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Linear Programming-Based Optimization of the Productivity and Sustainability of Crop-Livestock-Compost Manure Integrated Farming Systems in Midlands of Vietnam

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ABSTRACT: Farmers' livelihood in the midlands of the northern part of Vietnam relies mainly on crop production and livestock rearing. Green manure and animal dung are commonly used for crops, particularly in rice culture - a staple food crop, and sugarcane - a cash crop. Due to the small-scale livestock systems, the animal dung is limited, which results farmers in preferring a smaller sugarcane cultivation area. This research study was to investigate and to optimize the effect of animal and green manures and their combination together with heat-compost technique on the improvement of the quality of organic manure, soil fertility and yield in three farm categories. The study revealed that the farmers in the small, medium and large farm categories should raise livestock up to 4 pigs and 3 buffaloes, 7 pig and 5 buffaloes, and 20 pigs and 13 buffaloes, respectively to match with the available resources. The optimized livestock herd holding and sugarcane cultivation area resulted in 88.7% increase of the return from livestock and 62.5% from crops in the small farm size, 25% from livestock and 9% from crops in the medium farm size and 171% from livestock while unchanged from crops in the large farm size.

KEYWORDS: livestock, heat-compost manure, sugarcane, linear programming, Vietnam, animal dung.

INTRODUCTION

Integrated activities of crop production, livestock raising and organic manuring still bear important roles in the subsistent farming systems in northern mountain and midland regions of Vietnam, where large land areas, green hills or barren stone mountains, isolated hamlets, under-developed markets, poor living standards, and low level of education, exist[1]. In these areas crop production essentially relies on organic matter for nutrient supplementation with the use of animal and green manures. Animal manure is mixed with kitchen ash and applied once at harrowing and again during weeding in rice farming systems in high and medium-hills and low mountainous areas[2]. In addition to livestock manure, green material, usually Lao grass (*Eupatorium odoratum*) and wild plants, collected from forest and shrublands are mixed with the soil during land preparation. In the subsistent agricultural systems in Vietnam, the farmers believe that green manure has less effect in terms of nutrient supply to crops compared to animal manures, and hence it is not widely practiced despite its availability in the area. Animal manure is limited in both midlands and highlands due to small-scale livestock raising[1], use of indigenous breeds and locally available feed sources. This in turn limits the extent of cash crop cultivation in both midlands and highlands.

Currently, the number of farmers using green materials as organic manure in Mong Hoa commune is very low. Out of the respondents, 68% had used green material in the past, but at present only 32% still uses it. The main reasons are a lack of labor and time for collection and a ready and easy access to chemical fertilizers. Some farmers (22%) believe that the change of cropping pattern in two-season field from one to two rice seasons also influenced the reduced use of green manure. Green materials are often ploughed into rice field during land preparation and allowed to decompose under flooded conditions before transplanting. The change of cropping pattern has resulted in a short turning time between two rice seasons. Thus, the decomposition of green material becomes ineffective. Composting of both green material and animal dung together would bring a sustainable solution to this problem. In the lowland areas in Vietnam the heat-composting or aerobic composting is often adopted by farmers, but is not familiar to the farmers in the midlands and highlands. Composting is carried out either in heaps or pits and organic matter is processed in such a way to fit and safe to add to the soil where crops are to be grown[3]. The super phosphate is added to the organic material before composting in the heat-composting method, and helps to reduce ammonia loss, in addition to increase the P content of final manures [4, 5].

Compared to many other crops grown, sugarcane is a highly versatile plant which is successfully grown as a cash crop under a wide range of conditions in Vietnam. Sugarcane is grown in sloping lands up to 10 per cent, with soil texture varying from light sands to heavy clay and under pH ranging from 4 to 7, and it also shows remarkable resistance to drought[6]. In the northern mountainous parts of Vietnam, the average yield of sugarcane is 49.2 t/ha[7]. Sugarcane has the highest harvest index of all crops[8]. All components of the plant have an economic value in Vietnam. Therefore, sugarcane is grown as a cash crop in many arable lands in midlands and highlands of Vietnam. However, there is no regular method of determining the extent of the crops grown in the area as it is partly governed by the availability of animal dung and other resources. If the fresh animal dung were composted together with freely available green material in the midlands and highlands, it would provide opportunities for the farmers to expand the cultivated extent of sugarcane, and to receive greater cash and other benefits when compared to the traditional farming systems.

