Feeding livestock for compost production: A strategy for sustainable upland agriculture on Java

J.C. Tanner,[1] *S.J. Holden,*[2] *M. Winugroho,*[2] *E. Owen*[3] *and M. Gill*[4]

1. Cwm Mawr, Hyssington, Montgomery, Powys SY15 6DZ, UK
2. ODA Animal Health Project, c/o FCO (Jakarta), King Charles Street, London SW1A 2AH, UK
3. Department of Agriculture, University of Reading, Earley Gate, P O Box 236, Reading RG6 2AT, UK
4. Livestock Section, Natural Resources Institute, Chatham Maritime, Chatham, Kent ME4 4TB, UK

Abstract

Ruminant livestock are an integral part of smallholder farming systems in Indonesia. However, the extent and continuous nature of cropping on densely populated islands such as Java leaves very little land suitable for grazing. The majority of livestock are therefore permanently housed in backyards and fed indigenous forages cut from field margins and roadsides. Cut-and-carry feeding is labour-intensive and the supply of forage is often the most expensive input to ruminant production. Surprisingly, farmers collect quantities of forage greatly in excess of the requirements of their livestock. In an experiment, indigenous forage dominated by *Axonopus compressus*, was fed to sheep at increasing rates: 25, 50 or 75 g DM/kg live weight (W) per day. The results showed that although DM intake and liveweight gain rose with increasing offer rate, the incremental improvements from 50 to 75 were non-significant ($P<0.05$) and less than from 25 to 50. It is unlikely that farmers justify their excess-feeding strategies on the basis of these marginal gains in animal productivity alone. The rationale for excess feeding may lie in manure-compost production. Farmers collect uneaten feed in pits beneath their animal barns. The uneaten feed combines with faeces and urine falling through the slatted floors to produce manure-compost. In the above experiment, the quantity of manure-compost made from refused forage mixed with sheep excreta increased markedly as the forage offer rate rose. It is possible that farmers adjust their feeding rates to optimise total output, i.e. including manure-compost, as opposed to animal production *per se*. Manure-compost is ranked by farmers as one of the most important outputs from livestock production. In the upland regions of Java, 90% of the fertiliser used on smallholdings is manure-compost. It is hypothesised that livestock are used to produce high quality compost and that their integration into Javanese agriculture is essential to the sustainability of some of the most intensive cropping cycles in the world.

Alimentation du bétail en vue de la production de compost: une stratégie destinée à promouvoir une agriculture viable en altitude à Java

J.C. Tanner[1], *S.J. Holden*[2], *M. Winugroho*[2], *E. Owen*[3] *et M. Gill*[4]

1. Cwm Mawr, Hyssington, Montgonery, Powys SY15 6DZ (R.-U.)

2. ODA Animal Health Project, c/o FCO (Jakarta), King Charles Street, Londres SW1A 2AH (R.-U.)

3. Department of Agriculture, University of Reading, Earley Gate
P.O. Box 236, Reading RG6 2AT (R.-U.)

4. Livestock Section, Natural Resources Institute, Chatham Maritime
Chatham, Kent ME4 4TB (R.-U.)

Résumé

L'élevage de ruminants fait partie intégrante du système de la petite exploitation agricole en Indonésie. Toutefois, compte tenu de l'importance et du caractère continu de l'agriculture à Java, une île à très forte densité de population, il ne reste que très peu de terres adaptées aux pâturages. La plupart des animaux sont en permanence parqués derrière les cases et alimentés avec du fourrage provenant des bordures des champs et des routes. L'alimentation à l'auge étant une opération à forte intensité de travail, l'affouragement est généralement l'intrant le plus coûteux de la production animale dans cette région. Et pourtant, les éleveurs amassent d'importantes quantités de fourrage, excédant de loin les besoins de leurs animaux. Au cours d'un essai, des quantités croissantes (25, 50 ou 75 g de MS/kg de PV/j) de fourrage local constitué principalement d'Axonopus compressus ont été distribuées à des moutons. Les résultats montrent que bien que la consommation de MS et les gains de poids augmentent avec les quantités de fourrage ingérées, ces augmentations n'étaient pas significatives entre 50 et 75 g de MS/kg de PV/j ($P<0,05$) et étaient plus faibles que celles obtenues entre 25 et 50 g de MS/kg de PV/j. Il est peu probable que ces améliorations marginales de productivité justifient la stratégie d'alimentation excédentaire adoptée par les éleveurs. Celle-ci pourrait par contre s'expliquer par la production de fumier-compost. En effet, les paysans recueillent les refus dans des fosses situées sous les étables. Ces refus, mélangés aux fèces et à l'urine passant entre les lattes du plancher, produisent du fumier-compost. Dans cette expérience, la quantité de fumier-compost obtenue à partir des refus et des déjections des moutons augmentait sensiblement avec l'accroissement de la quantité de fourrage proposée. Il est possible que les éleveurs ajustent les quantités de fourrage pour optimiser la production totale, c'est-à-dire fumier-compost inclus, et pas seulement la production des animaux. Celui-ci est considéré comme l'un des produits les plus importants de l'élevage. Dans les régions montagneuses de Java, le fumier-compost représente 90% des engrais utilisés dans les petites exploitations. Il semble donc que les animaux d'élevage sont utilisés pour produire du compost de qualité. Leur intégration dans l'agriculture javanaise est vitale pour la durabilité de certains des systèmes agricoles les plus intensifs du monde.

Introduction

Although Java represents only 7% of the total land area of Indonesia it supports 60% of the country's population (180 million people). Half of Java's population are farmers (Biro Pusat Statistik, 1991) who cultivate small plots of land up to 0.5 ha in size (Booth, 1988). Cropping is continuous. Java is thus not only one of the most densely populated areas of the world with 814 persons/km^2, but also one of the most intensively cultivated.

Ruminant livestock are an integral part of the farming system. However, intensive cultivation on Java leaves little land for grazing. The majority of animals are therefore permanently housed in backyards and fed indigenous grasses and sedges. Fodder is hand-cut each day from roadsides and field margins by the farmer and carried back to the homestead. Forage collection is labour intensive. For example, it has been estimated that sheep farmers spend between 0.8 (Amir et al, 1985) and 2.3 (Thahar and Petheram, 1983) hours/head per day just to supply their animals with fodder. The high labour inputs that are required to supply forage makes it the most expensive cost to small ruminant production.

