete block design, and (iii) Latin square design. Each of these layouts are discussed in the following sub-sections.

1). Completely Randomised Design

In Completely randomised design (CRD), various levels (treatments) of **one** factor with several replications in each are tested while all other factors are kept at uniform level. The treatments are arranged completely at random over the **whole** experimental units (e.g. plots). Each experimental unit has an equal chance of receiving a certain treatment. Each treatment can appear anywhere among total plots, even in adjacent plots. It is called completely randomised design because selection of plot for each treatment is done considering all total plots and all treatments together.

Suppose there are (t) treatments that are replicated (r) times each. The experiment will require, t x r = n number of crop experimental plots. Let us suppose there are **five** treatments designated as **A, B, C, D** and **E** which are to be evaluated using their **four** replications in the CR design. The total number of plots required for this experiment will be, n = 5 x 4 = 20 plots. Any one of the five treatments, say C, will occupy any **four** plots (r) of the total 20 plots of experimental area.

The process used in layout of experiment in CRD is as follows. (1) Determine the number of treatments and the number of replications in the experiment. (2) Determine the number of plots (n) required for the experiment by multiplying number of treatments (t) with the number of replications (r), i.e., n = t x r. (3) Divide the environmental area into (n) number of plots of equal size and assign each plot a serial number in any manner starting with one. (4) Arrange treatment units equal to number of replications (r) of each

Table 1. Commonly used layout arrangements for assigning treatments (or treatment combinations) to agricultural experimental plots.

Single factor experimental layouts	Multi-factor experimental layouts
i) Completely randomised design (CRD) ii) Randomized complete block design (RCBD) iii) Latin square design (LS design)	**i) Factorial designs:** Using randomisation arrangements of (a) CRD (b) RCBD (c) LS design **ii) Split-plot designs:** Using randomisation arrangements of (a) CRD (b) RCBD

treatment. (5) Put serial number on all the experimental treatment units together. (6) Assign each of the treatments (experimental material units) to each of experimental plots without any restriction by any randomisation scheme.

A sample layout of CRD is shown in Table 2. It may be noted that each treatment occurs four times in the total 20 plots but not necessarily in each row or column of the layout.

Table 2. An example of single factor experimental layout in Completely Randomised Design with five treatments (A, B, C, D and E) each replicated four times. Total number of plots in experimental layout is 5 x 4 = 20. (Numerals denote plot numbers in the experimental area).

1 B	2 A	3 E	4 A	5 D
6 B	7 C	8 D	9 A	10 E
11 E	12 D	13 B	14 C	15 C
16 D	17 E	18 A	19 B	20 C

The CRD layout has many advantages. (1) It is a very flexible design as any number of treatments can be used. (2) The number of replications per treatment need not be the same, i.e. it allows for unequal replications between the treatments and this is useful if some treatments have inadequate experimental resources and therefore will have less replication than others. (3) The statistical analysis of CRD data is comparatively easy and unaffected if some observations for any treatment are lost or missing. (4) Comparatively, it provides researcher with more error degrees of freedom.

There are some limitations of CRD layout. (1) This design is suitable only if the experimental units are uniform or homogeneous. It does not account for heterogeneity in experimental material, e.g. fluctuation due to variation in soil fertility in the experimental field. (2) Because the randomisation is unrestricted, systematic error, if any present, will render the estimate of variance an invalid estimate of random variation. (3) The statistical efficiency of the CR design reduces significantly when the number of treatments and/or replications increase as this will require a larger experimental field to accommodate/fit the increased number of plots which may result in the loss of homogeneity amongst the plots.

Completely Randomised Design is generally used when experimental area happens to be homogenous. This design is generally used in laboratory experiments where homogeneity of experimental materials can be easily achieved. In experiments using CRD layout, the total source of variation is made up of differences between treatments and within treatments (Snedecor & Cochran, 1980; Sokal & Rohlaf, 2011).

2). Randomised Complete Block Design

The Randomised Complete Block Design (RCBD) is most suitable if the experimental area is unidirectional heterogeneous, say due to soil fertility gradient or slop of experimental field etc. Main purpose of blocking is to reduce a known source of systematic variation among experimental material (plots) by grouping them into homogenous blocks. Each block of experimental area is kept of equal size and subdivided into the number of plots according to the number of treatments (t) planned to be applied in the experiment. Unlike CRD layout where the treatments are arranged randomly over the whole experimental units (e.g. plots), in RCBD, the random allocation of a treatment to each plot in the block is done separately and independently of other blocks. Hence, each treatment can appear only once anywhere among the plots of a block and each block contains the entire set of treatments (complete block). In CRD layout each treatment can appear anywhere among total plots, even in adjacent plots, but in RCBD this is not possible.

The process used in RCBD layout is as follows. (1) Decide the number of treatments (t) and the number of their replications (r) to determine the total number of plots (t x r) required for the experiment. (2) Divide the experimental area into homogenous blocks of equal sizes; their number being equal to number of replications (r). (3) Divide each block into equal sized plots their number being equal to the number of treatments (t) in the experiment. (4) Give serial number to plots of each block. (5) Assign treatment to each plot of a block independently without regard to plots of other blocks by any randomisation scheme.

Suppose there are four treatments, say nitrogen levels ($\mathbf{N_0}$, $\mathbf{N_1}$, $\mathbf{N_2}$, and $\mathbf{N_3}$) to be replicated **five** times in a fertiliser trial on a

crop. Then the experimental area is to be divided into five blocks for replication and each block is divided into four plots. A sample layout of RCB design for an experimental field having North-South gradient is shown in Table 3 and a sample layout of RCB design for a field having gradient from West to East is shown in Table 4.

Table 3. An example of RCBD layout for four nitrogen treatments (N_0, N_1, N_2, and N_3) and five blocks (Gradient of field: North to South ↓).

Five Blocks (Replications)	Four Plots: Random allotment of four treatments of N to four plots of each block 1	2	3	4
I	N_3	N_0	N_1	N_2
II	N_0	N_1	N_3	N_2
III	N_1	N_0	N_2	N_3
IV	N_0	N_2	N_3	N_1
V	N_2	N_3	N_1	N_0

Table 4. An example of RCBD layout for four nitrogen treatments (N_0, N_1, N_2, and N_3) and five blocks (Gradient of field: West to East →).

Plots (four plots)	Five Blocks (replications): Random allotment of four treatments of N to four plots of each of five blocks I	II	III	IV	V
1.	N_3	N_0	N_1	N_0	N_2
2.	N_0	N_1	N_0	N_2	N_3
3.	N_1	N_3	N_2	N_3	N_1
4.	N_2	N_2	N_3	N_1	N_0

The Randomised Complete Block Design is an improvement over Completely Randomised design because it provides the block variation separately. By grouping the experimental units into blocks, variability within each block is minimised and variability among blocks is maximised. The total source of variation may be categorised as differences between blocks, differences between treatments, and interaction between blocks and treatments. The latter is usually taken as the error term for testing differences in treatments. An experiment laid out in RCBD has two main advantages. (1) The treatments are compared equally in each block as all the treatments are included in each block. Hence, each block can also be considered as a separate experiment. (2) Treatment effects are estimated more precisely as error mean square is expected to be smaller due to formation of homogenous blocks.

There are two main limitations of RCBD layout. (1) If more treatments are included in the experiment, the block size increases and the within block variability tends to increase. (2) RCBD layout is useful for eliminating the contribution of one directional source of variation only, i.e. it will be efficient only if the variability in experimental units exists in one direction. If variation exists in two directions, the experiment with RCBD layout will not be efficient (Peterson, 1994; Quinn & Keough, 2002).

3). Latin Square Design

When the variation in experimental field occurs in two directions, perpendicular to each other, and each is equally strong, then a two-way blocking will be needed in the experiment, one for each variation. Latin square design (LS design) treats two sources of variations as two-independent blocking criteria, instead of only one as in the RCBD layout.