This study was to optimize the productivity of livestock - sugarcane farming system in the midlands of Vietnam using linear programming-based modeling. The specific objectives were to maximize the nutrient contents of compost manure prepared using optimum combination of pig dung, buffalo dung, green manure and super phosphate by taking into account the overall input-output relationship and to determine the optimum number of livestock size and types that should be raised to obtain the highest possible extent of sugarcane production and optimum income under maximum use of animal dung heat-compost nutrient management method.

Materials and Methods

The study was conducted in Mong Hoa commune (situated between 105.11° and 105.2°E and 20.35° and 21.01°N), Ky Son District, Hoa Binh Province in the north-western region of Vietnam. The location receives continental monsoon rains with two distinguished seasons: the cold and dry season (November to April) and the hot and rainy season (from May to October). The average monthly temperature varies from 15.5°C in January to 29°C in July with the yearly average of 21°C. The average annual sunshine hours range from 1400 to 1900 hours (175 to 237.5 sunshine days per year). Total thermal input is 8,666° growing degree days (GDD) which 80% is effective for growth and development of crops. In 2005, the lowest rainfall was in January (11.1 mm) and the highest was in August (519.8 mm). The average humidity is 84 to 86%, the highest in August and September (87-89%) and the lowest in January and February (59-70%). The annual average evaporation is around 1000 mm. The rainy season started in May and had 19 rainy days during the month and increased ten times toward April. The topography is low hills and rocky-mountains. Mong Hoa has an average altitude of 300m above MSL, ranging between 200 and 800m above MSL. Shortage of water in the dry season is one of the main limiting factors for cropping, particularly in home gardens and upland fields.

Mong Hoa has a population of 4,863, with 17 villages and 1,102 farms. Total land area in Mong Hoa is 1875.8 ha which includes resident, agricultural, forestry, infrastructure and industrial, water area and unused lands. The agricultural lands occupy approximately 440.64 ha, which is divided into four categories, i.e. lowlands (27%), uplands (19%), permanent-crop lands (19%), and home gardens (35%) .

The diversity of land types influences the cropping system in the study area. Each land category has one specific cropping system, which is true in lowlands, upland fields and home gardens. Home garden covers the lands around farmer's house, which are typically used as mixed gardens. Many crops are planted with irregular patterns hence biodiversity is rather high, with a large number of fruit trees, vegetables, herbs, and ornamental species planted at various stages of the cropping cycle and also year-round. Lowland areas are usually flat land areas lying along the rivers, streams, etc and has an access to irrigation water, and hence these lands are used for growing rice during spring - summer (February - June) and summer- autumn (July - October) periods. Vegetable and other food crops (sweet potato and maize) are grown in the lowlands in the winter season. Uplands are located in the higher altitude, where there is almost no access to the irrigation water. Thus, the farmers select sugarcane, cassava and lemon grass together with annual crops to be grown year-round under water-stress conditions. Sugarcane is considered as the most economic crop due to its high income generation yet both sugarcane area and its yield are limited in many farms because of the limited availability of organic manure and inaccessibility to chemical fertilizers.

Livestock raising is one of the main farm activities in Mong Hoa. Among three major livestock species, poultry is raised by almost all the farmers for family consumption. Pigs are raised mainly for the market and dung collection at medium scale (average of 8.36 pigs/ farm/year) and fed by locally available feed, and in some situations supplemented with commercial feeds. Buffaloes are raised for dung and ploughing in the short-term, and for selling to earn money in the long-term. The average number of buffaloes raised is 2.3 heads per farm per year. A lot of farmers use animal dung as an indispensable organic manure source for their crops. Therefore, raising pigs and buffaloes is not only a contribution to the farm income, but also an indirect contribution through dung for increasing crop productivity and reducing cost of crop cultivation by substituting artificial fertilizer needs while improving and maintaining soil fertility[9].