Surprisingly, farmers collect large quantities of grass, often greatly in excess of the appetites of their livestock (Mathius and van Eyes, 1983; Ludgate, 1989; Lowry et al, 1992; Wahyuni et al, 1993). Offer rates for sheep and goats have been estimated at between 50 and 60 g dry matter (DM)/kg live weight (W).day (d) (van Eys et al, 1984; Johnson and Djajanegara, 1989). A large proportion of the grass on offer is rejected by the animals. Some studies suggest that as much as 400 g/kg DM offered may be refused (Little et al, 1988; Subagio, 1991).

Despite high levels of feeding, the productivity of small ruminants under village conditions is considered low (Johnson and Djajanegara, 1989). This would imply that there were limited advantages to high levels of feeding under these village conditions. However, several authors have observed that the refused feeds associated with 'excess feeding' are composted with animal manure for subsequent use on surrounding fields (Palte, 1989; Sabrani et al, 1989). Manure-composts are an important output of the livestock system (van Eys et al, 1984; Ludgate, 1989; Levine, 1990). High levels of feeding might thus be employed to optimise both manure-compost production and animal productivity as opposed to animal production *per se*.

This paper covers two trials. The first was a feeding trial that quantified the relationship between forage offer rate, intake and animal growth, forage refusal rate and manure-compost production. The second experiment evaluated the quality of the manure-composts produced as fertiliser for maize. The economic optimum level of feeding was determined for this system in which manure-compost and animal production are both valued as outputs.

Experiment I: Effect of quantity of forage offered to sheep on intake and growth, and on compost made from uneaten feed and excreta

Materials and methods

Both trials were conducted at the Research Institute for Animal Production, Ciawi, West Java (6°40'S 106°55'E). The institute is located in an upland site at an altitude of 500 m. The daily range in ambient temperature is 20–31°C with little seasonal variation. The climate is wet monsoonal with an annual rainfall of about 3600 mm. Only three months of the year receive less than 200 mm of rain.

Thirty Javanese thin-tailed rams (aged 18 months, mean initial live weight 29.1 kg, s.e. 0.3) were blocked according to initial live weight (W) and then randomly allocated to one of three forage offer rates: 25, 50 or 75 g dry matter (DM)/kg W.d. The forage offer rates were selected to cover the range measured on-farm by van Eys et al (1984).

Indigenous forage was hand-cut each morning in the vicinity of the animal house where the trial was conducted. A 2.5 kg sample of the forage on offer was taken each day to determine species composition. Table 1 shows the average proportions of forage species on offer over the last 34 days of the trial. These forage species were similar to those identified as being fed to stock on farms in the area (Little et al, 1988). The forage offered had concentrations of 185 g DM/kg, s.e. 26; 155 g ash/kg DM, s.e. 8.5 and 20.4 g N/kg DM, s.e. 1.4.

Table 1. *Average species composition of the forage offered each day during the feeding trial (n = 34 days).*

	Mean % in daily forage ration(fresh-weight basis)	
Forage genus/species	%	sd
Grasses: *Axonopus compressus/ Paspalum conjugatum*	28.8	17.92
Eleusine indica	7.1	10.16
Digitaria spp	8.3	9.20
Brachiaria spp	5.2	7.03
Setaria palmifolia	2.9	6.33
Paspalum scrobiculatum	2.7	5.92
Cynodon dactylon	2.4	6.01
Ischaemum timorense	2.4	8.01
Sporobolus spp	0.4	1.34
Other grass species	3.8	4.84
Sedges: *Kyllinga monocephala/Cyperus* spp	5.8	8.99
Broad-leaved plants	15.5	7.94
Grass fragments	7.2	6.97
Dead plant material	7.6	3.23

The rams were individually penned and fed half of their daily forage ration at 0800 and

recorded on a daily basis and representative samples of forage offered and refused were taken for DM, ash and N analysis. The trial lasted a total of 70 days. From day 5 to 25, faeces were collected from three rams per treatment to measure digestibility. Rams were weighed each week following a 12-hour fast. Water and salt (NaCl) blocks were available throughout the experiment.

Refused forage, faeces and urine were collected each morning from three rams per treatment penned individually in metabolism crates. The crates were fitted with excreta separators which directed faeces and urine into different containers positioned under each crate. Immediately after weighing, the uneaten forage was bulked by treatment, mixed with the faeces and urine voided by each treatment group over the previous 24-hour period and then placed in slat-sided bins measuring 1.5 m x 1.5 m x 1.0 m. Uneaten forage and excreta were collected in this manner over 50 days and composted in the bins for a further 50 days. The compost was turned every three days to assist aeration. Following the composting period the compost was sacked-up for weighing and samples were taken for analysis of N, phosphorus (P), potassium (K) and organic carbon (C).

Results

Table 2 shows that DM intake of forage and growth rate of sheep increased with offer rate but the incremental improvement for 50 to 75 g/kg W.d was not significant (P>0.05) and less than that observed from 25 to 50 g DM/ kg W.d. The quantity of grass refused increased from 109 g DM/kg DM offered at the lower feeding rate to 526 g DM/kg DM offered at the highest feeding rate. Forage digestible organic-matter contents improved with increasing offer rates and the forage refused contained less nitrogen and more ash than the forage offered. It was calculated that the N content of the forage actually consumed (i.e. selected) improved from 21.2 to 22.5 and 23.8 g/kg DM as offer rate increased.