Supposing an experimental area has two sources of variation: (i) cropping history, and (ii) soil fertility gradient. Suppose direction of fertility gradient is from West to East and direction of cropping history is from North to South at right angle as is shown below:

Soil fertility gradient →
Cropping history↓

In such cases, two-way blocking is necessary in the experimental layout. The two-directional blocking in a LS design is commonly referred to as row-blocking and column-blocking. In LS design each row and each column is a complete block or replication. This blocking is accomplished by ensuring that every treatment occurs only once in each row-block and once in each column-block. This necessitates that the number of replication-blocks is equal to the number of treatment-blocks. Hence, in the layout of LS design the number of rows is equal to the number of columns, forming shape of the layout arrangement as a square matrix. In the Latin square design, each row as well as each column is a replication containing all the treatments of the experiment. The

randomisation process is performed in such a way that each treatment appears once, and only once, in each column (e.g. fertility gradient blocks) and in each row (e.g. cropping history blocks).

Latin square design is identified as 4 x 4 Latin square, 5 x 5 Latin square, etc., according to the number of rows and columns in the layout arrangement. The number of treatments shall not be less than four so that degrees of freedom associated with the experimental error are adequate.

The process used in the layout of LS design is as follows. (1) Decide the number of treatments (t) in the experiment. (2) Determine the total number of plots (t x r) required for the experiment; the number of replications (r) equal number of treatments. (3) Divide the experimental area into homogenous blocks of equal sizes; their number being equal to number of replications (r = t). (4) Divide each block into equal-sized plots, their number being equal to the number of treatments (t) in the experiment. (5) Give serial number to plots of each block separately. (6) Assign treatment to each plot of a block in such a way that each row as well as each column contains all the treatments of the experiment. A sample layout arrangement of LS design is shown in Table 5. The four row blocks correspond to four different cropping histories, and four column blocks correspond to four different varieties of crop.

Table 5. A sample layout of 4 x 4 Latin square design, with four treatments (i.e. four varieties of rice crop: V_1, V_2, V_3 & V_4) and four crop history on experimental plots, showing two way blockings.

Row-blocking: (Cropping history) ↓	**Column-blocking: Random allotment of four varieties of rice crop to four soil fertility gradient plots →**			
	1	**2**	**3**	**4**
Fallow	V_1	V_2	V_3	V_4
Maize	V_2	V_1	V_4	V_3
Taro	V_3	V_4	V_1	V_2
Cassava	V_4	V_3	V_2	V_1

The LS design thus minimises the effect of differences in fertility status within each cropping history block. In this layout design, it is possible for the researcher to estimate variation among row-blocks as well as among column-blocks, and to isolate them from experimental error. The total sources of variation are made up of treatment differences, experimental error and two known sources of variations running at right angles to each other. The main advantage of LS design is that it is more efficient than RCBD and CRD layouts, if more than one source of known systematic variations exist in two different directions normally perpendicularly to each other.

The main limitation of the LS design is that it is not as flexible as the RCB D layout as the number of treatments in it is limited, being equal to the number of rows and columns of the layout.

As pointed out previously, the main aim in CRD is to compare and estimate effect of a single set of treatments randomised over all experimental units. In RCBD, blocking of experimental units is done to make allowance for unwanted but unavoidable heterogeneity of experimental units. In LS design which is a further improvement on RCBD, number of replications and number of treatments are kept equal and the application of treatments is randomised in such a way that they all appear in each row-blocks and in each column-blocks of the layout.

MULTI-FACTOR EXPERIMENTAL LAYOUTS

In the single-factor experimental designs, the effects of a single set of treatments are estimated and compared by holding most of the variable factors constant and allowing only one or two to vary in each experiment. When response to the factor of interest is expected to differ under different levels of other factors, the use of single factor experimental design would require a series of single-factor experiments in which only one factor is varied at a time. This research procedure would be both lengthy and costly. Use of wide range of factor combinations in one multi-factorial experiment would provide a reliable basis for making practical recommendations that will be valid in variable circumstances. Moreover, if the factors are not independent of one another, factorial experiment can give a satisfactory account of their interaction. Hence, the advantage of using multi-factor experiments is that the researcher can obtain a broad picture of the effect of each factor in the different conditions due to variations in the other factors.

Two most commonly used multi-factor experimental layout arrangements are: (i)

Factorial experiments, and (ii) Split-plot experiments. Factorial experimental designs and Split-plot designs are most commonly used in the multi-factor experiments. In factorial experiments, all possible combinations of factors are formed and considered as independent treatments which are assigned randomly to various plots of the experimental area by using randomisation procedure of CRD, RCBD, or LS design. The Split-plot design is useful when one of the treatments requires larger size plots than others. In this design, main treatments are first applied to main-plots and the second factor is assigned to subplots of the main-plot using randomisation procedure of CRD or RCBD layouts. This experimental design provides researcher with increased precision for the effects of sub-plot treatments and interaction between main-plot and sub-plot treatments. Layout arrangements and other characteristics of multi-factor experimental designs are described below.

1). Factorial Experimental Layout

In the Factorial experiment all combinations of all the levels of two or more factors are included in the layout design. The term "factorial" describes a specific way in which the treatments are formed in the experiment. Wide range of factor combinations helps the researcher to predict what will happen when two or more factors are used in combination. Studies such as fertiliser trials combined with weeding, pest control, crop variety or rate of planting commonly use factorial experiments. There is a considerable saving of the experimental resources in the factorial experiments.

A design for two factors each at two levels is referred to as a 2x2 or a 2^2 factorial design requiring four plots for each replication. A Factorial experiment can be laid out in CRD, RCBD, or LS design arrangement.

Supposing there are two factors each at two levels, such as two levels of nitrogen fertiliser (N_0 and N_1) and two levels of weeding of crop (W_0 and W_1). This experiment will have four treatment combinations as shown in Table 6.

If a 2x2 factorial experiment is in a Complete Randomised Block Design, then it is called a 2^2 factorial experiment in a randomised complete block design. Sample layouts of 2^2 Factorial experiments with Completely Randomised Design, with Randomised Complete Block Design, and with Latin Square design are shown in Tables 7, 8 and 9, respectively. In these three sample layouts each of four treatment combinations is replicated four times requiring 16 experimental plots.

The procedure of Factorial experiment layout involves the following steps. (1) Decide the factors and their levels in the experiment. (2) Identify treatment combinations and number them serially. (3) Decide the number of replications of the treatment combinations in the experiment. (4) Subdivide experimental area into different blocks of equal size, the number of blocks being equal to the number of replications of the treatment combinations. (5) Subdivide each block into different plots of equal size, the number of plots being equal to the number of treatment combinations. (6) Randomly assign treatment combinations to the plots by following a randomisation scheme of CRD, RCBD, or LS design. In the randomisation process, all factor combinations (treatments) are considered as unrelated treatments.

If the above mentioned example of two factor (fertiliser, N and weeding, W) factorial experiment is expanded to include a third factor, say pesticide (Z), with two levels (Z_0 and Z_1), the experiment will become a 2x2x2 or a 2^3 factorial experiment. A factorial experiment of three factors with two levels each will have eight possible treatment combinations. Treatment combinations for

Table 6. Possible treatment combinations of the two factors each with two levels (a 2^2 factorial experiment).

Treatment number	Two factors with two levels		Treatment combinations	Explanation
	N	W		
1	N_0	W_0	N_0 W_0	No fertiliser, no weeding
2	N_0	W_1	N_0 W_1	No fertiliser, weeding only
3	N_1	W_0	N_1 W_0	No weeding, fertiliser only,
4	N_1	W_1	N_1 W_1	Both fertiliser and weeding

Table 7a. A sample layout of a 2^2 Factorial experiment with Completely Randomized Design having **four** treatment combinations with **four** replications and requiring 16 experimental plots.

1 N_0 W_0	2 N_1 W_0	3 N_0 W_1	4 N_0 W_0
5 N_0 W_1	6 N_1 W_0	7 N_1 W_1	8 N_1 W_1
9 N_0 W_1	10 N_0 W_1	11 N_0 W_0	12 N_1 W_0
13 N_1 W_1	14 N_0 W_0	15 N_1 W_0	16 N_1 W_1

Note: Figures in numerals denote plot number.

Table 7b. A sample layout of a 2^2 Factorial experiment with Randomized Complete Block Design having **four** treatment combinations with **four** replications and requiring 16 experimental plots.

