Supplementary Material: Detailed results for manure value chain participants

## I. Value chain participants

### 1. Lowland farmers

Smallholder cattle farmers interviewed in lowland communes owned less than four head on average (An Chấn Commune (AC) = 3.9 head with SE ± 0.38 head, Nhơn Khánh Commune (NK) = 2.7 head with SE ± 0.22 head) and owned and rented 0.268 ha with SD ± 0.195 ha of land. Overall, 83% of farmers reported at least one manure sales event and the odds of at least one manure sales event[1] increased by 46% for each additional cow owned when commune was held constant. Proportion of available manure sold did not depend on commune ($P = 0.9611$). Daily grazing time in AC was 7.5 h with SE ± 0.28 h, a distance of 1.6 km with SE ± 0.13 km from the household. The daily grazing time in NK was 3.6 h with SE ± 0.26 h, a distance of 269 m with SE ± 31.5 m from the household. Only two AC farmers and three NK farmers collected manure when cattle were out grazing. The two AC farmers reported collection of manure from cattle owned by other farmers to augment manure available for sale. Daily grazing was supplemented near the household with ingredients consisting primarily of grass, rice straw, rice, and rice bran (Table A1). All animals were crossbred in NK. Cattle in AC were a mix of crossbred and local yellow cattle.

[1] Analyzed using PROC LOGISTIC (SAS Institute Inc. 2013. SAS 9.4 for Windows. SAS Inst., Cary, NC.)

**Table A1** Ingredients fed to cattle as reported by farmers in An Chấn and Nhơn Khánh communes, and the mean and SD of the amount fed. Not all respondents were able to report daily quantities fed. Total farmers interviewed in AC and NK were 50 and 51, respectively.

| Ingredient (as fed) | AC | | | | NK | | | |
|---|---|---|---|---|---|---|---|---|
| | Frequency (# of respondents) | Amount fed (kg/animal per d) | | | Frequency (# of respondents) | Amount fed (kg/animal per d) | | |
| | | *n* | Mean | SD | | *n* | Mean | SD |
| Concentrate | - | 1 | 1 | | - | | | |
| Dried cassava | 4 | 4 | 0.258 | 0.162 | - | | | |
| Fresh grass | 44 | 44 | 16.3 | 12.6 | 21 | 18 | 14.7 | 7.85 |
| Maize | 1 | 1 | 16.7 | | 6 | 5 | 0.303 | 0.123 |
| Rice [a] | 28 | 27 | 0.428 | 0.932 | 25 | 23 | 0.746 | 2.02 |
| Rice bran | 19 | 19 | 0.375 | 0.324 | 13 | 13 | 0.474 | 0.326 |
| Rice straw | 47 | 47 | 3.85 | 4.53 | 12 | 9 | 5.81 | 2.55 |
| Salt | 1 | 1 | 0.0450 | | - | | | |
| Water spinach or leafy vegetables | 31 | 28 | 2.27 | 1.21 | 21 | 20 | 3.80 | 2.29 |

[a] Rice was ground up and fed in water.

Manure not sold was retained and composted for use as fertilizer for crop and forage production (Table A2), and manure retention for agricultural use was the most important reason for not selling any manure in both communes (14% of farmers). Most farmers composted cattle manure during the late dry season (August) and the rainy season (September to December), and applied prepared compost on the first rice crop (winter-spring), second rice crop (summer-fall), or forage grass (Table A2). Compost was most commonly applied to rice and forage grasses at rates below 10 Mg DM/ha per yr. The most commonly reported manure management challenge was lack of a manure pit to collect manure during the rainy season (11% of farmers). Manure loss during high rainfall periods due to flooding was problematic for these farmers.

**Table A2** Land area and fertilization rates by crop as reported by farmers in An Chấn (AC) and Nhơn Khánh (NK) communes. Land area means are calculated only from households that plant a given crop. Fertilization rate means are calculated only from households that use a given fertilizer. Composted manure dry matter rates were determined assuming 50% dry matter in applied compost.

| Commune | Crop Name | Area (ha) | | | Compost (Mg DM/ha per yr) | | | Urea (kg/ha per yr) | | | NPK blends (kg/ha per yr) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *n* | Mean | SD | *n* | Mean | SD | *n* | Mean | SD | *n* | Mean | SD |
| AC | Rice (winter-spring) | 46 | 0.0868 | 0.0571 | 7 | 5.55 | 6.07 | 45 | 349 | 191 | 33 | 232 | 142 |
| AC | Rice (summer-fall) | 40 | 0.088 | 0.0429 | 12 | 6.72 | 4.79 | 39 | 349 | 165 | 31 | 217 | 147 |
| AC | Rice (late year) | 19 | 0.207 | 0.22 | 5 | 7.34 | 4.19 | 19 | 300 | 153 | 3 | 133 | 28.9 |
| AC | Forage grass | 47 | 0.0807 | 0.0630 | 29 | 7.90 | 9.67 | 47 | 805 | 1060 | 1 | 500 | |
| AC | Maize | 12 | 0.118 | 0.08 | 5 | 5.73 | 4.11 | 11 | 230 | 151 | 2 | 66.7 | 47.1 |
| AC | Watermelon | 10 | 0.09 | 0.0768 | 9 | 3.75 | 1.62 | 8 | 274 | 202 | 4 | 155 | 95.4 |
| AC | Peanut | 7 | 0.204 | 0.11 | 1 | 12.8 | | 3 | 129 | 24.1 | | | |
| AC | Cassava | 7 | 0.168 | 0.152 | 1 | 0.8 | | 3 | 128 | 75.2 | | | |
| AC | Leafy vegetables | 7 | 0.0531 | 0.0275 | 3 | 7.5 | 4.33 | 7 | 1250 | 964 | | | |
| AC | Eggplant | 3 | 0.0667 | 0.0289 | 3 | 15.3 | 8.08 | 2 | 320 | 113 | 1 | 800 | |
| AC | Squash | 3 | 0.127 | 0.108 | 3 | 5.71 | 3.74 | 2 | 140 | 84.9 | | | |
| AC | Jicama | 1 | 0.03 | | 1 | 8.33 | | 1 | 200 | | | | |
| AC | Gourd | 1 | 0.04 | | 1 | 6.25 | | 1 | 250 | | | | |
| AC | Sesame | 1 | 0.15 | | | | | | | | | | |
| NK | Rice (winter-spring) | 48 | 0.223 | 0.129 | 34 | 6.71 | 5.41 | 45 | 177 | 87.6 | 48 | 212 | 96.7 |
| NK | Rice (summer-fall) | 50 | 0.225 | 0.125 | 9 | 2.9 | 2.41 | 48 | 193 | 97.6 | 49 | 226 | 105 |
| NK | Forage grass | 25 | 0.0638 | 0.057 | 7 | 2.02 | 1.72 | 23 | 705 | 604 | | | |
| NK | Maize | 36 | 0.112 | 0.0493 | 6 | 2.21 | 1.87 | 36 | 364 | 240 | 21 | 306 | 216 |
| NK | Peanut | 10 | 0.118 | 0.0442 | | | | 1 | 500 | | | | |
| NK | Leafy vegetables | 6 | 0.05 | 0.0158 | | 4 | 2.83 | | | | 5 | 736 | 355 |
| NK | Watermelon | 1 | 1 | | 1 | 0.225 | | 1 | 100 | | 1 | 1100 | |
| NK | Bonsai | | 150 trees | | | 1 kg DM/tree per yr | | | | | | 0.48 kg/tree per yr | |