Table 2. *Cut-and-carry feeding for Javanese Thin-tailed sheep: Effect of increasing forage offer rate on intake, diet selection, animal growth and manure-compost yield.*

Quantity of forage offered (g DM/kg W.d)			25	50	75	s.e.d.
Number of rams			10	10	10	
Initial live weight (W) (kg)			29.2	29.1	28.9	0.33
Growth rate (g/d)			–16.5	25.8	28.5	4.73
Intake						
Forage offered (g/d)			3627	7772	11616	
Forage offered (g DM/d)			671	1438	2149	
Forage refused (g DM/kg DM offered)			109	359	526	
Forage intake (g DM/d)			598	922	1019	
Forage intake (g DM/kg W.d)			22.1	31.7	34.9	1.16
Estimated intake of digestible forage organic matter (g DOM/kg W.d)			11.8	19.0	21.7	
Forage quality	Forage offered					
	Mean	s.e.	Forage refused			
DM (g/kg)	185	26	375	239	217	8.9
Nitrogen (g/kg DM)	20.4	1.4	14.0	16.7	17.3	0.5
Ash (g/kg DM)	155	8.5	257	199	208	11.4
Manure-compost yield (g/sheep/day)			540	1620	2320	

As expected, compost yield increased with increasing forage offer rate. Table 3 shows that the contents of N, P, K and organic C also showed slight improvements with increasing offer rate. After composting for 50 days the compost produced from the lowest offer rate contained faecal material still in pelleted form, however, composts produced from the higher offer rates were structureless and more humus-like in appearance.

Table 3. *Estimated costs of production (Rp[1]/sheep/day), value of outputs (Rp/sheep/day) and returns to labour (Rp/hour) whenfeeding indigenous forage to rams at 25, 50 or 75 g DM/kg W.d.*

	Costs[2]		Outputs		Returns to labour	
Offer rate	Labour[2] (hrs)	Other[3] (Rp/day)	Compost[4] (Rp/day)	Weight[5] (Rp/day)	Including compost (Rp/hour)	Excluding compost (Rp/hour)
	0.42	18.6	18	-50	−120	−163
	0.83	18.6	54	77	135	70
	1.20	18.6	77	86	120	56

1. 1 US$ = Indonesian Rupiah (Rp) 2110.
2. The lowest cost of forage input corresponds to the lowest forage offer rate (25 g DM/kg W. d) and the highest forage cost to the highest forage offer rate (75 g DM/kg W.d), assuming it takes 5.9 minutes to cut 1 kg of grass (derived from van Eys et al, 1984 and Amir et al, 1985).
3. Non-labour costs, in decreasing order of magnitude, include depreciation on the sheep barn, minerals, anthelmintic treatments and miscellaneous expenses on ropes etc.
4. On average, a 30-kg sack of manure-compost fetches Rp 1000 (Holden et al, 1993), equivalent to Rp 0.033/g.
5. Assuming a sale price of Rp 3000 per kg live weight (or Rp 3/g) (Biro Pusat Statistik, 1991).

Determining the economic optimum offer rate

Liveweight gain and manure-compost production were greatest at the highest feeding rates (Figure 1). However, these gains must be offset against the extra time required to supply the feed. The most profitable ration would be that which yields the highest returns to labour inputs. In this instance 'returns' are defined as the difference between the value of outputs namely, liveweight gain and manure-compost, and the value of non-labour inputs such as drugs, mineral supplements, depreciation on the animal barn and miscellaneous expenses on items like buckets and ropes. This can be expressed in the following equation:

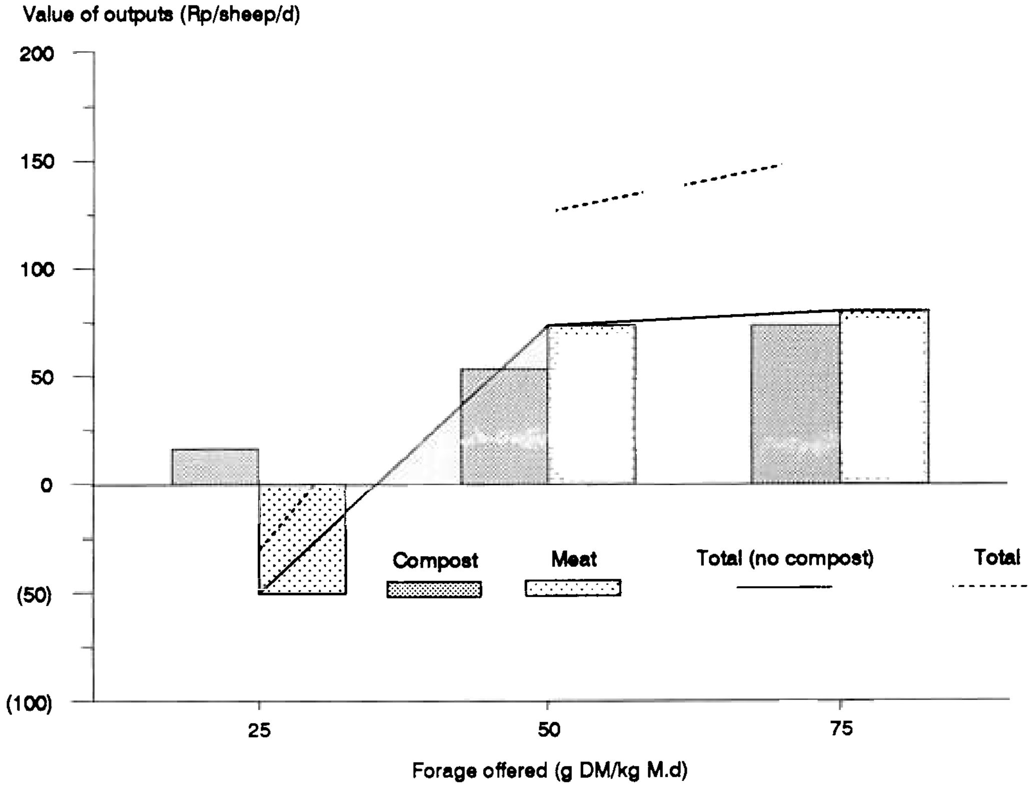
$$\text{Returns to labour} = \frac{\text{(Value of outputs)} - \text{(Non labour costs)}}{\text{Hours labour}}$$

Returns to labour can be thought of as the 'wage' family labour 'earns' from the sheep enterprise.