Experimental Design and Treatments

The field experiments were collection of information from a pre-experiment survey which composed of different types of manure combinations or the set ratios of pig dung, buffalo dung and locally available green materials and processing methods (i.e. fresh and composted forms) as shown in Table 1, and tested for the potential contribution for soil fertility improvement using leaf mustard crop. Eleven experimental treatments were arranged in a randomized complete block design (RCBD) with 3 replicates, plot size of 4m x 2.1m and block size of 23.1m x 4m and with total experimental area of 313 m^2.

Table 1. Experimental treatments and composting combinations.

No.	Form	Manure composition ratio (dry weight)			Treatment
		Pig	Buffalo	Green	code
1	Fresh	1	0	0	F100
2		0	1	0	F010
3		1	1	0	F110
4		0	0	1	F001
5	Heat Compost	1	1	1	H111
6		1	1	2	H112
7		1	0	1	H101
8		0	1	1	H011
9		1	1	0	H110
10	Control	No manure but with fertilizer			C000F
11		No manure and fertilizer			C0000

Compost Preparation Procedure

Heat composting method, as adopted by farmers in the lowland areas, was used. The pit method (0.5 m deep pit) was used in the dry season (from 5th March to 23rd April, 2005, total of 50 days) and above ground level heap method was used in the wet season (from 17th April to 3rd July, 2005 total of 80 days). The raw material included either fresh pig dung, buffalo dung or raw green manure or combinations as per treatments. In compost manures that should contain green manure as a component, leaves and stems collected plants were chopped up to 2-3 cm pieces to increase the rate of decomposition, and mixed with fresh animal dung at required ratios (based on dry matter content) (Table 1). Both chopped green manure and animal dung were arranged as alternative layers on the site. The mixtures were just spread, but not pressed in order to facilitate aeration for microbial activities. In addition, 5 kg of super phosphate (P_2O_5 15 -17 %; CaO 28 -34; MgO 15 -38 %; SO_2: 24 -30 %) was evenly sprinkled on every layer of the heap to reduce N losses due to evaporation. A slurry made of pig dung, buffalo dung or both with water was poured on the heap to maintain suitable moisture content for the decomposition process, and the heap of manure was covered by a plastic sheet for 50 to 80 days, and then the heap was thoroughly mixed and applied to corresponding plots.

Heat compost manure preparation was arranged predecessor to the experimental site development. Composted manures, fresh green leaves and stems, fresh pig dung, fresh buffalo dung and their mixture were applied as per treatments at the field experiments at basal application. For treatments receiving combinations of green manure and animal manure, each material was mixed according to ratios shown in the treatments. Organic manure was applied at the rate of 2.7 kg m^{-2} on the dry matter basis (17.82 kg dry organic manure per plot) as basal application at the final land preparation. Of the two control treatments, one received neither fertilizer nor organic manure, while the other was given N, P, and K at the rate of 75, 64 and 37 kg/ha, respectively, at the basal application using 5:10:3 N:P:K commercial fertilizer mixture, and N and K were applied at the rate of 46 and 40 kg/ha, respectively, using urea and Kalisuynphat (K_2SO_4 – 50% K and 18% S), respectively at 7, 15 and 25 days after transplanting (DAT) as per Department of Agricultural Extension recommendation.

Land Preparation and Crop Management

Land was prepared using buffalo-pulled mould-board plow and raised beds were arranged to a height of 15 to 20 cm, width of 1.8 m and 3.7 m long. Plots were separated by a 30 cm deep drain. Organic manure was applied and incorporated 5 to 10 days before transplanting. Thirty-day old leaf mustard seedlings were transplanted in the plots with the planting space of 32cm x 40cm (7 plants per m^2) in dry season and 25 x 30 cm (10 plants per m^2) in wet season. Watering was carried out everyday in the dry season (Spring-Summer) and only whenever needed in the wet season (Summer). Integrated pest management methods were employed to control pests and diseases after monitoring the pest population. Leaf Mustards were harvested by pulling out the whole plant including root system at 40 days after transplanting. Soil and dry matter production data were gathered to estimate the potential benefits of selected manure types on crop production and soil fertility analysis.