**Table A2, Part 2**

| Commune | Crop Name | Diammonium Phosphate (kg/ha per yr) | | | Potassium blend (kg/ha per yr) | | | Phosphorus blend (kg/ha per yr) | | | Ammonium Sulphate (kg/ha per yr) | | | Lime (kg/ha per yr) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n | Mean | SD | n | Mean | SD | n | Mean | SD | n | Mean | SD | n | Mean | SD |
| AC | Rice (winter-spring) | 12 | 126 | 78.3 | 30 | 111 | 94.9 | 12 | 121 | 72.9 | 4 | 106 | 30.3 | | | |
| AC | Rice (summer-fall) | 11 | 130 | 79.3 | 30 | 122 | 129 | 12 | 116 | 67.4 | 4 | 110 | 26.8 | | | |
| AC | Rice (late year) | | | | 4 | 60 | 27.1 | 1 | 100 | | 2 | 70 | 42.4 | | | |
| AC | Forage grass | | | | 1 | 250 | | | | | 2 | 1300 | 707 | | | |
| AC | Maize | | | | | | | | | | 3 | 261 | 67.4 | | | |
| AC | Watermelon | 8 | 160 | 62 | 4 | 97.9 | 45.3 | | | | | | | | | |
| AC | Peanut | | | | 1 | 200 | | 1 | 333 | | 7 | 231 | 121 | | | |
| AC | Cassava | | | | | | | 1 | 500 | | 7 | 398 | 206 | | | |
| AC | Leafy vegetables | | | | | | | | | | | | | | | |
| AC | Eggplant | 2 | 205 | 276 | | | | 1 | 400 | | | | | | | |
| AC | Squash | 3 | 294 | 236 | | | | | | | | | | | | |
| AC | Jicama | | | | 1 | 333 | | | | | 1 | 333 | | | | |
| AC | Gourd | | | | | | | | | | | | | | | |
| AC | Sesame | 1 | 20 | | | | | | | | | | | | | |
| NK | Rice (winter-spring) | 9 | 73.7 | 39.9 | 38 | 104 | 90.6 | 11 | 239 | 162 | 1 | 70 | | | | |
| NK | Rice (summer-fall) | 10 | 90 | 34.1 | 40 | 105 | 88.6 | 13 | 251 | 164 | 1 | 70 | | | | |
| NK | Forage grass | | | | | | | | | | | | | | | |
| NK | Maize | 3 | 300 | | 10 | 291 | 321 | 16 | 373 | 157 | | | | | | |
| NK | Peanut | | | | 1 | 333 | | 6 | 378 | 138 | | | | 3 | 378 | 107 |
| NK | Leafy vegetables | | | | | | | 1 | 200 | | | | | | | |
| NK | Watermelon | 1 | 50 | | 1 | 200 | | 1 | 500 | | | | | | | |
| NK | Bonsai | | | | | | | | | | | | | | | |

In AC, the most commonly reported reasons for selling manure were to cover daily expenses (14% of AC farmers) and to increase household income (14%). Three farmers indicated that they sold due to manure excess after accounting for all agricultural needs. Farmers in NK most frequently reported excess manure after accounting for agricultural needs as the reason driving sales (29% of NK farmers). Increasing income (12% of NK farmers) and purchasing cattle feed (e.g., rice straw) (20% of NK farmers) with cash from manure sales were also important. Other reasons for manure sales mentioned in both communes were challenges in transporting manure to distant fields, labor shortfalls for manure collection and application, to purchase fertilizer, and to buy vegetables.

Manure was sold by the bag, and average bag volumes were determined from local traders on the basis of bags per cubic meter (AC and NK traders reported 24 and 14 bags/$m^3$ respectively, for bag volume of 41.7 L in AC and 71.4 L in NK). Full bag weights were reported at approximately 15 kg/bag in AC and 25 kg/bag in NK. Empty bags were provided to farmers by lowland traders.

Farmers were asked if manure sold was different than manure retained for household use. Among 65 respondents that said they sell and use manure, 92% indicated that composted manure was retained for household use while dried manure (broken-up or cakes) was sold. Most farmers (54% of 65 question respondents) believed that the quality of dry (sold) manure was equal to manure retained for household use, while 46% believed composted manure was higher quality than dry (sold) manure.

Many farmers would like to continue to dry and sell manure during the rainy season (51% of 79 question respondents), but low prices, buyer scarcity, and difficulty drying manure inhibited sale. Farmers would use manure for crop production (75% of 76 question respondents)

and/or store it until the following dry season (37% of question respondents) if they could not sell it. Some farmers (21% of all farmers) reported intentional stockpiling of manure during the rainy season to dry and sell early in the dry season. Two farmers shared manure with other local farmers during the rainy season or sold composted cattle manure during the rainy season. Two farmers traded cattle manure with other farmers for forage or rice straw to feed cattle. Thus, non-monetary manure trade was uncommon.

Farmers were asked about the impact of not selling manure on farm nutrient management. All question responses ($n$ = 61) included increased soil organic matter and soil nutrients in agricultural fields, fostering improved plant development and decreased reliance on chemical fertilizers.

### 1.1 Lowland farmer manure transactions

Sale price[2] in farmer-reported transactions ($n$ = 130 transactions reported by 82 farms) was \$16.27/$m^3$ with SE ± \$0.22/$m^3$. Mean price did not differ by commune ($P$ = 0.0623), manure type (cakes or broken-up) ($P$ = 0.5517) or buyer type (local trader or small-scale collector) ($P$ = 0.0662). All NK manure was spread to dry on the ground, roadside, or cement slabs. Approximately 50% of AC manure was formed into cakes while the rest was spread to dry on the ground or roadside. Drying times were approximately four days under favorable (sunny, dry) conditions. Manure price in AC cake transactions ($n$ = 39) was significantly lower (\$16.00/$m^3$ with SE ± \$0.36/$m^3$) than manure that was spread on the ground to dry ($n$ = 20) (\$18.23/$m^3$ with SE ± \$0.51/$m^3$) ($P$ = 0.0015). Household explained just 2% of residual variance in this model,

[2] Monetary values reported during interviews were in Vietnam đồng (VND). An approximate exchange rate in 2013 was 21,000 VND/USD, and value data are reported throughout the manuscript in USD using this conversion factor.

suggesting consistent transaction prices within individual households. Only one farmer (AC) said that selling a minimum of 15 bags (0.625 $m^3$) per transaction would save time.

Manure prices reported in transactions indicated highest prices early in the year (Fig. A1), with prices declining quadratically ($P = 0.0001$) from April onward. Most reported transactions (71%) occurred in May and June, and variances were larger during these months than others reported, potentially due to high trader and collector competition during these months.

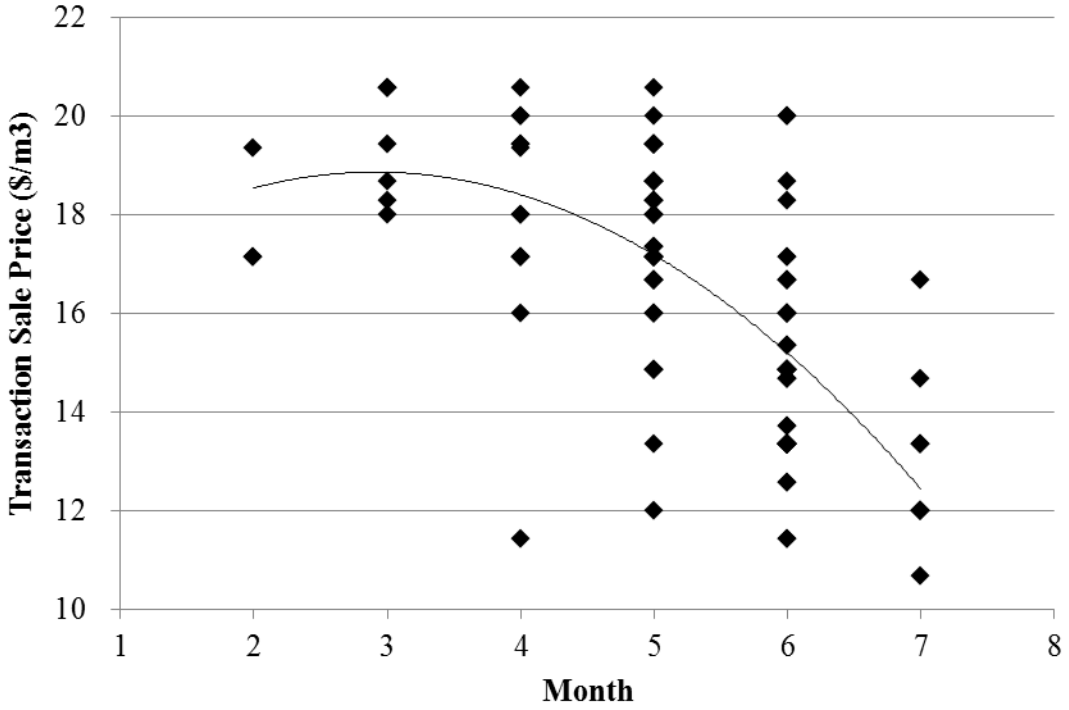


**Figure A1** Transaction sale prices ($n = 130$) reported by lowland farmers declined from April onward. The quadratic relationship is described by: $y = 0.384x^2 + 2.24x + 15.6$. Coefficient of determination ($R^2$) was 0.46.