Data from studies elsewhere in Indonesia (Kartamulia et al, 1993) are used to estimate the costs associated with fattening rams (Table 3). These costs are derived from farms that treat their sheep regularly with anthelmintics and thus best mimic on-station experimental conditions. Labour inputs include a component for watering the animals and cleaning the barn. Manure-compost and the liveweight gain associated with each level of feeding are valued using farm gate prices. The purchase and sale price of rams on a per kg liveweight basis is assumed to remain constant. Returns to labour are calculated for (i) the combined value of manure-compost and liveweight gain and (ii) the value of liveweight gain only. The effect of manure-compost production on returns to family labour can thus be examined.

Table 4 shows that the most profitable offer rate, i.e. the one that yields the highest returns to family labour was 50 g DM/kg W.d irrespective of whether manure-compost is included as an output. The lowest level of feeding would appear to be unprofitable: the costs of production alone (excluding labour inputs) outweigh the value of growth and compost-manure production. Although feeding at the highest offer-rate yielded a positive return to labour invested in animal production, the computed

Figure 1. *Relationship between forage offer rate and value of compost and live weight.*



'hourly wage rate' was 11% less than that obtained from feeding at 50 g DM/kg W.d where compost is included in the output value, and 25% less where compost is excluded from outputs.

Returns to labour are lower if compost production is excluded from the value of outputs. At 25, 50 and 75 g DM/kg W.d offer-rates, returns to labour are, respectively, 36%, 40% and 53% less than returns to labour if manure-compost is included as an output. At the most profitable offer-rate of the three levels studied, i.e. 50 g DM/kg W.d, the production of manure-compost increased the returns to labour by 93% from Rupiah (Rp) 70/hour (without manure-compost) to Rp 135/hour (with manure-compost).

Table 4. *The chemical properties of the manure-composts produced from the feeding trial and a compost made from plant material only (vegetable-compost).*

	Manure-compost			Vegetable-
Type of compost	25[1]	50	75	compost
Nitrogen (g/kg DM)	17.6[2]	18.2	19.4	14.8
Organic carbon (g/kg DM)	240.6	245.7	255.7	213.5
P_2O_5 (g/kg DM)	6.2	6.7	7.2	3.9
K_2O (g/kg DM)	32.4	36.8	42.3	0.5

1. Manure-composts 25, 50 and 75 were produced by composting faeces, urine and uneaten forage from sheep offered forage at either 25, 50 or 75 g DM/kg W.d, respectively.

2. All results produced from the analysis of one sample per compost type only.

The results of the mineral contents of the manure-composts are based on a small sample taken from each compost. An agronomic trial was therefore conducted to evaluate the effect of offer rate on the overall quality of the manure-composts. The composts were used to fertilise maize grown on an upland soil and compared with similar application of inorganic fertiliser and compost made from plant material only (vegetable-compost).

Experiment II: Inorganic fertiliser, manure-composts and compost made from plant material only as fertiliser for maize grown on upland soil

Materials and methods

The trial featured five fertiliser treatments: three manure-composts, a vegetable-compost and inorganic fertiliser (NPK). The three manure-composts were produced from the feeding trial described above. Manure-compost 25, manure-compost 50 and manure-compost 75 were produced as a result of mixing excreta and refused forage from sheep offered indigenous forage at 25, 50 or 75 g DM/kg W.d. The vegetable-compost was produced by composting plant material only. Although containing grasses similar to those fed to the sheep during the trial, the vegetable-compost also contained other plant material such as rice straw.

The composts and local upland topsoil, Andosol, (Horne, 1988) were sieved individually through a 1 cm x 1 cm screen. The four types of compost were then added to the soil at the rate of 0 (control), 20 or 50% by volume. After mixing thoroughly, the compost-soil mixtures were placed in free-draining plastic pots (total volume 7.7 litres, top diameter 0.3 m). The chemical properties of the soil were as follows: pH 4.8, 18.1 g organic C/kg DM, 1.9 g N/kg DM, 0.2 g K_2O/kg DM, P_2O_5 1.4 ppm (Bray-1) and cation exchange capacity 4.66 meq/100 g.

The 20% and 50% compost application rates were estimated to provide, on average, 3.56 g N/pot (sd 0.79 g N) and 9.20 g N/pot (sd 2.65 g N), respectively. The inorganic fertiliser doses were calculated so that the urea provided equivalent quantities of N. Thus, urea (containing 46% N) was applied at 7.74 g or 20.0 g/pot. In accordance with the seed producers' recommendation, the total urea dose was split into three application times; at planting, 21 days and 42 days post-emergence. Therefore, at each of these times either 2.58 g or 6.66 g urea was added to the pots. Triple super phosphate (TSP) and potassium chloride (KCl) were applied to the NPK pots at planting time only in the ratio 2:2:1 (urea : TSP : KCl). In order to relate to the upper and lower compost application rates the equivalent inorganic fertiliser rates will be referred to as "NPK 50" and "NPK 20" treatments, respectively.

The maize used in the trial was a hybrid of varieties F 3228 and M 3228. Three seeds were planted per pot and the pots placed in a greenhouse. The seedlings were visually assessed at three days after emergence and the two weakest were removed. Two litres of water were provided per pot each day of the trial and the pots were allowed to drain freely.

A randomised block design was used with five fertiliser treatments (compost 25, compost 50, compost 75, vegetable compost and NPK), three fertiliser application rates (0% [control], 20% or 50% compost by volume [or calculated NPK equivalent]) and three blocks in which each fertiliser treatment was replicated five times (total of 225 pots).

Thirty-two days after emergence two plants per treatment in each block were destructively sampled. The height of the plant from soil level to the top node was measured and then the plant was cut at soil level, oven-dried at 85°C for 48 hours and then weighed. The remaining plants (three plants/treatment/block) were harvested at 60 days post-emergence when the same measurements were made.

Results

At the time of writing, statistical analysis had not been carried out. However, Table 5 and Figure 2 reveal some clear trends. Maize plants fertilised with manure-composts out-performed those receiving vegetable-compost or NPK at both levels of application and throughout growth. The most noticeable response was the dramatic improvement in plant height and dry weight caused by increasing the application rate of all three manure-composts from 0 to 20%. Increasing manure-compost application from 20% to 50% showed marginal improvements in plant height but there were large gains in plant dry-weight at 60 days. Application of NPK or vegetable-compost produced small improvements in plant growth and the response to increasing application rate was minimal at both stages of growth.