The Linear Programming Model

Many quantitative mathematical analysis tools have been developed to analyze and support decision making in agricultural research and farming systems[10]. Linear programming (LP) is a mathematical systems analysis technique, which optimizes some linear objective functions subject to certain linear constraints in order to explore the optimum solution. For this study, LP was selected to formulate the appropriate composition of pig dung, buffalo dung and green manure for compost making, which has optimum potential to increase yield of crops, fertility of soil. It was also intended to optimize the livestock raising capacity at smallholder level matching with the appropriate dung production for compost making.

The LP models can be maximizing or minimizing functions[11]; the maximizing model used in this study was as follows:

The objective function; $$Z_{\max} = \sum_{i=1}^{j} C_i X_i \quad (1)$$

Subjected to constraints; $$\sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} X_i \le b_j \quad (2)$$

Non-negative constraints; $$X_i \ge 0 \quad (3)$$

Where, Z_{max} = Maximizing objective function
X_i = Decision variables
a_{ij} = Coefficients of usage of resources
b_j = Coefficients of amounts of resources
c_i = Coefficients of increase of units to optimize Z
i = 1, 2, 3, … n, number of variables
j = 1, 2, 3, … m, number of constraints

The objective function is to maximize the nutrient contents of compost manure prepared using pig dung, buffalo dung green manure and concentrated super phosphate and to optimize the profitability from leaf mustard production using compost manure. The combination will start with preparation of 100 kg dry weight of compost.

Compost manure: 100 kg dry weight

X_1 = Dry weight of pig dung in 100 kg dry weight of compost

X_2 = Dry weight of buffalo dung in 100 kg dry weight of compost

X_3 = Dry weight of green manure in 100 kg dry weight of compost

X_4 = Weight of concentrate super phosphate to be added to mixture (1 to 2% of fresh weight of mixture)

$$Z\max = 0.021X_1 + 0.014X_2 + 0.0422X_3 + 0.093X_4 \quad (4)$$

Source of Data

The primary data collected from field experimentations on the effect of animal and green manure and their combination on soil fertility and yield of crops and field survey on the use and effect of organic manure on practical crop production in Mong Hoa Commune, Hoa Binh province in the Midlands of Vietnam during 2005 cropping seasons. Secondary data sources, extracted from the annual reports of District Agricultural Extension Station and review of literatures, were used as supplementary sources to the primary data.

Objective function of the LP model 1: Maximization of nutrient contents of compost manure using pig dung, buffalo dung and green manure based on sugarcane nutrient requirement.

This function was established based on the nutrient (nitrogen - N, phosphorus - P and potassium - K) contents of locally available organic materials, which included pig dung, buffalo dung and green manure and phosphorus content in super phosphate fertilizer (Table 3). The constraints imposed on the model were mainly

Table 2. Constraints: Composting period, material availability, labor and material cost, yield increase potential, crop nutrient requirement.

No.	Constraints	Detail	Constrain equation
1	Weight of mixture	100 kg	$X_1 + X_2 + X_3 = 100$ (1)
2	C/N ratio in the mixture	20 to 40	$4X_2$ e” $2X_1 + X_3$
3	Availability of animal dung		X_2 e” X_1
4	Availability of green manure		X_3 e” $X_2 + X_1$
5	Pig dung price (US$/kg dry weight)	0.089 (1,430 VND)	X_1 d” 25
6	Buffalo dung price (US$/kg dry weight)	0.070 (1,120 VND)	X_2 d”25
7	Green manure price (US$/kg dry weight)	0.044 (700 VND)	X_3 e”50
8	Mustard yield when applied pig manure	10.76 ton/ha	X_1 e” 15
9	Mustard yield when applied buffalo manure	7.04 ton/ha	X_2 e” 10
10	Mustard yield when applied green manure	6.94 ton/ha	X_3 d” 80
11	Leaf mustard N,P,K requirement:	130:30:70 kg/ha	$1.11 X_1 + 0.18X_2 - 1.02X_3 + 34.88X_4$e”0

Table 3. Nutrient contents and cost of pig, buffalo and green manures used for compost making.