Average transaction volume ($n$ = 132 transactions) was 0.724 $m^3$ with SE ± 0.0639 $m^3$, and revenue per transaction ($n$ = 130 transactions) was $12.26 with SE ± $1.17. Volume and revenue models included a continuous month covariate and household as a random effect. Household accounted for 65% and 69% of residual variance in volume and revenue models, respectively, indicating considerable transaction variation within households. Transaction volume and revenue differed by commune ($P$ = 0.0002, $P$ = 0.0018) and buyer type ($P$ = 0.0002, $P$ = 0.0002), with higher volumes and revenues for NK transactions and transactions with local traders, respectively. Commune and buyer type remained significant in multivariate mixed models containing a transaction month covariate with square root-transformed volume and revenue responses (Table A3), suggesting that these factors impacted volume and revenue when controlling for transaction time.

**Table A3** Back-transformed least squares means (geometric means) and 95% CIs from square root-transformed lowland farmer manure transaction volume model ($n$ = 129) and square root-transformed transaction revenue model ($n$ = 128).

| Effect | Category | Volume ($m^3$/transaction) | | | Transaction revenue ($/transaction) | | |
|---|---|---|---|---|---|---|---|
| | | Mean[a] | Lower 95% CI | Upper 95% CI | Mean[a] | Lower 95% CI | Upper 95% CI |
| Commune | | | | | | | |
| $P$<0.0001 | NK | 0.901 a | 0.744 | 1.07 | 14.9 a | 12.2 | 17.9 |
| | AC | 0.337 b | 0.231 | 0.462 | 5.58 b | 3.73 | 7.81 |
| Buyer type | | | | | | | |
| $P$<0.0001 | Local trader | 0.812 a | 0.639 | 1.01 | 13.7 a | 10.7 | 17.2 |
| | Small-scale collector | 0.395 b | 0.301 | 0.501 | 6.35 b | 4.73 | 8.22 |

[a] Means not connected by the same letter for each effect in each model are significantly different ($P \leq 0.05$).

One AC farmer purchased composted manure from a neighboring farm in May for $9.52/500 kg oxcart load (approximately 250 kg DM), plus a $2.38 delivery fee, for use in watermelon production. A second compost sales transaction was reported in May in AC. Four 500 kg oxcart loads (approximately 250 kg DM/load) were sold to a neighboring watermelon farmer for $8.57/load, including transportation.

**1.2 Annual lowland farmer manure sales**

Manure sales and prices were also reported on an estimated annual basis. The AC farmers sold 6.57 $m^3$/yr with SD ± 5.67 $m^3$/yr at an average price of $17.40/$m^3$ ± $1.31/$m^3$, yielding total annual household revenue of $116.36 ± $102.18. Farmers in NK sold 7.03 $m^3$/yr with SD ± 5.56 $m^3$/yr at an average price of $17.02/$m^3$ ± $1.04/$m^3$, yielding total annual household revenue of $119.98 ± $93.94. Annual sales volumes, prices and revenues did not differ by commune. Annual revenue from manure sales was positively correlated with household cattle ownership ($r$ = 0.68) and owned and rented land ($r$ = 0.38). In a multivariate statistical model estimating square root-transformed annual manure revenue for lowland farms, significant effects included commune ($P$ = 0.0011), number of cattle owned ($P$ < 0.0001) and amount of land owned and rented ($P$ = 0.0251). In this model, annual revenue from manure sales in NK ($125.04, 95% CI ($107.36, $144.07) was significantly higher than AC revenue ($80.30, 95% CI ($64.20, $98.20)) ($P$ = 0.0251, Power = 0.9172). Yearly commune sales volumes (AC = 1,947 $m^3$/yr; NK = 6,612 $m^3$/yr) may be overestimated by farmer-reported annual volumes, based on a comparison with probable volumes based on cattle numbers, farmers selling manure, grazing time, and proportion of available manure sold in each commune (AC = 1,066 $m^3$/yr; NK = 2,327 $m^3$/yr).

### 1.3 Lowland farmer labor and returns to labor

Manure preparation steps varied according to manure type (compost, broken-up, cakes). Composting of manure generally included daily transfer from the cattle shed to the manure pit or pile. Labor associated with turning the compost pile was considered minor and was not reported by farmers. Crop application of composted manure was not included.

Labor to prepare and sell broken-up manure included: (1) daily transfer of fresh manure from cattle shed to manure pile, (2) spreading of fresh manure on a cement slab, on the ground, or roadside to dry in a broken-up form, (3) a minimum of four days of sun drying (duration is weather dependent), (4) bagging in large sacks, and (5) sale. Sale-related labor was included only if farmers delivered bags to buyers. Many local collectors and traders gathered bags directly from farmer homes.

Labor for AC manure cakes included: (1) Collection of fresh manure from the cattle shed and preparation of manure cakes by hand (young and elderly were often responsible for this step), (2) placement of cakes on the ground, fences, posts, and exterior walls to sun dry for approximately four days (weather dependent), (3) bagging in small sacks, and (4) sale. Sale-related labor was only included if farmers delivered bags to buyers.

Total annual manure-related labor in lowland households ($n$ = 101) was 254 h/yr (median = 200 h/yr) with SE ± 19.9 h/yr, and did not differ by commune. In a mixed model with household as a random effect, yearly labor reported for preparation of manure was highest for traded manure (cakes and broken-up) and lower for compost and fresh manure used for household crop production (Table A4). Labor associated with composted manure and fresh manure was in preparation for household crop fertilization use. Household explained 28% of residual variance in the model, suggesting significant within household variation in labor for

different manure types. Total manure-related labor was positively correlated with number of cattle owned ($P = 0.0004$). In a multivariate model predicting total manure-related labor, significant effects included number of cattle owned ($P < 0.0001$) and commune ($P = 0.0131$).

**Table A4** Back-transformed least squares means (geometric means) and 95% CI for model estimating log-transformed annual hours invested in preparation and sale of cattle manure by manure type for lowland households ($n = 161$).

| Manure type | Manure related labor (h/yr) | | |
|---|---|---|---|
| | Mean[a] | Lower 95% CI | Upper 95% CI |
| Broken-up | 202 a | 170 | 240 |
| Cakes | 153 a | 117 | 199 |
| Fresh | 86.2 ab | 22.6 | 329 |
| Compost | 52.7 b | 44.9 | 61.8 |

[a] Means not connected by the same letter are significantly different ($P \leq 0.05$).

Time invested in preparation and sale of manure (hours/$m^3$ dry manure) did not differ by commune or manure type (Table A5). Returns to labor were just over \$0.50/h (Table A5), which is in the same range as estimated off-farm labor wages (\$2 to \$5/day). Sale prices for broken-up manure were numerically higher than for manure cakes. Returns to labor were positively correlated with total cattle owned ($P = 0.0110$, $r = 0.28$) and total land owned and rented ($P = 0.0065$, $r = 0.30$). Returns to labor did not depend on total labor to prepare and sell manure.

**Table A5** Labor requirements and returns to labor for the preparation and sale of cattle manure in Nhơn Khánh and An Chấn Communes.

| *n* | Labor (hours/$m^3$) | | | Returns to labor (\$/h) | | |
|---|---|---|---|---|---|---|
| | mean | median | SE | mean | median | SE |
| 81 | 54.0 | 31.0 | 6.18 | 0.69 | 0.55 | 0.064 |

## 2. Manure collectors and traders

Manure collectors and traders consisted of lowland compost manure traders, small-scale lowland collectors, lowland traders and highland traders. All lowland collectors and traders identified during lowland farmer interviews were included in the sample ($n$ = 23). The group consisted of 13 in NK (5 traders and 8 small-scale collectors) and 10 in AC (3 traders, 5 small-scale collectors, and 2 compost traders). Collectors and traders in NK and AC were each geographically distributed in four villages throughout their respective communes. Lowland trader households were predominately located on main commune roads. The trader dealing in highest annual volumes among those interviewed was located just outside AC on the main north-south highway, and collected manure from AC and other neighboring communes. Two traders in each commune identified manure trade as their primary occupation. One additional trader in each commune identified commercial transport of goods. Most lowland traders were truck owners (75%), and transported manure from lowland to sales locations. Small-scale collectors and remaining traders identified agriculture (farming and/or livestock) as their primary occupation.