Table 5. *The effect of fertiliser type and application rate on the mean dry weight and mean height of maize plants after 32 and 60 days of growth.*

		Growth period			
		32 days		60 days	
Compost type	Application rate (%)	Dry weight g [n=6]	Height cm [n=6]	Dry weight g [n=9]	Height cm [n=9]
	0	0.7 (0.29)*	10.8 (3.71)	2.0 (1.30)	15.7
Compost 25	20	14.6 (1.80)	40.7 (5.85)	73.6 (7.59)	192.7
	50	15.8 (2.23)	46.3 (4.23)	153.3 (46.7)	199.9 (14.98)
	0	0.5 (0.26)	8.6 (2.57)	2.9 (3.12)	18.3 (8.44)
Compost 50	20	10.3 (1.84)	37.3 (3.32)	57.5 (10.97)	172.0 (11.94)
	50	12.8 (2.11)	38.9 (6.71)	132.2 (56.26)	199.4 (16.50)
	0	0.5 (0.12)	8.7 (0.99)	1.7 (0.29)	15.1 (3.73)
Compost 75	20	10.8 (1.28)	34.6 (2.92)	62.4 (21.1)	174.9 (12.73)
	50	12.4 (1.98)	39.5 (3.10)	101.5 (35.82)	183.0 (20.52)
	0	0.5 (0.28)	9.0 (3.13)	4.5 (5.54)	18.6 (10.27)
Vegetable compost	20	1.05 (0.4)	14.3 (4.5)	10.0 (1.97)	37.6 (9.22)
	50	2.3 (0.18)	20.5 (1.14)	28.3 (3.93)	77.3 (14.75)
	0	0.5 (0.12)	8.4 (1.59)	2.1 (0.59)	17.4 (4.6)
NPK	20	1.5 (1.91)	11.9 (5.19)	29.1 (23.18)	82.2 (55.9)
	50	4.8 (3.62)	20.5 (9.0)	34.0 (27.2)	78.1 (52.52)

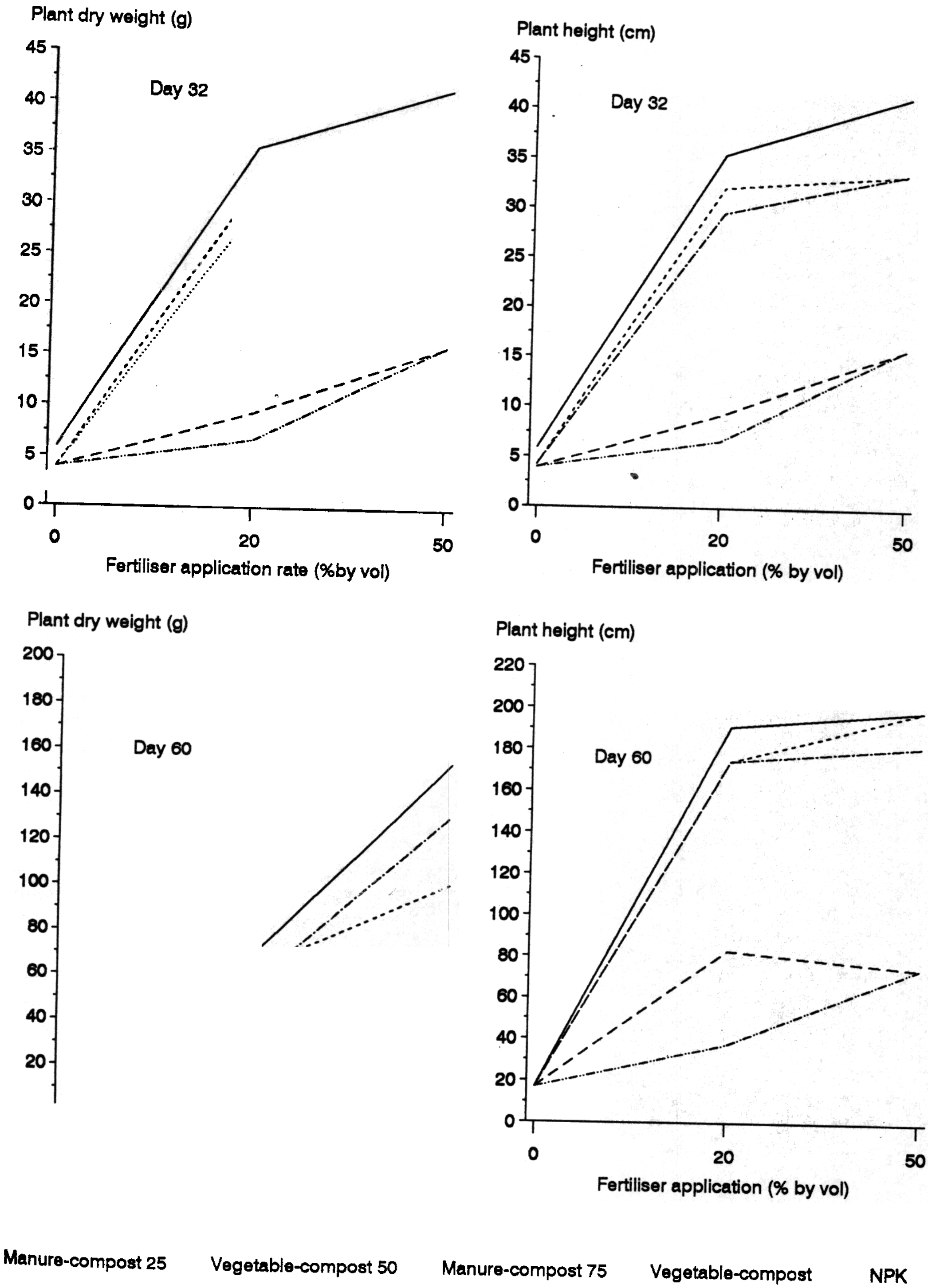
* Means followed by standard deviations in brackets.