Blocks (for five replications)	**Random allotment of four treatment combinations to four plots of each block**			
	1	**2**	**3**	**4**
I	N_0 W_0	N_1 W_1	N_0 W_1	N_1 W_0
II	N_0 W_1	N_1 W_1	N_1 W_0	N_0 W_0
III	N_1 W_1	N_0 W_1	N_0 W_0	N_1 W_0
IV	N_1 W_0	N_1 W_1	N_0 W_0	N_0 W_1

Table 7c. A sample layout of a 2^2 Factorial Experiment with Latin Square Design having four treatment combinations and four replications requiring 16 experimental plots.

Row blocks (for four replications)	**Random allotment of four treatment combinations to four plots of each block (Column blocks)**			
	1	**2**	**3**	**4**
I	N_0 W_0	N_1 W_0	N_0 W_1	N_1 W_1
II	N_0 W_1	N_1 W_1	N_1 W_0	N_0 W_0
III	N_1 W_1	N_0 W_1	N_0 W_0	N_1 W_0
IV	N_1 W_0	N_0 W_0	N_1 W_1	N_0 W_1

three factors (N, W and Z) each at two levels are shown in Table 8.

If these **eight** treatment combinations are replicated **four** times, the experiment will require 32 (i.e., 8 x 4) plots. A sample layout of a 2^3 factorial design for determining the effect of fertiliser (N), weeding (W) and pesticide (Z) on the crop yield is shown in Table 9.

Now supposing we want to conduct a factorial experiment involving **four** rates of fertiliser (N_0, N_1, N_2, N_3), and **three** crop varieties (V_1, V_2, V_3), this experiment will have 12 possible treatment combinations as shown in Table 10.

If the treatment combination of this experiment is replicated three times, the total number of plots required for the experiment

Table 8. Possible treatment combinations of three factors (N, W & Z) each with two levels (a 2^3 factorial experiment).

Treatment number	**Three factors with two levels each**			**Treatment combinations**	**Explanation**
	N	**W**	**Z**		
1	N_0	W_0	Z_0	N_0 W_0 Z_0	No fertiliser, no weeding, and no pesticide
2	N_0	W_0	Z_1	N_0 W_0 Z_1	No fertiliser, no weeding, and pesticide
3	N_0	W_1	Z_0	N_0 W_1 Z_0	No fertiliser, weeding, and no pesticide
4	N_0	W_1	Z_1	N_0 W_1 Z_1	No fertiliser, weeding, and pesticide
5	N_1	W_0	Z_0	N_1 W_0 Z_0	Fertiliser, no weeding, and no pesticide
6	N_1	W_0	Z_1	N_1 W_0 Z_1	Fertiliser, no weeding, and pesticide
7	N_1	W_1	Z_0	N_1 W_1 Z_0	Fertiliser, weeding, and no pesticide
8	N_1	W_1	Z_1	N_1 W_1 Z_1	Fertiliser, weeding, and pesticide

Table 9. A sample layout of a 2^3 factorial design of eight treatment combinations with four replications using RCBD process.

Plot number in each block	Random allotment of eight treatment combinations to 8 plots of each of the four blocks			
	I	II	III	IV
1	$N_1 W_0 Z_1$	$N_0 W_1 Z_1$	$N_0 W_1 Z_0$	$N_0 W_1 Z_1$
2	$N_0 W_0 Z_0$	$N_0 W_1 Z_0$	$N_1 W_0 Z_1$	$N_1 W_1 Z_0$
3	$N_0 W_1 Z_1$	$N_1 W_1 Z_1$	$N_0 W_0 Z_0$	$N_1 W_1 Z_1$
4	$N_0 W_0 Z_1$	$N_0 W_0 Z_0$	$N_1 W_0 Z_0$	$N_0 W_0 Z_1$
5	$N_1 W_0 Z_0$	$N_0 W_0 Z_1$	$N_1 W_1 Z_0$	$N_1 W_0 Z_0$
6	$N_1 W_1 Z_1$	$N_1 W_0 Z_0$	$N_0 W_0 Z_1$	$N_0 W_0 Z_0$
7	$N_0 W_1 Z_0$	$N_1 W_1 Z_0$	$N_0 W_1 Z_1$	$N_1 W_0 Z_1$
8	$N_1 W_1 Z_0$	$N_1 W_0 Z_1$	$N_1 W_1 Z_1$	$N_0 W_1 Z_0$

Table 10. Possible treatment combinations of a 3 x 4 factorial experiment with three varieties of the crop (V) and four levels of fertiliser (N).

Treatment combination number	Two factors (4 fertiliser levels and 3 crop varieties)		Treatment combination
	Nitrogen (kg/ha)	Crop variety	
1	$0 = N_0$	V_1	$N_0 V_1$
2	$40 = N_1$	V_1	$N_1 V_1$
3	$80 = N_2$	V_1	$N_2 V_1$
4	$120 = N_3$	V_1	$N_3 V_1$
5	$0 = N_0$	V_2	$N_0 V_2$
6	$40 = N_1$	V_2	$N_1 V_2$
7	$80 = N_2$	V_2	$N_2 V_2$
8	$120 = N_3$	V_2	N_3V_2
9	$0 = N_0$	V_3	$N_0 V_3$
10	$40 = N_1$	V_3	$N_1 V_3$
11	$80 = N_2$	V_3	$N_2 V_3$
12	$120 = N_3$	V_3	$N_3 V_3$

will be 36 (i.e. 12 x 3). A sample layout of this type of factorial experiment using randomised complete block design process is shown in Table 11.

As compared to a single-factor design, in the multi-factor design experiment, effect of many factors can be examined simultaneously for individual factor as well as for their combinations, in one experiment. Therefore, experiment with multi-factor design saves time, money and effort of the researcher. The Factorial experiment has two main advantages. (1) There is reduction in the number of experiments, if done separately for each factor. (2) There is a possibility of studying the impact of interactions among the various factors (Montgomery, 1991; Quinn & Keough, 2002). A significant interaction implies that changes in one factor may be dependent on the level of the other factor. If such dependency exists between the factors and the researcher adopts separate single-factor experimental designs for each of the factors separately, interpretation of the results obtained should be done cautiously.

2). Split-Plot Layout Arrangements

In Split-plot experiments also, various factors are applied simultaneously. This design

Table 11. A sample layout for a 3 x 4 factorial experiment having three varieties of the crop (V_1, V_2, V_3) and four levels of fertiliser (N_0, N_1, N_2, N_3) with three replications using RCBD process.

Plot No.	Three replication Blocks each with 12 plots (Random allotment of 12 treatment combinations independently to 12 plots of each of 3 blocks)		
	I	II	III
1	N_1 V_1	N_2 V_1	N_0 V_1
2	N_0 V_2	N_0 V_2	N_1 V_2
3	N_3 V_2	N_0 V_1	N_2 V_2
4	N_1 V_2	N_1 V_1	N_2 V_1
5	N_0 N_3	N_2 V_2	N_3 V_3
6	V_3 V_3	N_1 V_3	N_0 V_3
7	N_2 V_1	N_1 V_2	N_3 V_2
8	N_1 V_3	N_3 V_2	N_1 V_3
9	N_3 V_1	N_3 V_1	N_1 V_1
10	N_2 V_2	N_2 V_3	N_3 V_1
11	N_2 V_3	N_0 V_3	N_2 V_3
12	N_0 V_1	N_3 V_3	N_0 V_2

is very useful for combining certain treatments, one of which requires larger plots than others for practical convenience. Hence, the layout of this type of experiment is designed keeping in view the large plots (main-plots) and small sub-plots of the main-plots. The main factor is assigned to the main larger plots and, thus, is called the main-plot factor. Examples of main factors are situations requiring spraying insecticides, irrigation or tillage trials on various crops, etc. The second factor is assigned to the sub-plots of the main-plot and, thus, is called the sub-plot factor. Usually, the treatment on which maximum information is desired is placed in the split-plot or in the smallest plot.