Traders and collectors traded only in cattle manure, except for one NK trader who occasionally traded chicken manure. Traders and collectors in NK traded only in broken-up manure, while AC traders and small-scale collectors traded in both broken-up manure (51%) and manure cakes (49%). Most AC traders (two of three) mixed manure cakes with broken-up manure prior to resale to increase product attractiveness; buyers did not favor a high fraction of manure cakes. The remaining trader purchased only broken-up manure. Small-scale collectors purchased manure by the bag, and sold from their homes to lowland traders, highland traders, or highland farmers. Sales were both by the bag and per cubic meter, depending on buyer preference. Lowland traders generally purchased manure by the bag directly from farmers or

from small-scale collectors and resold manure by the cubic meter. Two of 13 small-scale collectors sold only to highland farmers or highland traders. Most small-scale collectors (85% of 13 collectors) provided a collection service for traders by purchasing bagged manure from farmers and storing it for later pickup; six of these collectors also sold to highland traders. Lowland traders paid 1,000 to 1,500 VND/bag ($0.05/bag to $0.07/bag) for the collection service. Hired laborers were paid by traders at the same rate per bag for manure collection, loading and unloading or 15,000 VND/$m^3$ ($0.71/$m^3$). Most small-scale collectors stored manure at their home to prevent theft (85% of 13 collectors), although some traders managed collection points on the main road for daily pickup. Seven (of eight) traders reported oral contracts with small-scale collectors, with the understanding that traders set purchase prices (variable from month-to-month), provided sacks to small-scale collectors for manure collection, and established small-scale collector revenue per bag. Similarly, sacks were provided by all traders and collectors to farmers, who prepared and bagged the manure prior to sale.

Stored manure was covered with a tarp to prevent losses, especially in the event of rain. Traders and collectors reported a decrease in manure volume during storage, perhaps due to settling. One small-scale collector in NK removed rice straw and soil from the manure, which reduced volume available for sale and increased quality, according to traders and collectors (reported by 84% of 19 question respondents). Estimated losses from all these were low, between 0 and 5%. Collectors and traders evaluated manure quality (81% of 21 responding traders and collectors), preferring dry manure with minimal rice straw, soil, and other foreign materials, and a yellow or black color. These factors were not usually problematic, and had little to no impact on willingness to purchase or prices paid in transactions with lowland farmers.

Greatest challenges and risks reported by manure collectors and traders were price decline at the onset of the rainy season (four of 17 respondents) and competition among collectors and traders (including highland traders and farmers who come to the lowlands to buy manure) (three respondents), lack of means or difficulty transporting manure (three respondents), and volume and quality losses during rainfall events (eight respondents). One lowland trader noted that occasionally a translator was needed to facilitate highland sales transactions with ethnic minorities that did not speak Vietnamese.

Collectors and traders were asked if there have been times when they wanted to buy and sell manure, but could not. Among 12 traders responding affirmatively, 10 reported inability to operate in manure trade during the rainy season. Manure scarcity was also identified by two traders during periods of peak competition (April to June, when highland traders come to the lowlands to buy).

### 2.1 Lowland trader and collector transactions

Overall manure purchase price ($n$ = 48) and sale price ($n$ = 47) in lowland trader and collector-reported transactions was \$19.05/$m^3$ with SE ± \$0.28/$m^3$ and \$26.14/$m^3$ with SE ± \$1.11/$m^3$, respectively. Multivariate manure purchase price and sales price models were fitted separately (Table A6). Significant effects in the purchase price model included commune, trader type (small-scale lowland collector or lowland trader), manure type (broken-up, cakes or mixed), and transaction month. Traders and collectors purchased manure in AC at a significantly higher price than NK. Trader type also affected purchase price, with lowland traders offering a higher purchase price than small-scale lowland collectors. Transaction purchase price for broken-up manure or a mix of broken-up and caked manure was higher than manure cake transactions.

Significant effects in the sale price model included trader type and transportation inclusion in transaction (Table A6). Lowland traders sold manure for significantly higher prices than small-scale lowland collectors. Sales transactions that included transportation to distant buyer destinations fetched a significantly higher price than those not including transportation (e.g., buyers or highland traders traveled to the lowlands to purchase manure directly from traders or collectors).

Mean transaction purchase ($n$ = 47) and sales volumes ($n$ = 47) were 8.83 $m^3$/transaction (median = 1.67 $m^3$/transaction) with SE ± 3.63 $m^3$/transaction and 29.5 $m^3$/transaction (median = 14.3 $m^3$/transaction) with SE ± 10.7 $m^3$/transaction, respectively. A multivariate model estimating transaction purchase volume indicated significantly higher volumes for lowland trader transactions than small-scale collector transactions (Table A7). Significantly higher volumes were also detected when collectors or traders provided transport from farmers or small-scale collectors to trader collection points. Sales volume model indicated significantly higher sales volumes for lowland trader transactions than small-scale lowland collectors (Table A7). Higher sales transaction volumes occurred for transactions of broken-up manure and mixed broken-up and caked manure than manure cakes alone.

**Table A6** Least square means (LSM) and standard errors for lowland trader and collector purchase price model (left, $n = 48$) and sale price model (right, $n = 47$).

| Effect[c] | Category | Purchase price[a] ($/m$^3$) | | Sale Price ($/m$^3$) | |
|---|---|---|---|---|---|
| | | LSM[b] | SE | LSM[b] | SE |
| Commune | | | | | |
| $P < 0.0001$ | AC | 20.23 a | 0.32 | | |
| Power = 0.9998 | NK | 17.66 b | 0.46 | | |
| Trader Type | | | | | |
| $P = 0.0003$ | Lowland trader | 19.70 a | 0.42 | | |
| Power = 0.9743 | Small-scale lowland collector | 18.19 b | 0.33 | | |
| Manure Type | | | | | |
| $P = 0.0039$ | Broken-up | 19.90 a | 0.22 | | |
| Power = 0.8774 | Mix | 19.15 ab | 0.81 | | |
| | Cakes | 17.78 b | 0.49 | | |
| Transport to buyer | | | | | |
| $P < 0.0001$ | Y | | | 33.21 a | 0.96 |
| Power = 1.0 | N | | | 22.35 b | 0.68 |
| Trader Type | | | | | |
| $P = 0.0030$ | Lowland trader | | | 29.91 a | 0.70 |
| Power = 0.8661 | Small-scale lowland collector | | | 25.65 b | 0.90 |

[a] Purchase price model contains transaction month continuous covariate ($P < 0.0001$).
[b] Least squares means not connected by the same letter are significantly different ($P \leq 0.05$).
[c] Effect $P$ values and power are indicated below effect name.

**Table A7** Back-transformed least square means (geometric means) and 95% confidence intervals for log-transformed transaction purchase volume model ($n$ = 47) and log-transformed transaction sales volume model ($n$ = 47).

| Effect[c] | Category | Purchase volume ($m^3$/transaction) | | | Sales Volume[a] ($m^3$/transaction) | | |
|---|---|---|---|---|---|---|---|
| | | LSM[b] | Lower 95% CI | Upper 95% CI | LSM[b] | Lower 95% CI | Upper 95% CI |
| Trader Type | | | | | | | |
| $P$ = 0.0007 | Lowland trader | 4.11 a | 2.37 | 7.13 | | | |
| Power = 0.9452 | Small-scale lowland collector | 1.16 b | 0.76 | 1.76 | | | |
| Collector transports manure | | | | | | | |
| $P$ = 0.0029 | Y | 3.77 a | 2.47 | 5.76 | | | |
| Power = 0.8700 | N | 1.26 b | 0.72 | 2.18 | | | |
| Trader Type | | | | | | | |
| $P$ < 0.0001 | Lowland trader | | | | 27.3 a | 19.5 | 38.2 |
| Power = 1.0 | Small-scale lowland collector | | | | 7.99 b | 6.08 | 10.5 |
| Manure Type | | | | | | | |
| $P$ = 0.0008 | Mix | | | | 29.8 a | 17.7 | 50.2 |
| Power = 0.9561 | Broken-up | | | | 15.4 a | 12.6 | 18.9 |
| | Cakes | | | | 7.02 b | 4.36 | 11.3 |

[a] Sales volume model also contains transaction month continuous covariate ($P$ = 0.0006).
[b] Least squares means not connected by the same letter for each effect in each model are significantly different ($P \leq 0.05$).
[c] Effect $P$ values and power are indicated below effect name.

### 2.2 Annual manure purchases and sales for lowland traders and collectors

Lowland traders and collectors also reported manure purchase and sale prices and volumes on an estimated annual basis, and purchase prices reported by lowland traders in AC were significantly higher than prices indicated by small-scale lowland collectors in both communes (Table A8). Similarly, sales prices by lowland traders were significantly higher than sales prices by small-scale lowland collectors (Table A8). Annual manure trade volumes ($n$ = 21) were significantly

higher for lowland traders than small-scale lowland collectors by a factor of 12.6:1 (Table A9).