After 32 days' growth maize plants receiving manure-compost 25 at both the 20% and 50% application rates were heavier and taller than those fertilised with manure-composts 50 and 75. At this early stage of growth manure-composts 50 and 75 produced similar plant response.

At 60 days the plants fertilised at the 20% rate with manure-compost 25 were slightly taller than those receiving manure-composts 50 or 75. Increasing the application rate to 50% resulted in very little further response in plant height. Plants fertilised with manure-compost 25 at the 20% application rate had lost some of their dry-weight advantage observed over the other manure-composts at 32 days' growth. Raising the application rate to 50% did, however, give a pronounced increase in plant dry weight for all manure-compost treatments.

The control plants remained stunted throughout the trial although no plant parasites or symptoms of disease were observed. Whatever adverse soil conditions existed these were not ameliorated by application of NPK or vegetable-compost. The NPK application rates used in this experiment exceed those advised by the local supplier of maize seed and therefore it might be suggested that a deficiency in these macro-nutrients was not the main reason for the stunted growth. Application of the vegetable-compost, whilst possibly improving the physical condition of the soil, lacked the nutrient content of the manure-composts (Table 3).

Figure 2. *The effect of fertiliser type and application rate on dry weight and height of maize plants after 32 and 60 days of growth.*



Discussion

Historically, Java has been one of the most populous areas of the world. However, Raffles (1817) noted that settlements were concentrated only on the fertile lowlands whereas the uplands remained unpopulated. The uplands contain the Ultisol and Oxisol soil orders (Perkins et al, 1986) which are generally of low fertility, exhibit deficiencies in plant nutrients and have poor physical structure (KEPAS, 1985). Furthermore, the topography and heavy rainfall in the uplands can lead to serious erosion problems once these soils are cleared for agricultural use. Cultivators have thus traditionally avoided these areas. However, during the early 19th century, rapidly growing population pressure on Java forced farmers to move into more marginal regions (Palte, 1989).

In the 1870's, the colonial government predicted widespread soil erosion, declining crop yields and eventual degradation (Pelzer, 1945). Despite such gloomy prophesies, over 100 years later, upland areas represent 42% of the land used for annual crop production (RePPProT, 1990) and support an average population density of around 600 persons/km^2 (Palte, 1989). Farmers seem therefore to have mitigated some of the worst consequences of continuous cropping on these marginal soils.

Palte (1989) suggests a key factor that contributed to the successful colonisation of the uplands was the attention to soil fertility which enabled sequential planting of dry-land crops. It has only been acknowledged comparatively recently that Javanese farmers have well-defined soil management strategies for dry-land cultivation (Colfer, 1991). Farmers produce large quantities of organic fertiliser, in particular manure-based composts, which are incorporated into the soil: around 90% (by weight) of the fertiliser used on these farms is in the form of organic fertiliser (Palte, 1989; Sabrani et al, 1989). A variety of manure-composts are produced to suit particular soil and crop types, and manure-compost applications are often integrated into an overall soil nutrient management strategy that includes application of inorganic fertilisers (Holden et al, 1993).

Figure 2 and Table 5 suggest that manure-composts support higher crop production compared to inorganic fertilisers when applied to maize grown in an upland soil. Manure-composts are not only rich in organic matter but may also represent a balanced source of readily available plant nutrients (Parnes, 1990). The improved response of the maize plants to manure-compost application was possibly a direct result of higher organic matter. However, the quality of organic fertiliser is also important. The addition of vegetable-compost gave poor plant response perhaps because this compost had a lower nutrient content compared to the manure-composts (Table 3). Livestock excreta would thus appear to be a vital ingredient of organic fertilisers used on poor quality soils.

Livestock ownership in these areas is argued by Palte (1989) to be a reflection of the significance of manure-compost to the sustainability of crop production. Yet livestock do not usually readily co-exist with continuous cropping: the lack of grazing and risk to crops typically necessitates housing and manual feeding of animals (Grigg, 1974; Spedding, 1979). Such systems can have higher costs compared to grazing and are not usually economically viable (Jahnke, 1982). However, in the uplands of Java there exists a somewhat unusual situation where ruminant livestock production has effectively integrated into intensive cropping. We would argue that this is possible because farmers have devised a system for rearing livestock that not only effectively recycles nutrients but is also economically efficient.

Economic efficiency of cut-and-carry feeding systems

A feature of upland small ruminant production is high forage offer rates. Survey data show that forage feeding rates in Javanese villages allow livestock to refuse as much as 400 g/kg DM offered (Little et al, 1988; Subagio, 1991). Excess feeding can result in higher rates of growth. Table 2 shows that growth rates improved when the quantity of forage on offer increased from 25 to 75 g DM/kg W.d. Similar responses have been observed elsewhere by Zemmelink (1980) and Wahed et al (1990). It was suggested by these authors that the responses occurred because higher offer rates provided the animals with greater opportunity for selective feeding which in turn led to improvements in the quality of the diet ingested. Under experimental conditions, offer rates of 50 g DM/kg W.d are more profitable compared to offer rates of 25 and 75 g DM/kg W.d. This finding is consistent with village offer-rates that reportedly range between 50 and 60 g DM/kg W.d (Johnson and Djajanegara, 1989).

However, farmers do not excess-feed to secure high growth rates alone. The larger quantity of feed refusals associated with higher offer rates are mixed with faeces and urine to produce compost. Increased offer rates not only improve the quality of intake but also result in larger quantities of manure-compost. Significantly, when farmers feed at 50 g DM/kg W.d manure-compost comprises 41% of total output from the production system and the conversion of the high uneaten forage levels into compost increases the returns to labour by 93% at this offer rate (Table 4). Production of high value manure-composts thus enables farmers to offset some of the extra costs associated with rearing livestock in intensively cultivated areas.