The process of designing layout of split-plot experiments involves following steps. (1) Divide experimental area into required number of main-plot blocks so as to provide one main-plot to each main factor treatments in the experiment. (2) Divide main-plot into split-plots or sub-plots to provide one sub-plot to each of the sub-plot (second factor) treatments. For the sub-plot treatments, each main-plot is like a block. (3) Assign main factors to various main-plots at random. (4) Assign various levels of sub-plot factor to the sub-plots (small plots) within each main-plot separately by a randomisation process. Hence, split-plot design involves two separate randomisation processes – one for the main-plot in each replication and another for the sub-plot within each main-plot. Each randomisation is done by the CRD or RCBD randomisation process. (5) Replicate main-plot treatments in various replication blocks of the experimental area. (6) In each replication, repeat the same procedure to allot sub-plot treatments of the experiment to the subplots of main-plots.

An illustration of split-plot experimental design for evaluating effects of fertiliser on different varieties of a crop is shown in Table 12. In this example, three varieties of the crop are randomised in main-plots of each replication and the five levels of fertilisers are randomised in sub-plots of each main-plot. In this illustration, randomised complete block design procedure is followed in assigning main factor treatments to main-plots and sub-plot treatments to subplots in each of the main-plots.

Split-plot design has two main advantages. (1) It is very useful for combining certain treatments one of which requires larger plots than others. (2) This layout arrangement provides researcher with more precise results for the effects of sub-plot treatments and interaction between main-plot and sub-plot treatments equally (Montgomery, 1991; Kuehl, 2000; Sokal & Rohlf, 2011). In the example given in Table 12, increased precision of the estimation of the effects of the five nitrogen levels and the interactions between the three levels of variety and five levels of nitrogen are achieved, while the effects of the three levels of variety are poorly estimated. The major limitation of these types of research designs is that they require larger area for experiments (Kuehl, 2000; Quinn & Keough, 2002).

SUMMARY AND CONCLUSION

Importance of generating continuous flow of new relevant and adaptive agricultural technologies in response to the emerging agricultural problems of developing countries like PICs and to harness the existing vast potential for their agricultural development cannot be overstated. The statistical design of

Table 12. Sample layout of a split-plot design involving three varieties of crop (V_1, V_2, V_3) as the main-plot treatments for three main-plots with four replications and five levels of fertiliser (N_0, N_1, N_2, N_3, N_4) as the sub-plot treatments for five sub-plots of each main-plot.

Blocks (for four replication blocks)	**Random allotment of three varieties of crop to three Main-plots of each of 4 replication blocks**	**Random allotment of 5 levels of fertiliser treatments to five Sub-plots of each of three Main-plots**				
		1	**2**	**3**	**4**	**5**
I	V_3	N_2	N_1	N_3	N_0	N_4
	V_1	N_1	N_0	N_2	N_4	N_3
	V_2	N_3	N_2	N_4	N_0	N_1
II	V_1	N_1	N_3	N_2	N_0	N_4
	V_2	N_0	N_1	N_4	N_3	N_2
	V_3	N_3	N_4	N_1	N_2	N_0
III	V_2	N_0	N_2	N_1	N_4	N_3
	V_1	N_3	N_4	N_0	N_2	N_1
	V_3	N_4	N_3	N_2	N_1	N_0
IV	V_2	N_0	N_2	N_1	N_3	N_4
	V_3	N_4	N_1	N_2	N_0	N_3
	V_1	N_1	N_3	N_0	N_4	N_2

experiments is an essential ingredient of successful product development and improvement, and provides an efficient and scientific approach to obtaining meaningful information. Depending on the specific needs of particular experiment, researchers select an appropriate research design to obtain reliable and precise results from their experiments. The aim of experimental design is to ensure that the experiment is able to detect the treatment effects that are of interest, and that it uses available resources to get the best precision possible. The choice of design can make a huge difference. Hence, in any programme on building research capability of potential researchers, the first step would be to enhance their knowledge and understanding of layout arrangements of various types of experimental designs, their merits, and limitations for conducting agricultural research of particular interest. This article is an effort in this direction. It gives a brief overview of various crop experiment layouts, defining the purpose and scope of each experimental design, differentiating between alternative types of experimental variables, underlying environment and constraints, and explaining steps of experimentation. The focus here is on the fundamental elements of crop experimental designs and their advantages and weaknesses. The single-factor experimental designs reviewed are completely randomised design (CRD), randomised complete block design (RCBD), and Latin square (LS) design. The multi-factor experimental designs discussed are factorial layout arrangements and split-plot layout arrangements

In the small island countries of the South Pacific where agriculture is the mainstay of the people and the research activity is very slow, enhancing agricultural research capability of staff through education, training and motivation is very essential so that they keep up and expand their research skills and core competencies, develop professionally, and become more productive.

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Growth performance of tilapia (*Oreochromis niloticus*) fingerlings offered different levels of copra meal with local ingredients as tilapia feed

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ABSTRACT

A growth trial was carried out to study the performance of tilapia fingerlings (*Oreochromis niloticus*) using local feed ingredients containing four levels (0 %, 10 %, 20 %, and 30 %) of copra meal as tilapia feed. Body weight gain (g), body length gain (cm), feed intake (g), feed conversion ratio, and mortality rate were measured weekly as variables. Feed was calculated at 10 % body weight of the weekly average weight of the fingerlings. The copra meal was the main energy and protein ingredient in the diets. The feeding period was seven weeks. There were significant differences in the final weight and length gains of the tilapia fed with different levels of copra meal. The final body weights (g) for the four feed treatments (0 %, 10 %, 20 %, and 30 % copra meal) were 11.08, 13.54, 13.92 and 10.62, respectively, and the final body lengths (mean, cm) were 86.77, 93.15, 94.69 and 85.54, respectively. Both body weight and body length recorded showed that feed had an effect on the performance of the fingerlings. It was apparent that feeds containing 10 % and 20 % copra meal had significantly better performance ($P<0.001$) than those with 0 % and 30 %. There was also a trend in the performance, in that as the level of copra meal increased the performance decreased. It is recommended that 20 % copra meal inclusion can be used in the tilapia feed for the local farmers.

Key words: Copra meal, local ingredients, tilapia fingerlings, growth performance.

INTRODUCTION

The history of rural aquaculture in Papua New Guinea (PNG) can be traced back to 1954 when the Department of Agriculture, Livestock and Forestry established the Highlands Aqua-culture Development Centre (HAQDEC) and soon afterward constructed four fish ponds at Aiyura. The principle reason for introducing aquaculture was and is to increase protein consumption in the diet of the people in the highlands. The second reason is to provide a means for farmers to earn cash income and help develop a commercial industry.

Aquaculture in PNG is gaining popularity and is growing very rapidly with small farmers and commercial farmers (Coates, 1989). Globally, especially in the south Asian countries, this is a big industry both domestically and for export. The PNG aquaculture industry is still in its infancy but it has huge potential for growth. There are more and more farmers venturing into inland fish farming, but they face a big problem with fish feed as the fish feed cost is very high. One way of reducing the fish feed cost and fish feed problem is by making our own fish feed and using locally grown feed ingredients. This study was, therefore, undertaken to evaluate the growth performance of tilapia fingerlings using locally formulated fish feed and local feed ingredients.

MATERIALS AND METHODS

Experimental site

This study was conducted at the PNG University of Technology agriculture farm located about 9 km from Lae city. The average annual rainfall is about 3500-4000 mm and the average annual temperature ranges from 27-30 ^{o}C.

Experimental tanks and building

The experiment was conducted in an open-sided permanent building, and plastic tanks of size 0.65 m x 0.45 m x 0.58 m were used (volume = 0.17 m^3).

Experimental fish

Two hundred fingerlings (3 g) were purchased from Potsy Inland Fish Ltd. These

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fish were held in a 1000 litre tank and were acclimatized for one week before being used in the experiment. During the acclimatizing period, the fingerlings were fed a basal feed of 35 % CP. After one week, the fingerlings were weighed individually and those with a 4-5 grams body weight were selected and randomly distributed to four plastic tanks. The fish were fed twice daily at a rate of 10 % of the weekly body weight adjusted. Measurements made were weekly average live body weight and body length, over a seven week period.

Water management

Rain water was used and water was changed weekly.