Annual volumes did not differ by commune for the two lowland trader types.

**Table A8** Least square means and standard errors for overall purchase price model (left, $n$ = 21) and overall sales price model (right, $n$ = 20) by lowland traders and collectors.

| Trader Type (commune)[b] $P$ = 0.0030, Power = 0.9247 | Purchase Price ($/m$^3$) | | Sale Price ($/m$^3$) | |
|---|---|---|---|---|
| | LSM[a] | SE | LSM[a] | SE |
| Lowland trader (AC)[c] | 22.10 a | 0.93 | | |
| Lowland trader (NK)[c] | 19.20 ab | 0.72 | | |
| Small-scale lowland collector (AC)[c] | 18.29 b | 0.72 | | |
| Small-scale lowland collector (NK)[c] | 16.96 b | 0.57 | | |
| Trader Type[b] $P$ < 0.0001, Power = 1.0 | | | | |
| Lowland trader | | | 30.68 a | 1.34 |
| Small-scale lowland collector | | | 19.67 b | 1.10 |

[a] Least squares means not connected by the same letter are significantly different ($P \leq 0.05$).
[b] Effect $P$ values and power are indicated below effect name.
[c] AC = An Chấn Commune; NK = Nhơn Khánh Commune

**Table A9** Back-transformed least square means (geometric means) and 95% confidence intervals for annual collector and trader log-transformed volume model ($n$ = 21).

| Trader Type[b] $n$ = 21, $P$ = 0<0.0001 Power = 0.9999 | Volume ($m^3$/yr) | | |
|---|---|---|---|
| | LSM[a] | Lower 95% CI | Upper 95% CI |
| Lowland trader | 3,350 a | 1,681 | 6,674 |
| Small-scale lowland collector | 266 b | 155 | 456 |

[a] Least squares means not connected by the same letter are significantly different ($P \leq 0.05$).
[b] Effect $P$ value and power are indicated below effect name.

Manure revenues, labor costs, and transportation costs varied by trader type (Table A10).

Only four small-scale lowland collectors reported labor costs, because many collectors do not

hire labor. Similarly, with the exception of lowland traders in NK, other traders and collectors did not report transportation costs. Average net incomes, calculated as *revenue - hired labor costs - transportation costs* for individual traders, were significantly higher for lowland traders than small-scale lowland collectors and compost traders (Table A11).

**Table A10** Descriptive statistics for lowland trader and collector revenue, manure-related labor costs, and manure-related transport costs.

| | | | NK[a] Lowland trader | AC[a] Lowland trader | NK[a] Small-scale lowland collector | AC[a] Small-scale lowland collector | AC[a] Compost trader |
|---|---|---|---|---|---|---|---|
| Revenue | $/yr | *n* | 5 | 3 | 7 | 5 | 2 |
| | | Mean | 44,039 | 41,578 | 931 | 505 | 86 |
| | | Median | 46,396 | 25,454 | 743 | 267 | 86 |
| | | SD | 35,403 | 46,506 | 828 | 574 | 81 |
| Hired labor costs | $/yr | *n* | 5 | 3 | 3 | 1 | |
| | | Mean | 3,058 | 7,223 | 347 | 714 | |
| | | Median | 2,619 | 2,880 | 371 | 714 | |
| | | SD | 2,574 | 8,188 | 229 | | |
| Transportation costs | $/yr | *n* | 5 | 1 | 1 | | |
| | | Mean | 19,795 | 14,141 | 102 | | |
| | | Median | 16,857 | 14,141 | 102 | | |
| | | SD | 19,801 | | | | |

[a] AC = An Chấn Commune; NK = Nhơn Khánh Commune

**Table A11** Back-transformed least square means (geometric means) and 95% confidence intervals for log-transformed trader net income from manure trade model ($n$ = 22).

| Trader Type (commune) $n$ = 22, $P$ = 0<0.0001, Power = 1.0 | | Net income ($/trader/yr) LSM[a] | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| NK[b] | Lowland trader | 16,953 a | 5,662 | 50,758 |
| AC[b] | Lowland trader | 11,949 a | 2,901 | 49,223 |
| NK[b] | Small-scale lowland collector | 484 b | 192 | 1,223 |
| AC[b] | Small-scale lowland collector | 226 b | 76 | 677 |
| AC[b] | Compost trader | 64 b | 11 | 362 |

[a] Lease squares means not connected by the same letter are significantly different ($P \leq 0.05$).
[b] AC = An Chấn Commune; NK = Nhơn Khánh Commune

### 2.3 Lowland trader and collector labor and returns to labor

Labor (time) included reported family labor (unpaid) and hired labor. Small-scale lowland collectors in AC did not hire laborers. Four small-scale lowland collectors in NK hired a team of 6 laborers to assist only with loading transporter trucks with manure. All lowland traders hired labor to assist with collection, loading, unloading and transport (for traders providing transport to distant buyers).

Small-scale collector labor consisted of the following steps: (1) collection of bagged manure from farmers, (2) unloading and storage at a collection point near the house, and, (3) sale to lowland or highland traders who picked manure up at collection points. Some transactions included labor to load trucks. One lowland collector removed rice straw and other foreign material from product to increase value.

Lowland trader labor consisted of: (1) collection from small-scale collectors and farmers, (2) unloading and storage at a collection point close to the house, (3) loading on a personal truck for transport to highlands or on highland trader truck, (4) transport to highlands to sell, and, (5) sale of manure at highland destinations. Traders owning trucks and transporting manure to the

highlands to sell sometimes brought highland products back to the lowlands to sell during the return journey to increase commercial travel benefits.

Time invested in trade of one cubic meter of manure ($n$ = 20) did not depend on commune or trader type, and was 2.67 h/m$^3$ (median = 2.18 h/m$^3$) with SE ± 0.510 h/m$^3$. Annual labor (hours) invested in manure trade activities was significantly higher for lowland traders than lowland collectors and compost traders (Table A12). Returns to labor, calculated as net income divided by annual manure trade labor, were significantly higher for NK traders than AC traders (Table A13). Returns did not depend on trader type.

**Table A12** Back-transformed least square means (geometric means) and 95% confidence intervals for log-transformed annual manure trade labor model ($n$ = 22).

| Trader Type (commune)[b] $P < 0.0001$, Power = 1.0 | | Labor (hours/yr) LSM[a] | Lower 95% CI | Upper 95% CI |
|---|---|---|---|---|
| AC[c] | Lowland trader | 10,489 a | 3,659 | 30,066 |
| NK[c] | Lowland trader | 6,776 a | 2,997 | 15,320 |
| NK[c] | Small-scale lowland collector | 475 b | 238 | 946 |
| AC[c] | Small-scale lowland collector | 417 b | 184 | 942 |
| AC[c] | Compost trader | 66 b | 18.1 | 239 |

[a] Least squares means not connected by the same letter are significantly different ($P \leq 0.05$).
[b] Effect $P$ values and power are indicated below effect name.
[c] AC = An Chấn Commune; NK = Nhơn Khánh Commune

**Table A13** Least square means and standard errors for returns to trader labor ($n$ = 22).

| Commune[b] $P = 0.0362$, Power = 0.5705 | Returns to labor ($/h) LSM[a] | SE |
|---|---|---|
| NK[c] | 2.15 a | 0.33 |
| AC[c] | 1.05 b | 0.36 |

[a] Least squares means not connected by the same letter are significantly different ($P \leq 0.05$).
[b] Effect $P$ values and power are indicated below effect name.
[c] AC = An Chấn Commune; NK = Nhơn Khánh Commune.

## 2.4 Highland traders

Four highland traders were interviewed in Gia Lai Province in Chư Sê ($n$ = 2), Đăk Đoa ($n$ = 1), and Ayun Pa ($n$ = 1) Districts. The Ayun Pa trader was the only trader operating in the district. The Đăk Đoa trader reported 10 other traders in the district. All traders purchased broken-up manure using pre-arranged oral agreements with sellers. Traders discussed the quality, quantity and price of manure with potential sellers by phone before agreeing to a transaction. Most transactions were with lowland traders. Two highland traders also reported purchases from lowland farmers and small-scale lowland collectors. Highland traders emphasized the need to maintain a close relationship with lowland traders and transporters to ensure successful transactions, and underscored the importance of checking manure quality prior to finalizing purchase transactions. High quality manure was reportedly yellow in color, dried on the ground and broken-up (not in cakes), and contained minimal rice straw and sand. Poor manure quality could result in transaction cancellation (reported by one trader).