Efficiency of nutrient cycling in cut-and-carry feeding

Several authors point out that under stall-feeding conditions, only faeces can be conserved and transported to cropland, whilst urine is usually lost from the system (Catchpoole, 1988; Powell and Ikpe, 1992). Powell and Ikpe (1992) stated that 40–60% of N excreted by animals is contained in urine and demonstrated that fields fertilised by grazing cattle produced 2.3 times more millet grain than those to which cattle faeces alone were added by hand. They attributed this finding to the fact that the grazed fields gained the added benefit of receiving urine.

To maximise the efficiency of nutrient cycling it is therefore important to conserve livestock urine. The Javanese stall-feeding system for small ruminants may go some way to achieving this aim. Sheep and goats are housed in small barns with slatted floors built over pits one to two metres deep. Rejected forage is thrown into the pit and absorbs some of the urine falling through the slats. It might be hypothesised that the proportion of urine captured in this way increases with rising quantities of refused forage.

The daily accumulation of layers of faeces and uneaten forage in the pit may also help to limit N loss by reducing the volatilisation of ammonia. Watson and Lapins (1969) estimated that around 50% of N contained in urine voided on to pasture by sheep in south-western Australia was lost through ammonia volatilisation, whilst Gillard (1967, cited by Henzell, 1973) calculated that up to 80% of N contained in faeces dropped on pasture was lost through a similar route. It is therefore important to minimise the exposure of livestock excreta destined for fertiliser from the damaging effects of the climate. The practice of excess feeding would lead to a more rapid formation of these "protective" layers of uneaten feed in the pit whilst the roof of a Javanese small-ruminant barn shelters the pit from sun and rain and the depth of the pit reduces exposure to wind.

The direct application of fresh faeces and urine on to pasture by grazing animals can lead to significant losses of N not only via ammonia volatilisation but also through denitrification and leaching. An advantage of the Javanese stall-feeding system is that it allows animal excreta and plant material to be composted. If carbon-rich materials, i.e. uneaten forage are mixed and composted with excreta they can intercept and stabilise N (Parnes, 1990). Composting may therefore represent a means of reducing the loss of vital plant nutrients. Also, this stabilising effect on nutrients might allow composted material to be stored without a significant drop in fertiliser quality thus allowing farmers to accumulate compost for more timely application to the growing crop.

The experimental data suggest that the quality of manure-composts increased as the proportion made up by rejected forage declined. However, although manure-compost 25 supported better plant growth at day 32 its superiority was diminished at 60 days. Holden et al (1993) found that farmers considered manure-compost with a higher proportion of excreta to be superior to manure-compost with a high content of vegetable matter. Farmers, aware of the trade-off between quantity and quality, prefer to maximise the quantity of manure-compost produced and so opt for high feeding rates which produce grass-rich manure-composts.

Conclusions

Despite poor growing conditions, the uplands of Java are continually cropped and support dense human populations. It is argued that the use of manure-composts is the key to sustaining soil productivity (Adiningsih et al, 1991). The intensity of cropping in these areas precludes grazing and farmers house their animals instead. Housing facilitates manure-compost production and farmers are probably able to offset at least some of the extra costs associated with cut-and-carry feeding against the value of manure-composts.

Farmers reportedly feed between 50 and 60 g DM/kg W.d (Johnson and Djajanegara, 1989) and under experimental conditions offer rates of 50 g DM/kg W.d yielded greater returns to labour compared to offer rates of 25 g or 75 g DM/kg W.d. Excess feeding increased returns to labour by 200% at the highest offer rate (Rp 120/hour at 75 g DM/kg W.d versus Rp –120/hour at 25 g DM/kg W.d). Raising offer rates from 25 to 75 g DM/kg W.d increases returns to labour because:

- the N content of the forage selected and intake of DOM increased by 12.3% and 83.9%, respectively, at the highest offer rate, and growth rates were thus enhanced
- uneaten feed is used to produce manure-composts. Under experimental conditions, manure-compost production is increased by 330% at the highest offer rate.

Acknowledgements

The authors would like to express their gratitude to the Directors of the Research Institute for Animal Production, Dr K Diwyanto and Dr M Sabrani (retired) for their support of the project. Thanks also to Dr P Hadley, School of Plant Sciences, University of Reading, for help with the design of the crop trial. The study was jointly funded by the Natural Resources Institute (ODA) and the ODA Animal Health Project, Indonesia.

References

Adiningsih J S, Semali A, Effendi S and Hadiwigeno S. 1991. Resources and problems associated with the development of upland areas of Java. In: Blair G and Lefroy R (eds), *Technologies for sustainable agriculture on marginal uplands of southeast asia*. Proceedings of a workshop, Ternate, Cavite, Philippines, 10–14 December 1990. ACIAR Proceedings 33. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia. 128 pp.

Amir P, Soedjana T D and Knipscheer H C. 1985. *Labour use for small ruminants in three Indonesian villages*. Small Ruminant – Collaborative Research Support Programme (SR–CRSP) Working Paper 62. Winrock International, Morrilton, Arkansas, USA. 6 pp.

Biro Pusat Statistik. 1991. *Statistik Indonesia, 1991*. Jakarta, Republic of Indonesia.

Booth A. 1988. *Agricultural development in Indonesia. Asian studies association of Australia.* Southeast Asia Publications Series 16. Allen and Unwin, Sydney, Australia. 295 pp.

Catchpoole D W. 1988. *The contribution of tree legumes to the nitrogen economy and forage production in the humid tropics*. PhD thesis, University of New England, Australia. 190 pp.

Colfer C J P. 1991. *Towards sustainable agriculture in the humid tropics. Building on the TropSoils experience in Indonesia*. TropSoils Bulletin 91–02. Soil Management – Collaborative Research Support Program. North Carolina State University, Raleigh, North Carolina, USA. 86 pp.

Grigg D B. 1974. *The agricultural systems of the world. An evolutionary approach.* Cambridge University Press, Cambridge, UK. 358 pp.

Henzell E F. 1973. The nitrogen cycle of pasture ecosystems. In: Butler G W and Bailey R W (eds), *Chemistry and biochemistry of herbage*. Volume 2. pp. 227–246.

Holden S J, Kusumaningsih A and Martindah E. 1993. *A participative assessment of the production and role of manure-composts in upland agriculture in west Java* (unpubl.) ODA Animal Health Project, c\o FCO (Jakarta), King Charles Street, London, UK.