Material	Total N (%)	Total P (%)	Total K (%)	C/N ratio	Labor cost (US$/kg)[1]	Price (US$/kg dry weight)	Seasonal availability
Pig dung	0.87	0.48	0.74	18	0.02	0.07	Year round
Buffalo dung	0.30	0.06	1.02	24	0.02	0.05	Year round
Green manure	2.38	0.26	1.59	19	0.04	0	Rainy & Spring
Super phosphate	0	9.3	0	0	0	0.38	

[1] VND – Vietnam Dong, 1US$ = 16,000 VND.

generated under the locally specific conditions and status. Both pig and buffalo dung are available year-round, while green leaves and stems can be collected only in the rainy and spring seasons. Due to small scale of pig production at smallholder level, pig dung had lower quantity than buffalo dung. In addition, pig dung was primarily used for rice crop and had higher nutrient content. Hence, it has higher price and potentials of yield improvement than buffalo dung. Green manure is freely available in the fallow and ranger lands and forest areas. However, the collection of green manure requires a lot of farm labor, i.e. to collect 150 kg of fresh green leaves and stems requires one man-day and costs 1.56 US$.

As the optimal range of C/N ratio for decomposition activities of microorganisms was 25-40[12, 13,] the C/N ratio in the mixture was taken into account. In addition, a constraint in the analytic models was nutrient requirement of sugarcane. Cultivation of 1 ha sugarcane requires 100 kg N (range 100 to 140), 150 kg P (range 50 to 250) and 100 kg K[6].

Objective function of the LP model 2: Optimizing livestock holding capacity to maximize the dung harvest for sugarcane cultivation

This function based on the estimated dung yield generated from pig and buffalo raising activities at three farm size categories: small, medium and large farms. The constraints imposed on the model were animal feed consumption, capital and labor requirement and number of pigs and buffaloes raised and the amount of dung applied to rice and sugarcane as well as farm availability of animal feeds, farm landholding, labor force and capital.

Data for Coefficients used in Objective Functions and Constraints in Models

Table 4 quantified the constraints of pig feeding in three farm categories. Pig feed requirement varied depending on pig growing stages, pig breeds and nutrient contents in the feed[14, 15]. Farmers noted that pig feeds were accessible since they used locally available feed sources and capital to buy supplemental feeds, which are mainly commercial brands and were available at the market.

Table 4. Feeding mode, capital requirement and manure utility of pig feeding.

Constraint	Farm size category/Feeding mode		
	Small (Using locally available feeds)	Medium (Using both locally available and commercial feeds)	Large (Using commercial feeds)
Estimation of dung collected (t/animal/ year)	0.24	0.2	0.18
Total investment (US$/ animal/year) [1/]	31.25	40.63	65.63
Amount of dung applied to rice (t/ha)	15	15	15 - 20

[1/] Currency conversion 16,000 Vietnam Dong = 1US$.

The Mong Hoa farmers often applied pig dung on rice at the rate of 15 t/ha. It was estimated that the capital investment required per pig per year for locally available feeds, both locally available plus commercial feeds and commercial feeds were US$ 31.25, 40.63 and 65.63, respectively.

Table 5 quantifies the constraints on buffalo raising in three farm categories. The average body weight range of an adult buffalo in Vietnam was 350 to 550 kg/ buffalo and daily feed consumed by a buffalo was from 4-5% of body weight or 20 to 25 kg per day [16, 17]. Management practices were based on extensive systems and buffaloes were freely grazed in natural grasslands, forests, roadsides, canal banks and rice fields after harvesting, etc. The farmers noted that buffaloes had enough feed from grazing on grassland in the rainy season, thus they do not feed buffaloes after grazing time. During dry season, the scarcity of green grasses occurred, besides the feed grazed from natural grasslands, buffaloes were also fed with rice straw and sugarcane biomass or other crop residues.

The availability of feeds for buffaloes in the dry season are estimated based on practical and possible sugarcane and rice cultivation areas as well as sugarcane residue and rice straw yield. Residual biomass such as stalk, top, shoot, etc are used as buffalo feeds. Sugarcane grown in the midlands area in northern mountain part of Vietnam generated 25 to 34 t/ha of residual biomass[18].