Three of four traders owned a truck that was used for hauling manure. The Chư Sê trader without a truck worked with lowland traders who delivered manure to a distribution point near the highland trader's household. Deliveries were made between 2:00 am and 6:00 am daily. From the distribution point, it was resold to highland transporters or farmers who visited the distribution point to complete the transaction. The second Chư Sê trader and the Đăk Đoa trader purchased manure in the Bình Định lowlands and transported it to the highlands in their truck for resale to highland farmers, often after a brief storage delay at a distribution point. The sale of manure from highland traders to farmers generally included delivery for the three traders with trucks. Storage was typically in a covered pile at the distribution point when manure was unloaded prior to resale. Loaded trucks were covered with a tarp during the transport process to

prevent manure loss. Only the Đăk Đoa trader reported problems with manure transport losses. Traders sold to coffee and pepper farmers, with all sales to farmers from the Đăk Đoa trader and one Chư Sê trader. The other Chư Sê trader and the Ayun Pa trader sold most manure to highland transporters (80% and 95%, respectively).

Traders reported seasonal fluctuations in manure price, which they attributed to changes in demand. Highland farmers apply manure at the beginning of the rainy season and must purchase manure one to three months in advance to prepare it for application (described below). Thus, prices are highest after coffee and pepper harvest until one month before the rainy season (December to May), and decrease with the onset of the rainy season. This report coincided with lowland farmer observations (Fig. A1). Highland traders observed a rapid decline in price with rainy season onset, which was frustrating from trader viewpoints as price changes were sudden with inconsistent year-to-year timing (climate change impacting onset of rainy season), and occasional high remaining inventories that had to be sold at lower prices or stored.

Challenges reported by highland traders included an inability to purchase manure in the volumes desired during periods of high demand, because of competition from other highland and lowland traders, and inability to sell manure during the rainy season (manure is stored). Manure volume losses from mineralization were reported as a high business risk for manure not sold prior to the rainy season. However, traders agreed that these risks (costs) did not offset the economic benefits of manure trade.

Highland trader transactions took place in May, July, and August 2013 (Table A14). Net purchase prices included transport and loading fees, and net sales prices included deductions for transport and loading fees. Purchase and sale net dollar amounts per transaction also accounted for these transport and loading fees, which were incurred independently for the purchase and sale

processes. Purchase volumes were numerically higher than sales volumes. Gross mark up in highland trader-reported transactions was 21%.

**Table A14** Descriptive statistics for highland trader-reported transactions (purchases and sales) including transaction volume, price, net price (adjusted for transport and loading fees), and $ per transaction net (adjusted for transport and loading fees).

| Transaction type | *n* | Volume ($m^3$/transaction) | | | Price ($/$m^3$) | | | Net price ($/$m^3$) | | | Transaction net ($/transaction) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Med | SD | Mean | Med | SD | Mean | Med | SD | Mean | Med | SD |
| Purchase | 5 | 30.5 | 22.0 | 18.1 | 21.71 | 23.81 | 6.91 | 23.57 | 23.81 | 10.26 | 706 | 548 | 480 |
| Sale | 5 | 12.3 | 14.3 | 3.95 | 29.43 | 26.67 | 6.46 | 28.57 | 25.71 | 6.06 | 358 | 381 | 153 |

Highland traders reported annual manure trade volumes and average purchase and sale prices (Table A15). The Chu Sê and Ayun Pa traders selling mostly to transporters traded in much higher annual volumes (mean = 24,975 $m^3$/yr) than the other traders (mean = 1,225 $m^3$/yr). Annual purchase and sale amounts ($) were calculated for individual traders by deducting loading fees. This impacted net incomes for high volume traders, because they covered the cost of loading transporter trucks. Thus, net incomes for traders dealing in high volume (mean = $15,411/yr) were close to net incomes for low-volume traders (mean = $12,232/yr). Low-volume traders did not report transport or labor costs, thus, net incomes could be inflated.

**Table A15** Descriptive statistics for annual manure trade volumes, average prices, and net incomes by highland traders, as well as price and annual dollar amounts for purchases and sales.

| | *n* | Volume ($m^3$/yr) | | | Price ($/$m^3$) | | | Annual amount ($) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean[a] | Median | SD | Mean[a] | Median | SD | Mean[a] | Median | SD |
| Purchase | 4 | 13,100 | 10,950 | 14,214 | 24.64 | 23.81 | 3.95 | 357,179 | 317,214 | 388,525 |
| Sale | 4 | 13,100 | 10,950 | 14,214 | 30.54 | 30.95 | 1.72 | 384,652 | 338,929 | 407,929 |
| **Net Income ($/yr)** | | | | | | | | **13,821** | **12,232** | **5,274** |

[a] Values reported are averages per trader.

### 3. End users

End users included Central Highland pepper and coffee farmers, Bình Thuận dragon fruit farmers and rubber companies in the Central Highlands.

### 3.1 Highland pepper and coffee farmers and Bình Thuận dragon fruit farmers

Highland farmers (*n* = 50) in five communes (12 villages) reported cultivation of 1.73 ha with SD ± 1.29 ha. Dragon fruit farmers (*n* = 20) interviewed were located in two communes (7 villages) in Bình Thuận Province, and reported cultivation of 0.749 ha with SD ± 0.529 ha.

Predominant crops cultivated by highland farmers were black pepper (78% of highland farmers) and coffee (70%). Less often cultivated crops included rice (14%), corn (6%), cashew (4%), rubber (2%) and sugar cane (2%). Highland farmers purchased cattle manure for use as an organic soil amendment for pepper and coffee lands. Farmers applied manure to pepper yearly, approximately one month post-harvest at the beginning of the highland rainy season (April to May). Applications to coffee were less frequent, every one to four years (mode = two years) at the beginning of the rainy season (April to May). Predominant crops cultivated by Bình Thuận farmers were dragon fruit (95% of respondents) and rice (25%). Bình Thuận farmers purchased

manure to use as an organic amendment on land established in dragon fruit. Farmers reported higher yields with manure use. Most farmers applied manure two times per yr, once between March and May and again between August and October.

Greatest nutrient management challenges in Bình Thuận included soil quality (25% of Bình Thuận farmers) and flooding during the rainy season (30%). Highland challenges included poor soil fertility (34% of highland farmers), flooding and erosion during the rainy season (12%), pepper bacterial diseases (8%), drought (4%), and lack of capital to buy cattle manure.

Manure purchase transactions and preparation in the highlands consisted of first calling Phú Yên, Bình Định, or highland traders, or travel to the main road. During the height of the manure trade season, many traders travel to the highlands and park their trucks on the main road. Farmers seeking manure visit the trucks to inspect the manure for quality and negotiate a price. Manure is then transported to the farm for delivery and unloading. Alternatively, some farmers who have trucks travel to the lowlands to purchase manure. Manure is composted on the farm for one to two months prior to use according to the recipe below. Crop application consists of digging a trench around the pepper or coffee tree and filling the trench with composted manure.

Manure purchase transactions and preparation for use in Bình Thuận consisted of first calling local traders, Phú Yên traders, or southeast coastal traders to inquire about manure availability and quality. Traders then transport manure to the farm and manure quality is evaluated prior to transaction finalization. Manure is composted by farmers at the house for one to two months, and then applied by digging a trench around the base of each dragon fruit tree, filling the trench with composted manure, and covering it with rice straw to maintain soil humidity. The purchase price of a truckload of rice straw is $90 to $150.

Only six highland farmers (12%) and one Bình Thuận farmer (5%) applied manure directly as an organic soil amendment without composting. Highland farmers described preparation of composted manure prior to application according to a variation of the following recipe. Urea fertilizer (3 kg) and potassium (2 kg) are dissolved in 200 L of water. Dry manure (200 kg) is mixed with coffee pulp (100 kg). The compost pile is formed with 30-cm layers of manure and coffee pulp. Each layer is moistened with the urea-potassium solution, along with probiotics (1 to 2 kg for the batch) and phosphorus (5 kg $P_2O_5$/batch). The compost pile usually reaches about one to 1.2-m high and one to 1.5-m base diameter. The pile is covered with a tarp and remoistened with water every three days. The pile is mixed after 15 days and covered again for one month. It is then ready for crop application or storage until crop application. Another ingredient commonly used in highland compost is lime.