Horne P M. 1988. *Tree legume/grass mixtures for forage production in the wet tropics.* PhD thesis, University of New England, Australia. 192 pp.

Jahnke H E. 1982. *Livestock production systems and livestock development in tropical Africa.* Kieler Wissenschaftverlag Vauk, Kiel, Germany. 253 pp.

Johnson W L and Djajanegara A. 1989. A pragmatic approach to improving small ruminant diets in the Indonesian humid tropics. *Journal of Animal Science* 67:3068–3079.

Kartamulia I, Karokaro S and de Boer J. 1993. *Economic analysis of sheep grazing in rubber plantations: A case study of OPMM Membang Muda.* Small Ruminant–Collaborative Research Support Programme (SR-CRSP) Working Paper 145. Winrock International, Morrilton, Arkansas, USA. 12 pp.

KEPAS (Kelompok Penelitian Agro-Ekosistem) 1985. *The critical uplands of eastern Java: An agro-ecosystems analysis.* Agency for Agricultural Research and Development, Republic of Indonesia. 213 pp.

Levine J. 1990. Small ruminants in the uplands of central and east Java. *Indonesian Small Ruminant Newsletter* 1(1):2–3.

Little D A, Petheram R J and Boer M. 1988. Observations on the mineral content and nutritive value of diets fed to village ruminants in the Indonesian districts of Bogor (West Java) and Pamekasan (Madura, East Java). *Tropical Agriculture (Trinidad)* 65(3):213–218.

Lowry J B, Petheram R J and Tangendjaja B (eds). 1992. *Plants fed to village ruminants in Indonesia. Notes on 136 species, their composition, and significance in village farming systems.* ACIAR Technical Reports 22. ACIAR (Australian Centre for International Agricultural Research), Canberra, Australia. 60 pp.

Ludgate P J. 1989. *Overview of feeding constraints on upland production systems.* Small Ruminant–Collaborative Support Programme (SR-CRSP) Technology Information Files (TIF/N–15). (unpubl). Balai Penelitian Ternak, Ciawi, Bogor, West Java, Indonesia. 6 pp.

Mathius I W and van Eys J E. 1983. *Feeds and feeding of sheep in Sukawargi village, West Java: A profile study.* Small Ruminant–Collaborative Research Support Programme (SR-CRSP) Working Paper 12. North Carolina State University, Raleigh, North Carolina, USA. 12 pp.

Palte J G L. 1989. *Upland farming on Java, Indonesia. A socio-economic study of upland agriculture and subsistence under population pressure.* PhD thesis, Faculty of Geographical Sciences, University of Utrecht, The Netherlands. 251 pp.

Parnes R. 1990. *Fertile soil: A grower's guide to organic and inorganic fertilisers.* agAccess, Davis, California, USA. 190 pp.

Pelzer K L. 1945. *Pioneer settlement in the Asiatic tropics. Studies in land utilisation and agricultural colonisation in southern Asia.* American Geographical Society, New York, USA.

Perkins J M, Semali A, Orchard P W and Rachman R. 1986. *An atlas of environmental and ruminant population characteristics of Java, A multivariate analysis approach.* Forage Research Project, Balai Penelitian Ternak, Ciawi-Bogor, Indonesia. 80 pp.

Powell J M and Ikpe F. 1992. Nutrient recycling through livestock: "Fertiliser factories". *ILEIA Newsletter* 8(3):13–14.

Raffles T S. 1817. *The history of Java.* Oxford University Press, Kuala Lumpur, Malaysia.

RePPProT (Regional Physical Planning Programme for Transmigration). 1990. *The land resources of Indonesia: A national overview 1990.* Land Resources Department, Natural Resources Institute (ODA) and Direktorat Bina Program, Departemen Transmigrasi, Jakarta, Indonesia. 282 pp.

Sabrani M, Levine J and Kusnadi U. 1989. Crop–animal interaction and its implications for design of sustainable farming systems in Indonesia. In Sukmana S, Amir P and Mulyadi D M (eds), *Developments in procedures for farming systems research.* Proceedings of an international workshop held in Puncak, Bogor, Indonesia, 13–17 March 1989. Agency for Agricultural Research and Development, Ministry of Agriculture, Indonesia. pp. 221–235.

Spedding C R W. 1979. *An introduction to agricultural systems.* Applied Science Publishers, London, UK. 169 pp.

Subagio I. 1991. *Livestock and feed.* Animal Production Section, Interdisciplinary Research Project, Brawijaya University, Malang, East Java, Indonesia (unpubl.). 26 pp.

Thahar A and Petheram R J. 1983. Systems of ruminant rearing during the dry season in West Java. In: Proceedings of the 5th World Conference on Animal Production. Volume 2:851–852.

van Eys J E, Mathius I W, Pulungan H, Rangkuti M and Johnson W L. 1984. *Small ruminant production in West Java: Results of one year monitoring by the nutrition village monitoring program.* Small Ruminant – Collaborative Research Support Programme (SR–CRSP) Working Paper 34. North Carolina State University, Raleigh, North Carolina, USA. 46 pp.

Wahed R A, Owen E, Naate M and Hosking B J. 1990. Feeding straw to small ruminants: Effect of amount offered on intake and selection of barley straw by goats and sheep. *Animal Production* 51:283–289.

Wahyuni S, Suparyanto A, Isbandi and Gatenby R M. 1993. *Re-evaluation of outreach pilot project.* Small Ruminant – Collaborative Research Support Programme (SR–CRSP) Working Paper 143. Balai Penelitian Ternak, Pusat Penelitian dan Pengembangan Peternakan, Bogor, Indonesia. 15 pp.

Watson E R and Lapins P. 1969. Losses of nitrogen from urine on soils from south-western Australia. *Australian Journal of Experimental Agriculture and Animal Husbandry* 9(36):85–91.

Zemmelink G. 1980. *Effect of selective consumption on voluntary intake and digestibility of tropical forages.* Agricultural Research Report 896. Centre for Agricultural Publishing and Documentation, Wageningen, The Netherlands. 100 pp.