Table 5. Feed and capital requirement and manure utility of buffalo raising.

Constraints	Quantity
Estimation of dung collected (t/animal/ year)	1.5
Buffalo feed availability in the dry season (t/year/farm):	
Small size farm	3.55 - 7.42
Medium size farm	8.2 - 13.5
Large size farm	53.4 - 64.9
Feed requirement (t/animal/year)	6 to 9
Supplemental feed in the dry season (t/animal/year)	3.6 to 5
Capital requirement (US$/ animal/year) [1/]	78.13
Amount of dung applied to rice (t/ha)	15
Amount of dung applied to sugarcane (t/ha)	25

[1/] Currency conversion 16,000 Vietnam Dong = 1US$.

The quantity of straw biomass varied from 2 to 8 t/ha depending on the variety of rice, productivity (high rice yield will result in high straw yield), and harvesting method (cutting closer to the ground will result in more straw). The straw to grain ratio typically varies from 0.8:1 to 1.2:1[19]. In Vietnam, the average of rice straw yield varied from 32 to 40 t/ha[20]. The Mong Hoa farmers often used buffalo dung for sugarcane at the rate of 25 t/ha. In some farms, it was also used for rice when there was a shortage of pig dung. The capital investment required for buffalo raising was mainly for purchasing of animals and the average cost was US$ 78.13 per buffalo.

Table 6 represents the accessibility constraints of farms for livestock and sugarcane production in Mong Hoa commune. The Mong Hoa farmers use family labor such as children and old-people for pig and buffalo raising. All daily free time was for feeding pigs, while grazing buffaloes always needed one family member spending half or whole day for a herd. Capital availability for livestock raising of each farm category is a difference between farm income and expenditure. Various credit programs from Agricultural Development Bank, the Bank for the Poor and Commercial had been implemented providing specific privilege conditions for all farm sizes.

Results and Discussion

LP Model 1: Maximization of nutrient contents of compost manure

The results of the simulation conducted with known data were presented in Table 7. N, P and K contents in the model simulation using fresh buffalo dung and green manure at the ratio of 3:7 (M037) were higher than those of three composts manures prepared in midlands of Vietnam using pig, buffalo and green manures at the ratios of 1:1:1, 0:1:1 and 1:1:0 (C111, C011 and C110) and LP simulation based on leaf mustard nutrient requirement (M239), but lower than that of two composts prepared using pig, buffalo and green manures at the ratios of 1:1:2 and 1:0:1(C112 and C101). The cost of M037 preparation is the lowest compared to other composts as well as M239. There is a possibility that farmers would reduce the manure and fertilizer costs by compost prepared using buffalo and green manures at the ratio of 3:7. The use of organic manure rather than chemical fertilizer tended to enhance yield of prime product and edible biomass, which can be used to feed ruminant[18]. In Mong Hoa, the farmers' believed that the application of buffalo manure as a basal dressing together with chemical fertilizers to sugarcane increases yield of sugarcane from 2 to 6 t/ ha. Hence, growing sugarcane by using M037 compost and fertilizers would improve the return from sugarcane production in Mong Hoa.

LP Model 2: Optimizing livestock holding to maximize the dung harvest

Small farm category : Small size farms generally consisted of 3 to 4 members and hold an average extent of 0.18 ha of unirrigated lands (home garden and upland) and 0.12 ha of irrigated lands (paddy fields) (Table 8). These farms were eligible for bank loans of 312.5 to 625 US$ from the Bank for the Poor. One farm currently feeds 4 pigs and 1 buffalo and annually collects 0.5 t of pig dung and 0.85 t of buffalo dung, which were used for 0.12 ha of rice and 0.09 ha of sugarcane, respectively.

Under these conditions, small farm size should optimize its livestock holding to 4 pigs and 3 buffaloes in order to harvest up to 0.9 t/year/farm of pig dung and 3.8 t/year/farm of buffalo dung. With such dung yield, sugarcane cultivation area could be increased up to 0.15 ha or with a magnitude of 0.67 times of the current sugarcane area. As a result of the optimal livestock holding, the farm return from livestock raising and crop production would be increased by 88.7% and

Table 6. Farm's accessibility for livestock and sugarcane productions.