Farmers reported composted manure application on 92% of pepper fields, 63% of coffee fields, and 100% of dragon fruit fields. Crop density (trees per ha) was positively correlated with compost application rate ($r$ = 0.45). A multivariate model was selected with composted cattle manure application rate response and fixed effects of crop (pepper, coffee, dragon fruit) and crop density (trees per ha) (Table A16). Establishment regions varied by crop, with respondents cultivating dragon fruit in Bình Thuận Province and coffee and pepper respondents in highland provinces of Đắk Lắk and Gia Lai. Significantly higher compost application rates reported for dragon fruit could be attributed to regional management differences rather than crop differences. Other fertilizers commonly used in pepper and coffee cultivation include phân vi sinh (a commercial organic amendment, described below), urea, NPK blends, ammonium sulfate, and fertilizers containing potassium and phosphorus (e.g., muriate of potash (KCl) and diammonium

phosphate). Composted manure and fertilizer application rates indicated average rates and variation for all crops (Table A17).

**Table A16** Back-transformed least square means (geometric means) and 95% CIs for composted manure application rate ($n$ = 90) in a model predicting log-transformed farmer-reported application rate.

| Crop | Compost application rate (Mg DM/ha per yr)[a] | | |
|---|---|---|---|
| | LSM[b] | Lower 95% CI | Upper 95% CI |
| Dragon fruit | 10.9 a | 9.24 | 12.9 |
| Coffee | 7.03 b | 6.01 | 8.21 |
| Pepper | 4.43 c | 3.96 | 4.96 |

[a] Model effects included crop ($P < 0.0001$, Power = 1.0) and density (trees/ha) ($P < 0.0001$).
[b] Least squares means not connected by the same letter are significantly different ($P \leq 0.05$).

**Table A17** Land area and fertilization rates by crop field as reported by farmers in Bình Thuận and highland communes. Land area means are calculated only from fields that households plant to a given crop. Fertilization rate means are calculated only from households that use a given fertilizer on a given field. Composted manure dry matter rates were determined based on the assumption of 50% dry matter in compost applied.

| Location | Crop Name | Land area (ha) | | | Compost (Mg DM/ha per yr) | | | Phân vi sinh (Mg/ha per yr) | | | Urea (kg/ha per yr) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *n* | mean | SD | *n* | mean | SD | *n* | mean | SD | *n* | mean | SD |
| Bình Thuận | Dragon fruit | 20 | 0.549 | 0.326 | 20 | 9.20 | 2.46 | | | | 4 | 1430 | 593 |
| Highland | Pepper | 51 | 0.663 | 0.536 | 47 | 6.54 | 3.93 | 12 | 3.55 | 3.14 | 15 | 839 | 760 |
| Highland | Coffee | 38 | 1.03 | 0.788 | 24 | 5.58 | 1.91 | 6 | 2.02 | 1.28 | 20 | 1124 | 628 |
| Bình Thuận | Rice | 10 | 0.400 | 0.327 | | | | | | | 10 | 32.0 | 20.2 |
| Highland | Rice | 7 | 0.686 | 0.647 | | | | | | | 6 | 31.7 | 18.3 |
| Highland | Maize | 3 | 1.20 | 1.57 | | | | | | | 3 | 36.7 | 11.5 |
| Highland | Rubber | 1 | 0.600 | | | | | | | | | | |
| Highland | Cashew | 2 | 2.00 | 0 | | | | | | | | | |
| Highland | Sugarcane | 1 | 0.200 | | | | | | | | 1 | 200 | |

**Table A17, Part 2**

| Location | Crop Name | NPK blends (kg/ha per yr) | | | Ammonium sulfate (kg/ha per yr) | | | Potassium blend (kg/ha per yr) | | | Phosphorus blend (kg/ha per yr) | | | NPK cao cấp (kg/ha per yr) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *n* | mean | SD | *n* | mean | SD | *n* | mean | SD | *n* | mean | SD | *n* | mean | SD |
| Bình Thuận | Dragon fruit | 20 | 4821 | 1590 | | | | 2 | 2958 | 2551 | 7 | 2737 | 1016 | 6 | 5946 | 4034 |
| Highland | Pepper | 36 | 1982 | 1398 | 2 | 1550 | 1344 | 18 | 818 | 704 | 10 | 1931 | 1567 | | | |
| Highland | Coffee | 29 | 1692 | 747 | 7 | 965 | 636 | 23 | 753 | 870 | 4 | 1627 | 920 | | | |
| Bình Thuận | Rice | 8 | 22.5 | 2.7 | | | | 8 | 14.8 | 9.6 | 2 | 10.0 | | | | |
| Highland | Rice | 4 | 36.3 | 9.46 | 2 | 50.0 | 35.4 | 5 | 26.0 | 23.0 | 1 | 35.0 | | | | |
| Highland | Maize | 3 | 36.7 | 12.6 | | | | 2 | 35.0 | 21.2 | | | | | | |
| Highland | Rubber | 1 | 417 | | | | | | | | | | | | | |
| Highland | Cashew | | | | 2 | 188 | 88.4 | | | | | | | | | |
| Highland | Sugarcane | | | | | | | | | | 1 | 300 | | | | |

Farmers were asked what could be done to add additional value to manure. Composting as per their guidelines prior to delivery would increase value (100% of 59 responding farmers). Common compost requests were with probiotics (39%), with phosphorus (14%), with lime (8%), with urea and phosphorus (8%), and compost without requests for addition of specific ingredients (15%). However, farmers did not trust traders to do it properly. Reported manure alternatives included phân vi sinh (an organic amendment, described below) (73% of 67 responding farmers), coffee pulp (16%) and household cattle manure (7%). Other alternatives mentioned were quail manure (1 farmer), rice straw (1 farmer), sugar cane byproducts (2 farmers) and chemical fertilizer (4 farmers).

Farmers with available cash prefer to buy inexpensive manure in August or December, and compost and store it for later use, but most small farmers do not have cash available at that time and must wait until post-harvest to purchase manure when prices and demand in the highlands are high, which suggests a role for credit to purchase manure in the region.

### 3.2 Highland and Bình Thuận farmer manure purchase transactions

Manure purchase transactions ($n$ = 88) were reported by 70 farmers in highland and Bình Thuận locations. Overall manure purchase price in transactions was \$36.15/$m^3$ with SE ± \$0.82/$m^3$. In a multivariate model, purchase price was affected by buyer location (highland or BT), and by the interaction between seller location and manure form (bag or $m^3$), suggesting that the impact of seller location on price depends on manure form (Table A18). All transactions were with traders, and price included unloading labor. Transaction month did not impact amount, volume or price. Purchase price for highland farmers was significantly higher than for Bình Thuận dragon fruit farmers. Bagged manure sold for a numerically higher price than non-bagged manure from all

seller locations except the southeast lowlands. Bagged manure from Bình Định Province was significantly more expensive than non-bagged product.

Mean transaction volume ($n$ = 88) was 22.2 $m^3$/transaction (median = 16.7 $m^3$/transaction) with SE ± 2.53 $m^3$/transaction. In a multivariate model, manure class, buyer province and their interaction were significant (Table A19). Interaction effect indicated that non-bagged transaction purchase volumes were higher than bagged volumes, and transaction volumes for buyers in Gia Lai and Bình Thuận tended to be higher than Đắk Lắk.

Mean transaction amount ($n$ = 88) was $778 (median = $490) with SE ± $95.1. In a multivariate model, significant effects included manure class and buyer province (Table A19). Transaction amounts were higher for non-bagged manure than bagged manure, mostly due to higher volumes. Transaction costs were significantly higher for purchase transactions in Bình Thuận and Gia Lai than Đắk Lắk, also consistent with reported larger transaction volumes in these regions.

Transaction challenges identified by farmers included difficulty in evaluating quality (45% of 31 farmers reporting challenges) and high manure prices, lack of capital to purchase enough manure, or inability to buy manure when price is lower due to cash flow problems (45%). Two farmers reported that some traders permit partial payment, with the balance due post-harvest. Farmers attributed high prices to demand early in the year when cash is available from recent harvests. Timing is also favorable for composting prior to application on the current year crop.