Feed preparation

Four experimental diets containing 0 %, 10 %, 20 %, and 30 % copra meal (identified as CM0, CM10, CM20 and CM30) were formulated. The treatments feeds were copra meal base protein concentrate formulated using the feed formulation software of Thomson (2006). All the feed ingredients were purchased locally. The diets used, as well as the overall protein and metabolizable energy contents of the diets are shown in Table 1. Each diet was made by mixing the protein concentrates with the basal portion of the diets. The protein concentrates were made from the various portions of the fish meal and copra meal, while the basal portion was made from the calculated portion of copra meal, cassava meal, rice mill and mill run. Mill run and cassava meal were used solely to enhance the floatation and binding qualities of the diets, respectively. Wheat mill run consists of wheat bran, wheat shorts, wheat germ, and wheat flour, and offal from the tail of the mill; ground run of the mill screenings are also normally added to the mill run.

All diets contained a fixed 25 % crude protein but the metabolizable energy estimates ranged from 12.3-14.7 mJ/kg (Table 1). All other ingredients were milled using the hammer mill before combination. Afterward, warm water (60-65 ^{o}C) was added to the basal and the concentrates mixed, and the resulting dough was further passed through a 3 mm dye mincer to form pellets. The pellets were dried in an oven at 80 ^{o}C for 12 hr before feeding. Each diet was replicated 13 times and each replicate contained one fingerling of the GIFT variety (Dey & Gupta, 2000) in a 0.17 m^3 water tank containing rain water.

Experimental design

The experiment was carried out using the completely randomised design with 13 replicates per treatment. A total of 52 tilapia fingerlings were randomly distributed to the tanks located in a grid pattern under a shed. A compressor was used for aeration. The water was changed weekly.

Data analysis

Analysis of variance (ANOVA) was carried out to study the effect of diets on the body weight and body length of the fish. The data were analysed using the Genstat computer package. And for any treatment means that were significant, a mean separation test was carried out using t-test and Least Significant Difference (LSD).

RESULTS

The trends in the mean weekly body weight and body length of the tilapia fingerlings fed the different treatment diets are shown in Figures 1 and 2, respectively. The estimates of the final mean body weight and body lengths are shown in Table 2.

Differences in the final body weights were highly significant ($P<0.001$), showing that CM0 and CM40 body weights were similar but significantly lower than CM10 and CM20; CM10 and CM20 were statistically similar (Table 2). The same trend was observed for mean body lengths. Therefore, the results showed that the experimental feeds

Table 1. Composition of experimental diets for tilapia.

Diets	Composition of concentrate portion of the diet	Crude protein (%)	Metabolizable energy (mJ/kg)	Energy:protein ratio
CM0	0 % copra meal	25.5	14.7	0.58
CM10	10 % copra meal	25.0	14.0	0.56
CM20	20 % copra meal	25.5	12.3	0.48
CM30	30 % copra meal	25.8	13.0	0.50

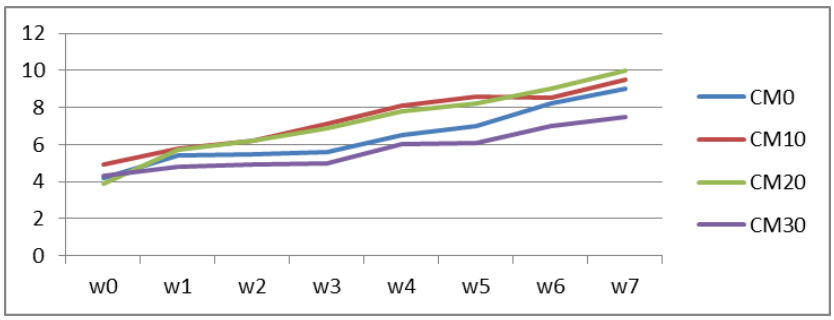

Figure 1. Average weekly body weights (g) of experimental tilapia.

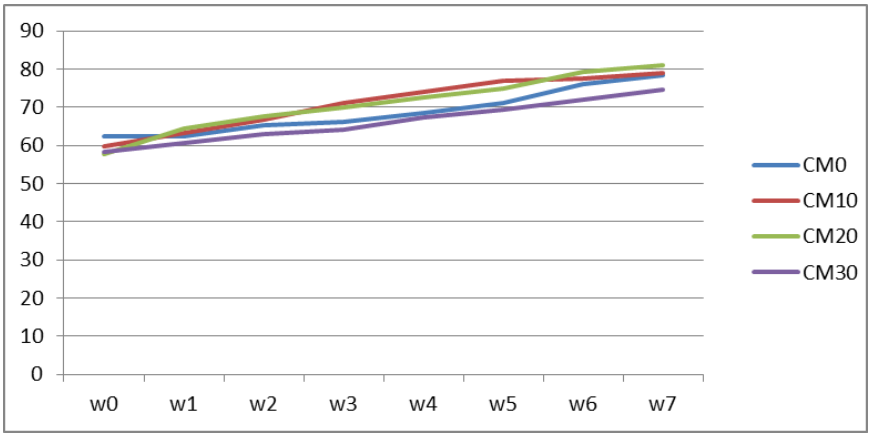

Figure 2. Average weekly body lengths (mm) of experimental tilapia.

Table 2. Estimated final mean body weights and body lengths of tilapia on the experimental diets.

Treatments diets	Mean body weights (g)	Mean body lengths (mm)
CM0	11.08_a	86.77_a
CM10	13.54_b	93.15_b
CM20	13.92_b	94.69_b
CM30	10.62_a	85.54_a

Within each column, values with different subscripts are significantly different from each other ($P<0.001$).

had significant effects on the growth of the tilapia fish.

DISCUSSION

The results of the findings from this study clearly show that growth of the tilapia fingerlings, in terms of body weights and body lengths, was highly influenced by the copra meal protein concentrate inclusions in the diets. The fingerlings on diets CM10 and CM20 had similar body weights and body lengths and significantly better growth performance than fingerlings on CM0 and CM40. This suggests that fingerling diets must have 10-20 % of copra meal; however, there is also an indicative trend of decline growth as copra meal increases beyond 30 %. The similar trends of body weight and body length performance are not surprising, as both of these variables are measures of growth in fish studies.

The generally better performance of the fingerlings fed CM10 and CM20 may be explained in quality and quantity of protein in the diets and also the energy:protein ratio of the diets. The amino acid profile of both fish meal and copra meal base concentrate used most closely meets the amino acid requirements of fish and also provide close energy:protein ratio in the diets. Tilapia, being monogastric and omnivores, would definitely perform better with diets considering these

facts.

One significant finding from this study is that 20 % or 10 % of fish meal can be replaced by copra meal in the diets for tilapia fingerlings. The main advantage of using copra meal by small scale farmers would be its relatively low cost and availability in even remote communities in the country compared to imported concentrates.

Some factors which need further investigation include the use of copra meal with other local sources of protein such as earthworm meal, snail meats and maggot meals. Digestibility studies of the diets can also be studied. Furthermore, the free choice feeding system use of the diets as protein concentrate base can be investigated because it is it well recognized that fish readily consume earthworm, snail flesh and maggot flesh, and this feeding system, if successful, will remove the need for processing and milling of protein ingredients.

Acknowledgement

The authors would like to sincerely thank the Agriculture Department, University of Technology and Agriculture farm for supporting this research under student research project.

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Present geographical occurrence of the giant African snail (*Achatina fulica* Bowdich) in Samoa

Falaniko Amosa[1], Adama A. Ebenebe[1] & Billy Enosa[2]

ABSTRACT

Field surveys were conducted on the Samoan Islands of Upolu and Savaii, between December 2011 and April 2012, to assess the present geographical occurrence of the giant African snail. A total of forty locations (20 locations each) along the main access roads on Upolu and Savaii were surveyed. The findings showed that the snail is currently more widely dispersed on Upolu compared to the situation in 1997 as shown in Hunter (2009). The snail is also present at several locations on Savaii. The survey also revealed that not only has the snail spread further, but infestation at most locations surveyed was readily observable. The findings of this research provide current information for government and other interest groups in Samoa.

Key words: Geographical occurrence, giant African snail, Upolu, Savaii, Samoa.