Farm size	Farm capita	Farm labor (no. labor/ farm)	Capital availability (US$)[1]	Loan accessibility (US$/year)	Home garden area (ha/farm)	Upland area (ha/farm)	Lowland area (ha/farm)
Small	3	1.3	62.5	312.5 to 625	0.14	0.04	0.12
Medium	5.2	2.75	312.5	312.5 to 625	0.20	0.14	0.18
Large	4	2	1875	Unlimited	0.89	0.17	0.12

[1] Currency conversion 16,000 Vietnam Dong = 1US$.

Table 7. Composition of different ingredients and nutrient contents and the cost of the end product of compost prepared using pig, buffalo and green manures in midlands of Vietnam and comparison with the linear programming model results.

Manure code [1/]	Composition of different ingredient added to the mixture for compost making (parts by dry weight)				Total nutrient content			End product cost (US$/kg dry weight) [4/]
	Pig dung	Buffalo dung	Green manure	SuperPhosphate (kg)	N (%)	P (%)	K (%)	
Linear programming simulation								
M037 [2/]	0	3	7	5	1.75	0.66	1.41	0.066
M239 [3/]	2	3	9	5	1.67	0.71	1.33	0.071
Compost prepared using pig, buffalo and green manures in midlands of Vietnam								
C111	1	1	1	5	1.64	0.59	1.42	0.082
C112	1	1	2	5	1.85	0.68	1.61	0.076
C101	1	0	1	5	1.75	0.68	1.60	0.081
C011	0	1	1	5	1.64	0.52	1.74	0.071
C110	1	1	0	5	1.55	0.58	0.96	0.94

1/ The first letter shows the type of manure (M - modeling and C - heat composted) and the three digits are the numbers in sequence of the mixture proportions of pig dung, buffalo dung and green manure, respectively.
2/ Based on sugarcane nutrient requirement (100 kg/ha N, 150 kg/ha P and 100 kg K/ha).
3/ Based on leaf mustard nutrient requirement (130 kg/ha N, 30 kg/ha P and 70 kg K/ha).
4/ Currency conversion 16,000 Vietnam Dong = 1US$.

Table 8. Livestock herd size, the amount of dung used by the farmers and sugarcane cultivation area in Mong Hoa commune and comparison with the linear programming model results.

	Farm size	Average herd size (no./year/farm)		Dung harvest(t/year/farm)		Sugarcane area(ha/farm)
		Pig	Buffalo	Pig	Buffalo	
Current status in Mong Hoa, 2005	Small	4	1	0.5	0.85	0.09
	Medium	10	3	1.6	3.7	0.25
	Large	40	4	7	5	0.865
Linear programming simulation	Small	4	3	0.9	3.8	0.15
	Medium	7	5	1.3	6.8	0.27
	Large	20	13	3.6	18.8	0.94

62.5%, respectively (Figure 1).

Medium farm category: A size farm in Mong Hoa had 5 to 6 members with an average of 3 labors (aged from 18 to 59 years old). A farm held 0.34 ha of non-irrigated lands and 0.18 ha of irrigated lands (Table 8). The farmer was eligible for a loan of US$ 312.5 to 625 from the Agricultural Development Bank. A farm currently raised an average of 10 pigs and 3 buffaloes and collected 1.6 t of pig dung and 3.7 t of buffalo dung annually. The average sugarcane cultivation area is 0.25 ha.

The medium farm could optimize its livestock holding to 7 pigs and 5 buffaloes and yielded dung harvest up to 1.3 t/year of pig dung and 6.8 t/year/farm of buffalo dung. Thus, sugarcane cultivation area would increase from 0.25 to 0.27 ha. As a result of the optimal livestock holding, the farm return from livestock raising and crop production would be increase by 25% and 9%, respectively (Figure 1).

Large farm size: A large farm in Mong Hoa had an average of 4 members with 2 labor members. The farm held 1.06 ha of non-irrigated lands and a 0.12 ha of irrigated lands (Table 7). These farms were eligible for an unlimited collateral loan from the Commercial Bank. The farm practically raised an average of 40 pigs and 4 buffaloes and collected 7 t of pig dung and 5 t of buffalo dung annually. The average sugarcane cultivation area was 0.865 ha.

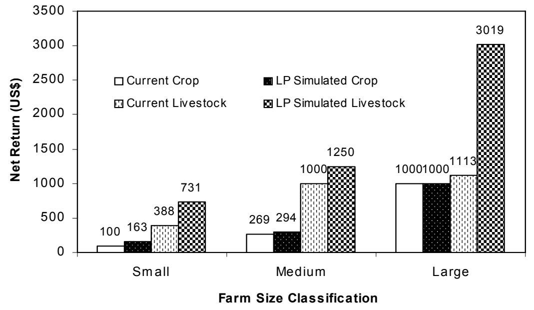

Fig 1. Return from livestock, rice and sugarcane productions in Mong Hoa commune in comparison with the linear programming model results [1/].
1/ Return includes cost of family labor and management. 1US$ = 16,000 VND.

The large farm size could optimize its livestock holding to 20 pigs and 13 buffaloes and dung harvest yielded up to 3.6 t/year of pig dung and 18.8 t/year of buffalo dung. Thus, sugarcane cultivation area should increase from 0.865 up to 0.94 ha. As a result of the optimal livestock holding, the farm return from livestock should be increased by 171%, while return from rice and sugarcane productions should remain unchanged compared to the current status in Mong Hoa commune (Fig. 1).

The results from the model indicated a considerable shift in the size of livestock holding in the three farm size categories. Pig herd size generally remained unchanged in the small farm size and reduces by 0.3 (3 pigs) and 0.5 times (20 pigs) as compared to the current pig herd size in medium and large sized farms respectively, while buffalo herd size increases by 3 (3 buffaloes), 1.6 (2 buffaloes) and 3.3 times (9 buffaloes) in small, medium and large sized farms, respectively. Profits from pig feeding in Mong Hoa varied depending on raising mode. Both locally and semi-locally available feed-based systems have a small herd size, low input cost and low daily weight gain, extend feeding time up to 5 to 6 months, and return from pig feeding is from 18.75 to 25.00 US$/pig. A commercial feed-based system needed high input cost and had a high daily weight gain, but the return was around 4.38 to 6.25 US$/pig. Thus commercial pig feeds seemed to be economically less efficient. Rearing buffaloes brought better returns than rearing pigs since buffalo could be allowed for free grazing in the large natural grazing lands or fed by readily available crop residues on farm. It was estimated that the returns from rearing one buffalo should range from 187.50 to 250 US$ within 2 to 3 years. Thus, reducing the herd size of pigs and increasing that of buffalo would increase return from livestock production and expand the area and crop yields for sugarcane, and hence will increase return from the integrated agriculture, particularly in the small and medium farm categories.

Conclusions and Recommendation

The results of the linear programming show that the farmers in the Mong Hoa commune can increase the sugarcane yield, and improve soil fertility and soil productivity with the heat-compost prepared by using buffalo and green manures at the ratio of 3:7.

The farmers in the small, medium and large farm categories should raise livestocks up to 4 pigs and 3 buffaloes, 7 pig and 5 buffaloes, and 20 pigs and 13 buffaloes, respectively based on the available resources. The maximum annual dung yield per farm from these livestock herd sizes in the small, medium and large farm categories were at a rate of up to 0.9 t for pig and 3.8 t for buffalo, 1.3 t for pig and 6.8 t for buffalo, and 3.6 t for pig and 18.8 t for buffalo, respectively. The sugarcane cultivation area can be expanded up to 0.15, 0.27 and 0.94 ha in the small, medium and large farm categories respectively. The optimized livestock herd holding and sugarcane cultivation area resulted a 88.7% increase of the return from livestock and 62.5% from crops in the small farm size, 25% from livestock and 9% from crops in the medium farm size and 171% from livestock and unchanged from crops in the large farm size.

Hence, the improvement of livestock production would directly benefit the sustainable agricultural production through improving soil fertility and thereby improving incomes of the farmer families.

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