INTRODUCTION

Production of horticultural crops in Samoa is often constrained by a complex of factors including high costs of inputs, unfavourable weather conditions, marketing difficulties, diseases, and pests. Based on a region-wide survey, Waterhouse (1997) listed slugs and snails (Mollusca: Gastropoda) among the four major invertebrate pests of crops in Samoa. Pest slugs and snails attack crops primarily by rasping plant tissues which may result in symptoms such as rasping marks on leaves, stems and fruits; shredding; partial or total defoliation; and severing of tender stems. Attack on seedlings and young plants may result in death. Apart from direct agricultural significance, some species of snails and slugs are reported to pose a health risk as intermediate hosts of the rat lungworm parasite, *Angiostrongylus cantonensis*, a nematode which can infect humans and cause potentially lethal meningitis. People may be infected with this parasite through eating contaminated, especially raw, fruits and vegetables (Robinson & Hollingsworth, 2006; Australian Quarantine and Inspection Service— AQIS, 2007).

Based on a survey conducted in 2005, Robinson & Hollingsworth (2006) reported that the African slug [*Laevicaulis alte* (Férussac)], and the Fijian semi-slug (*Parmella planata* H. Adams) are the important slug pests on subsistence and garden crops in Samoa. In the same report, the giant African snail (*Achatina fulica*), and the Asian tramp snail [*Bradybaena similaris* (Rang)] are mentioned as the main pest snail species.

The giant African snail in Samoa

A native of East Africa, the giant African snail is reported as one of the world's most destructive pests of fruit and vegetables (AQIS, 2007). Known locally in Samoa as '*sisi aferika',* the giant African snail is reported to have arrived in Samoa in 1990 (Cowie, 2003; Invasive Species Specialist Group, 2010). However, Pouno (2002) and Hunter (2009) both noted that the giant African snail had arrived in Samoa earlier in 1982 but was successfully eradicated before becoming re-introduced. Hunter (2009) stated that the species was re-introduced in 1991. Regardless of the exact year that this invasive species arrived and got established in the country, it is evident that the snail has since spread. Figure 1 shows the spread of the giant African snail on Upolu between 1991 and 1997. Presumably, the snail was still restricted to Upolu as of 1997. The giant African snail is the most recent mollusc pest to establish in Samoa (Robinson & Hollingsworth, 2006).

Since its re-introduction, the Samoa Quarantine Service (SQS) has been implement -ting post-entry quarantine measures, as well as public awareness campaigns, in an effort to

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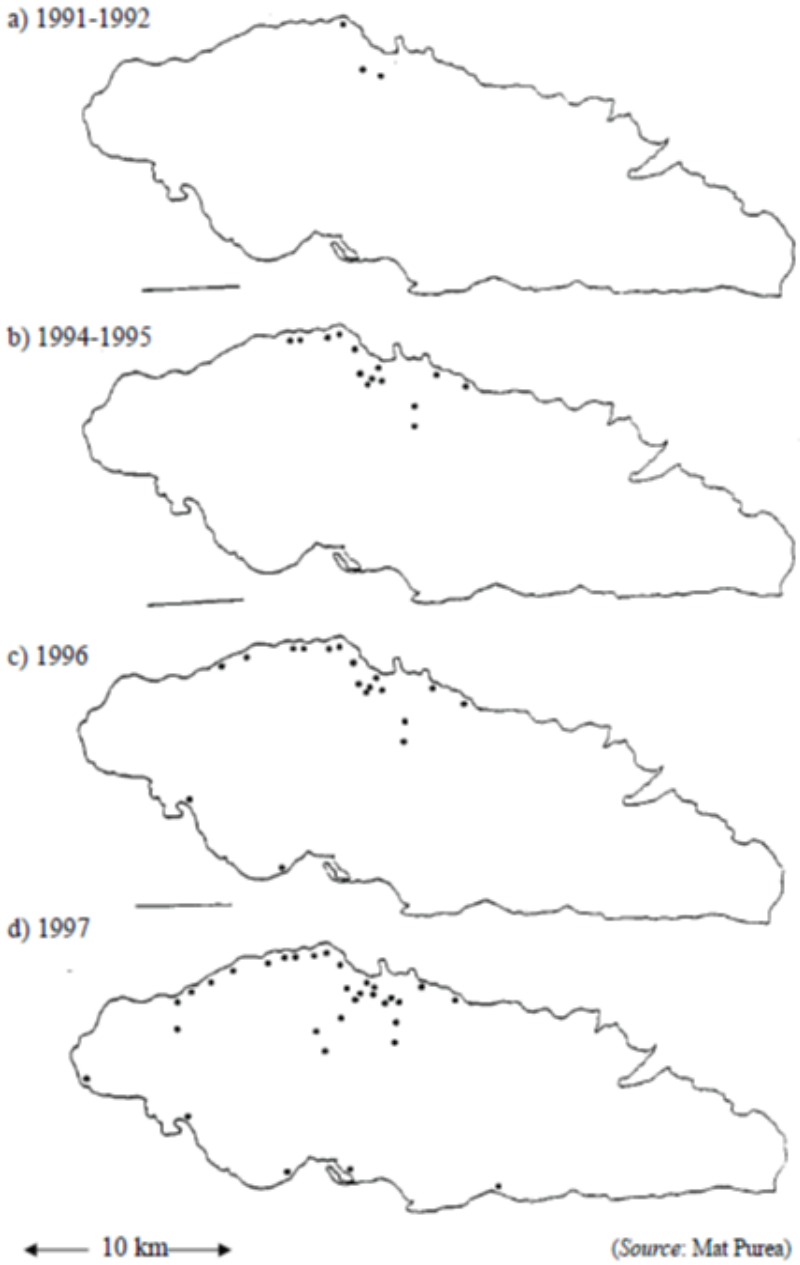

Figure 1. Map showing the spread of the giant African snail on Upolu Island from 1991-1997. Source: Hunter, 2009, p5.15.

curtail the spread of the giant African snail to other parts of the country (SQS Staff oral communication, 29 May 2012). Despite the efforts, the snail is known to have spread to other parts of the country, although the extent of the spread was unclear. However, the two other inhabited islands of Manono and Apolima are believed to still be free from it (SQS Staff, 29 May 2012).

Although the giant African snail is now a common sight in Samoa, especially on Upolu, the map presented as Figure 1 is the most recent published information regarding the species' geographical distribu-tion in the country; that is until this present survey. Perceiving a need for more current information, the authors of this paper were prompted to carry out an investigation, with the objective of determining the present geographical spread of this species in the country. This paper presents the findings.

METHODOLOGY

The geographical occurrence of the giant African snail was investigated through field surveys of the islands of Savaii and Upolu. In selecting sites for the surveys, a total

of 20 locations were randomly marked on a map of each of the islands prior to the actual survey exercise. The sites were spread out along the main access roads on each island. During the actual survey exercise, we visited a village at each marked location and requested access to a crop farm/garden. Positioning ourselves side by side, the researchers and field assistants walked through each targeted garden and its immediate surroundings, searching thoroughly and exhaustively for any sign of the giant African snail. Observations were made on plants, under debris, under rocks, logs, empty containers, and in/on any place that could possibly harbour the snail. Whenever possible, the garden owners were also interviewed (informally) regarding their knowledge of any occurrence of the giant African snail in their area. Based on visual observations, the presence/absence of the species was recorded, and apparent abundance was also noted.

RESULTS AND DISCUSSION

Twenty gardens were surveyed on Upolu and the same number on Savaii. Garden sizes ranged between 0.1 - 1.0 ha. The findings revealed that the giant African snail is well established on Upolu, and it is slowly finding its way around Savaii (Figure 2). As expected, the snail is more widespread on Upolu than on Savaii.

On Upolu, 19 (95 %) of the 20 locations surveyed had live giant African snail present, being readily observable to abundant at the locations. Most property owners spoken to indicated that the snail had been in their area for quite a few years.

On Savaii, live giant African snail was present at 7 (35 %) of the 20 locations surveyed, and the presence of empty shells at an eighth location (Satoalepai village) strongly suggests that the snail is present around this area also. When asked, the property owner at Satoalepai was positive that live snails were present in the area and the empty shells we observed were the remains of snails he and his family had killed earlier. The owner of the property surveyed at Neaifu village indicated that he first noticed the snail in his garden in 2011, and he suspected that it was inadvertently introduced on taro planting material he had acquired from Upolu. The snail was observed to be abundant at this location. The owners of the property surveyed at Satupaitea village indicated that the snail had been in their area for about two years, and they suspected that it was introduced through building construction materials brought in from Upolu. The snail was observed to be abundant here also. Strikingly heavy infestations of the giant African snail were observed at Salelologa and Salelavalu.

Comparing Figure 1 and Figure 2, it appears quite obvious that the giant African snail has gained substantial ground in terms of establishing itself in Samoa during the past 15 years (since 1997). According to Figure 1, the snail was recorded within the western half of Upolu as of 1997, and as noted earlier in this paper, the snail is presumed to be absent from Savaii at that time. Figure 2 shows that the situation has changed significantly. It is worthy of mention, also, that with the exception of Satoalepai and Puapua, the giant African snail was easy to find at all other locations where it was present on both islands.

CONCLUSION

This paper has provided an update of the current distribution of the giant African snail in Samoa. This information should be useful to government and other agencies that are concerned with environmental issues. It also enriches the information base for future studies and other actions related to this species in Samoa.

Acknowledgements

The authors wish to thank the property owners for their generosity in allowing surveys to be conducted on their farms. We also wish to thank Ian Faleono (University of the South Pacific, Alafua Campus) for providing practical assistance during the field work, Tali Ioane (Samoa Ministry of Agriculture and Fisheries) who served as liaison between the researchers and the property owners and as field assistant during the survey, and the staff of the Samoa Ministry of Natural Resources and Environment for constructing the maps showing our research findings. Lastly, we are immensely grateful to the Faculty of Business and Economics, University of the South Pacific, for providing the funds for this research.

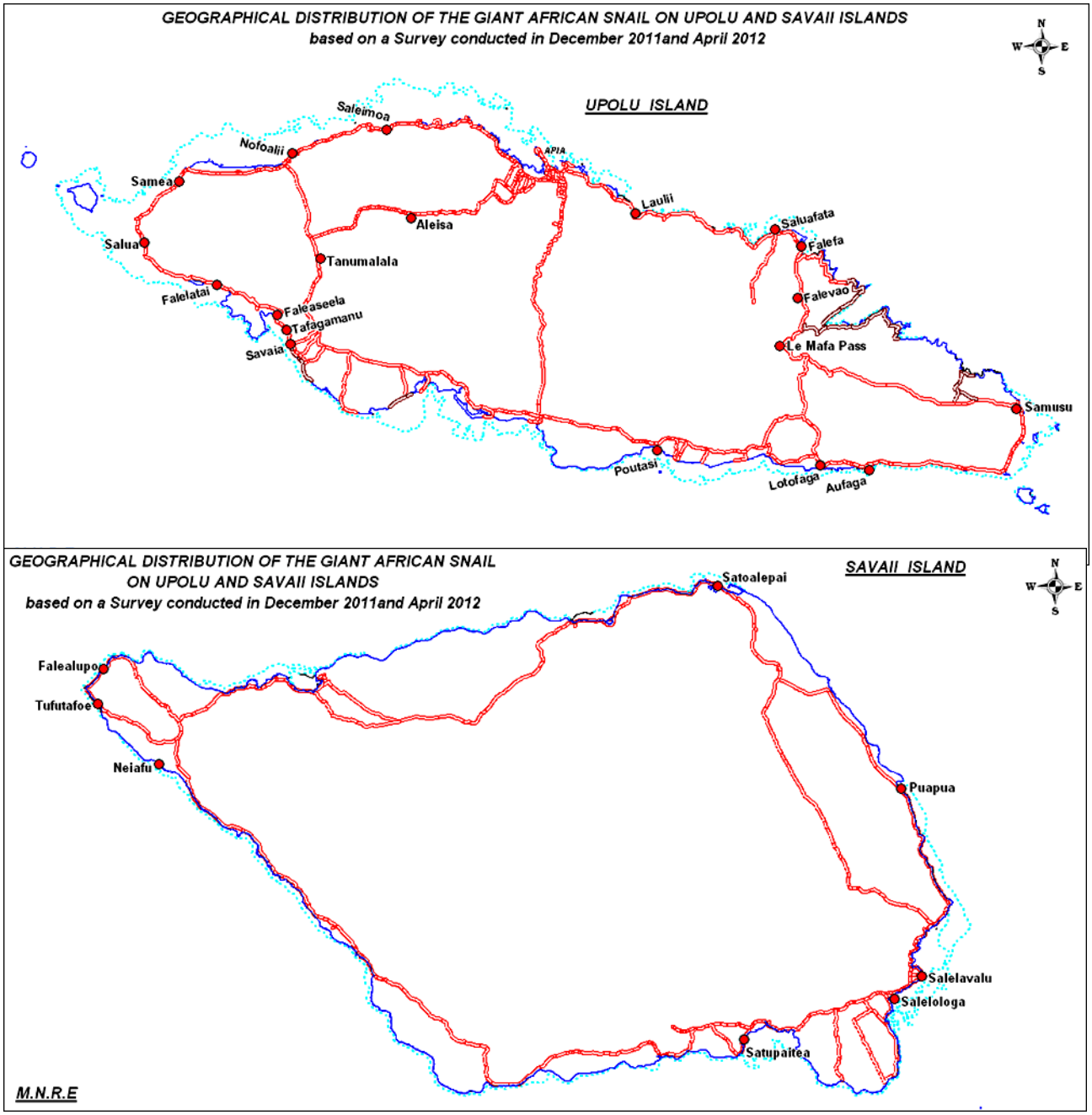

Figure 2: Survey sites (villages) where the giant African snail was found on Upolu and Savaii Islands of Samoa, as of April 2012.

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Short Communication

Traditional reef fish farming method in Panamecho village of New Ireland, Papua New Guinea: A sustainable and environmentally friendly fish farming method for food security

William Nano[1] & Takfulu Emos Nano[2]

ABSTRACT

Food security and sustainable and environmentally friendly farming are traditional concepts which have been carried out from generation to generation in most villages in Papua New Guinea. One of these concepts is the traditional reef fish farming practice to sustain food security in Panamecho village of New Ireland Province. A total of 30 reef gardens were constructed from coral stones. These farms were designed to provide daily fish supply for a month. Harvesting was conducted so that when the thirtieth garden was harvested the first garden was ready for harvesting at the beginning of the next month. Three of the 30 gardens were harvested to study the kinds of fishes harvested and the total kilograms of fresh fishes that were produced. The results of the study showed that out of the three harvests, a total of 12 different kinds of fishes was harvested and a total of 27.9 kilograms of fresh fish weight with an average of 9.3 kilograms per day. This is enough fresh fish daily for a household. 12 different types of fish were identified.

Key words: Traditional reef fish farming, Papua New Guinea, food security, sustainable methods.

INTRODUCTION

Fish has been one of the main sources of protein food along coastal areas of Papua New Guinea (PNG). Farming reef fish was a common cultural practice in many coastal villages of PNG in the past. Today, the art of reef sea farming has been largely forgotten in many of these villages and is no longer being practiced. As populations in the villages increase the demand on fish protein also increases and frequent fishing trips exhaust and deplete the fishing grounds; as consequence, food insecurity (protein) is created which in many cases has manifested in problems like malnutrition in many rural coastal villages.

However, there are some coastal areas that still practice reef sea fish farming, and one such area is where this study is undertaken, namely; Panamecho village, West Coast Kara-Nalik of Kavieng in the New Ireland Province, PNG. This study is done in line with the national government's food security programme for villages in PNG.

This study was carried out to see whether the traditional farming practices can sufficiently and reliably supply families with protein needs all year round.

MATERIALS AND METHODS

The study was conducted in Panamecho village, West-Coast, Kara-Nalik of Kavieng New Ireland Province. Thirty reef fish gardens were constructed, triangular in shape (7 m x 3 m x 0.3 m). The gardens were constructed following the current and known fish movements in the lagoon. The gardens were constructed in groups of 5-7 in the deeper parts of the lagoon and scattered along the pathway about 10-20 m apart. After the construction of the gardens, they were left alone for 3-4 months so that the fishes could take ownership and residence in the gardens. Everything else was left to take their natural course, so there was no supply of fingerlings and food and other needs. After 3-4 months, harvesting of the gardens began. The harvests were normally conducted on a daily basis so as to supply protein food need in a family. Since there were 30 of them, harvesting rounds were monthly and as soon as the 30th garden was harvested, garden #1 was ready to start the

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following month. Harvesting normally began from one end of the lagoon and ended on the other. This allowed the fishes to again take ownership and residence in the first harvested gardens.

Steps in harvesting

Step 1. The surrounding of the garden was vigorously disturbed, by hitting the top of the water around and close to the garden or by hitting the bottom of the surroundings.

Step 2. A small fishing net was pulled around the garden (a special one was normally made for this purpose). If no net was allocated someone disturbed the garden surrounding while removing the coral stone in the garden.

Step 3. A woven coconut basket (40 cm x 30 cm x 30 cm) was placed in the front point of the triangle of the garden. The basket's mouth was open and one of the coral stones was put in it.

Step 4. The coral stones were turned and removed and in the process another triangular garden was constructed. This process was progressive toward the triangle tip and the basket. As the removal of the stone moved slowly forwards the fishes also moved forward following the unturned stones. When the last stone was moved, the one in the mouth of the basket, all the fishes swam into the basket immediately.

Step 5. The basket mouth was then closed and the basket was lifted up above the water. Under normal traditional practice, selection or sorting of the big and small fishes would then take place. The big ones are taken home for the meal while the small ones are returned to the water. In this observation study, however, all fishes that were caught were taken to the house so the weights and types could be recorded; in other word, no sorting of the big and small fishes was done.

RESULTS AND DISCUSSION

Table 1 shows that a total of 27.2 kg of fresh fish and average of 9.12 kg of fresh fish per day was harvested. Twelve different types or kinds of reef fish were noted for the 3 days of observation.

The harvests per day can easily provide an average of 9.12 kg of fresh fish daily. Based on the recommendation in Table 2 (Edwards & Allan, 2004), 400 g of fresh fish is enough for a daily meal for an average household. In PNG, about 54 % of the population lives in the lowlands and coastal region. About half of this population lives near the sea. This kind of sustainable reef fish farming, if adopted, could easily cater for the 25 % of the population in their daily protein food requirement.

The results of the three days harvests have clearly shown that a sustainable food security programme can be achieved with the

Table 1. Daily harvests of reef fish fresh weight (kg) and type of locally known fishes.

Types	Day 1	Day 2	Day 3	Total	mean
Balang (eels)	1.6	1	0.4	3.0	1.0
Yagwung(crabs)	2.0	3	0.4	5.4	1.8
Ura (octopus)	0.3	1.0	0.6	2.6	0.87
M axira (black)	1.5	2.0	0.3	3.8	1.3
Cowboy	1.0	1.5	0.2	2.7	0.9
Ulavi	1.5	1.0	0.2	2.7	0.9
Ki (big eye red)	1.0	0.5	0.5	2.0	0.7
Ragugut	0.6	0.5	0.1	1.2	0.4
Bilas	1.5	1.0	0.1	2.6	0.9
Dudus	0.1	0.4	0.1	0.6	0.2
Kiaf	0.2	0.4	0.1	0.7	0.23
Unknown	0.2	0.3	0.5	1.0	0.33
Total	11.5	12.2	3.5	27.2	-
Mean	3.83	4.1	1.2	9.12	-

Table 2. Average protein requirement of 10 people in a typical home in Papua New Guinea.

Infant	5month-1year	14grams
Children	1-3years	16grams
	4-6years	24grams
	7-10years	28grams
Males	15-18years	59grams
	25+years	63grams
Females	11-14years	46grams
	19-24years	46grams
Pregnant		60grams
Lactating	Second 6 months	50grams
Total		406grams

Average fresh fish protein = 17%CP and 70% moisture.*Daily average caught = 9.12 kg x 70/100 x 17/100 = 474g, so there is sufficient daily protein provided in the traditional fish farming method.

present traditional farming methods especially in the coastal areas. The farming system is environmentally sound because it does not disturb the reef environment.

A total of 12 types of fishes was identified locally (Table 1) in the harvests. In the traditional practices only the big fishes are normally taken out for the meal and the small fishes are thrown back into the sea and gardens.

While doing this sort of farming in our area, it was clear that a lot of the children and young people did not know this type of sustainable farming. Like elsewhere in PNG, this cultural practice dying away.

This study was very short and it would be better to do a year cycle in order to properly study the true outcome of this farming system.

Acknowledgements

The authors are sincerely in debt and are very thankful to the people of Panamecho village, Kara-Nalik, Kavieng, New Ireland Province for sharing their traditional knowledge. We would like, also, to sincerely thank Associate Professor Dr.Gariba Danbaro for his valuable advice in writing up the paper.

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Lettering on diagrams, photographs, graphs, etc. should be sufficiently large and bold to permit legible reproduction when the illustration is reduced to a size suitable for inclusion in the journal. (Test the legibility of your illustration by reducing the size by 50%.)

Captions:

- Should be clear, descriptive, and not too long.
- Capitalise first word and proper names only, write scientific names in full.
- Should be formatted as follows:
  Table 1. Relative abundance of flowers in two varieties of tomato following treatment with hormones.
  Figure 1. Size of banana fruits at eight weeks after de-suckering.
- All illustrations (diagrams, graphs, photographs, line drawings, etc.) should be referred to as figures. They should be numbered consecutively (according to order of appearance in the paper).
- Capitalise the first letter when referring to a table or figure within the text, regardless of its position in the sentence. Examples:
  Table 1 shows that .....; This trend is clearly shown in Figure 10.

** All figures and tables must be referred to in the text.

Names of organisms:

With the exception of common domestic animals and crops, the preferred scientific name of organisms (according to the International Codes of Nomenclature) should be given in full at the first mention of the English common name. Thereafter, the common name may be used, provided there is no ambiguity. Common names should be avoided in titles and abstracts (but English common names of crops may be used, provided there is no ambiguity).

Names of pesticides

The internationally recognised common names (names of active ingredients) of pesticides and other chemicals should be used. Commercial (trade, brand) names may be used in inverted commas (but the internationally accepted common name should still be provided at first mention). Example:

> Glyphosate is the common name (or active ingredient) in Roundup, and Roundup is the commercial (or trade) name of a herbicide.

- Common names should be presented in lower case letters, except at the beginning of a sentence. The trade name, if used, should always start with a capital letter, and should be enclosed in inverted commas. Examples:
  The use of glyphosate is widespread in .....; Glyphosate is widely used .....
  'Roundup' was applied.... ; The application of 'Roundup' resulted in .....
  **Chemical names may also be used where appropriate.

Formulae:

- Wherever possible each formula should be typewritten (not scanned), with adequate space around the formula. (Consider placing the formula inside a borderless textbox to avoid shifting of items during subsequent formatting of the paper.)
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In general, do not write the numbers zero to nine in numerals within sentences, except in special cases (e.g. when followed by units of measurement, in ranges). Numbers from ten onwards may be written in numerals within sentences, but numerals should not be used to begin a sentence.

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  ...requires two inches of rainfall annually (May, 1989; Glen, 2000; Duke, 2001).
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- References to online publications (articles, ejournals, ebooks):
  BROWN, K.C. 2008. Growing button mushroom. *Urban Agriculture Newsletter*, [Online]. 42 (6). Available at: http://www.veg.ug/articles [Accessed 20 Jan. 2010].

  MVUNGI, J. B. & MATHI, C. J. 2000. A new incubation technique for small-scale poultry farms. *Poultry Digest*, [Online] 2 Feb., 13 (2):1-6. Available at: http://get.fraf.cw.twn/ejournals/ [Accessed 12 Feb. 2009].

  PASCAL, W. 2002. *The third degree.* [e-book] Herman: Zorrow Press.
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