**Table A18** Least square means and standard errors for transaction price model ($n$ = 88) for highland pepper and coffee farmers and Bình Thuận dragon fruit farmers.

| Effect[b] | Manure class, seller location | Manure price ($/m$^3$) | |
|---|---|---|---|
| | | LSM[a] | SE |
| Manure class x Seller location | | | |
| $P < 0.0001$ | Bagged, BD[c] | 41.09 a | 1.78 |
| Power = 1.0 | Bagged, highland | 39.63 ab | 2.61 |
| | Bagged, PY[c] | 37.25 ab | 0.86 |
| | Non-bagged, southeast lowlands | 35.57 abc | 2.06 |
| | Non-bagged, PY[c] | 35.44 ab | 0.98 |
| | Non-bagged, highland | 32.19 bcd | 1.68 |
| | Non-bagged, BD[c] | 27.74 cd | 1.34 |
| | Bagged, southeast lowlands | 23.10 d | 2.28 |
| Farmer (buyer) location | | | |
| $P < 0.0001$ | Highland | 38.81 a | 0.76 |
| Power = 1.0 | BT[c] | 29.19 b | 1.03 |

[a] Least squares means not connected by the same letter are significantly different ($P \leq 0.05$).
[b] Effect $P$ values and power are indicated below effect name.
[c] Bình Định Province = BD, Phú Yên Province = PY, Bình Thuận Province = BT

**Table A19** Least square means (geometric means) and 95% confidence intervals for log-transformed manure transaction volume model (left, $n$ = 88) and log-transformed transaction amount model (right, $n$ = 88) for highland pepper and coffee farmers and Bình Thuận dragon fruit farmers.

| Effect[b] | Manure class, buyer province[c] | Manure volume ($m^3$/transaction) | | | Transaction amount ($/transaction) | | |
|---|---|---|---|---|---|---|---|
| | | LSM[a] | Lower 95% CI | Upper 95% CI | LS mean[a] | Lower 95% CI | Upper 95% CI |
| Manure Class x buyer province $P$ = 0.0343, Power = 0.6402 | Non-bagged, GL | 27.6 a | 20.8 | 36.7 | | | |
| | Non-bagged, BT | 25.3 ab | 17.2 | 37.4 | | | |
| | Bagged, BT | 13.3 b | 8.90 | 19.9 | | | |
| | Non-bagged, DL | 7.73 bc | 3.63 | 16.4 | | | |
| | Bagged, GL | 5.94 c | 4.24 | 8.33 | | | |
| | Bagged, DL | 3.72 c | 2.10 | 6.59 | | | |
| Manure class $P$ < 0.0001, Power = 1.0 | Non-bagged | | | | 680 a | 523 | 883 |
| | Bagged | | | | 235 b | 182 | 304 |
| Province $P$ = 0.0118, Power = 0.7728 | BT | | | | 531 a | 398 | 708 |
| | GL | | | | 507 a | 404 | 635 |
| | DL | | | | 238 b | 148 | 380 |

[a] Least squares means not connected by the same letter for each model are significantly different ($P \leq 0.05$).
[b] Effect $P$ values and power are indicated below effect name.
[c] Gia Lai Province = GL, Bình Thuận Province = BT, Đắk Lắk Province = DL.

Farmers were skeptical of manure quality, and one farmer believed that traders may add other components to manure to increase volume (e.g., soil, rice straw). Thus, quality evaluation often occurred during the transaction process, and substandard product could result in transaction cancellation and reloading of any unloaded manure. This occurrence was not common, but possible. Common factors decreasing quality included sand, excess rice straw, and other non-

manure components. Transactions were contingent on high quality manure, thus most farmers (67%) did not pay a price premium for high quality manure. A minority of farmers (26%) were still willing to complete transactions for manure with quality deficiencies if the seller would drop the price. Farmers reporting a more positive experience recommended establishing a relationship with traders and local farmers to help ensure high quality manure and timely delivery. Transactions conditional on manure quality inspection were recommended. Highland farmers generally believed that manure quality was better for manure purchased from local highland cattle farmers than lowland manure.

### 3.3 Annual manure purchases by end users

Annual manure purchases were made by coffee and pepper farmers in highland provinces (Đắk Lắk and Gia Lai) and dragon fruit farmers in lowland Bình Thuận province. Purchase prices were higher in highland districts than in Bình Thuận (Table A20) in a multivariate model containing binary location (highland or southeast coast), district nested in location, and a categorical variable for manure purchase category (by the bag, truck, or both). Regional purchase price differences may be largely due to the timing of transactions, and supply and demand patterns in the highlands. Manure purchased by the bag was significantly more expensive than manure sold by the truckload. Prices reportedly dropped in the highlands as the rainy season began in July or August. Bình Thuận manure sales from south-central coastal regions commenced around the same time, and lower prices persisted for these sales to dragon fruit farmers.

Household land area in pepper, coffee and dragon fruit ($n$ = 70) was positively correlated with total annual manure purchase volume ($r$ = 0.53) and annual manure expenditures ($r$ = 0.59).

Multivariate models estimating square root-transformed purchase volume or square root-transformed annual expenditures contained significant effects of province and land area in pepper, coffee, and dragon fruit (Table A21). Volumes and expenditures differed among the three provinces, and decreased in order from Bình Thuận to Gia Lai to Đắk Lắk.

**Table A20** Least square means and standard errors for manure purchase price model ($n$ = 70) by farmers interviewed in manure purchasing districts.

| Effect[b] | | Manure price ($/m$^3$) | |
|---|---|---|---|
| | | LSM[a] | SE |
| District[c] | | | |
| $P$ = 0.0014 | Chư Pưh, GL, highland | 44.48 a | 2.14 |
| Power = 0.9589 | Chư Prông, GL, highland | 42.19 ab | 2.15 |
| | Buôn Hồ, DL, highland | 41.75 ab | 2.20 |
| | Chư Sê, GL, highland | 37.05 abc | 2.14 |
| | Đăk Đoa, GL, highland | 34.41 bcd | 2.26 |
| | Hàm Thuận Bắc, BT, southeast coast | 31.50 cd | 1.87 |
| | Hàm Thuận Nam, BT, southeast coast | 27.32 d | 1.98 |
| Sale type | | | |
| $P$ = 0.0479 | Bag | 36.91 a | 1.15 |
| Power = 0.5903 | Both | 34.27 ab | 3.38 |
| | Truck | 32.90 b | 1.09 |

[a] Least squares means not connected by the same letter are significantly different for each effect ($P \leq 0.05$).
[b] Effect $P$ values and power are indicated below effect name.
[c] District, Province (Gia Lai Province = GL, Bình Thuận Province = BT, Đắk Lắk Province = DL), highland or southeast coast.

**Table A21** Least square means (geometric means) and 95% confidence intervals for square root-transformed annual manure purchase volume model ($n$ = 70) and square root-transformed annual manure expenditures model ($n$ = 70) as reported by farmers purchasing manure.

| Province | Manure volume[b] ($m^3$/yr) $P < 0.0001$, Power = 0.9995 | | | Manure expenditures[b] ($/yr) $P < 0.0001$, Power = 0.9936 | | |
|---|---|---|---|---|---|---|
| | LSM[a] | Lower 95% CI | Upper 95% CI | LSM[a] | Lower 95% CI | Upper 95% CI |
| Bình Thuận | 45.5 a | 34.2 | 58.5 | 1403 a | 1,040 | 1,819 |
| Gia Lai | 21.6 b | 16.3 | 27.7 | 799 b | 612 | 1,012 |
| Đắk Lắk | 6.13 c | 1.67 | 13.4 | 265 c | 89 | 535 |

[a] Least squres means not connected by the same letter are significantly different for each model ($P \leq 0.05$).
[b] Effect $P$ values and power are indicated below effect name.

### 3.4 End users: rubber companies

Two rubber companies were interviewed, one in Gia Lai Province (8,400 ha in rubber), and one by phone in Khánh Hòa Province (300 ha in rubber) (directly south of Phú Yên). The Gia Lai company purchased manure as the foundation ingredient in production of phân vi sinh under the trademark "Long Vân". Phân vi sinh, a commercial organic fertilizer with microorganisms, is used as a soil amendment for rubber, coffee, pepper and dragon fruit plants. Many formulations exist but a representative product label contained 15% organic matter from manure, 1.5% $P_2O_5$, 2.5% humic acid, 1% Ca, 0.5% Mg, and 0.3% S (concentration of other nutrients was not indicated). Bacteria were also added including aspergillus, azotobacter, and bacillus ($1 \times 10^6$ CFU/g of each microorganism).

Manure purchases were made from traders in Phú Yên (60%) and Gia Lai (40%) Provinces, and transactions were completed as independent contracts. Contract payments were made after company associates verified agreed volume and manure quality in the transaction. Manure quality was considered higher for manure in broken-up form (cakes are considered of

lower quality) and manure containing < 5% rice straw. The company sometimes tests manure samples for OM, N, P, and K concentrations. Contracts can be terminated and the transaction cancelled if > 50% of a load is manure cakes. A cattle manure substitute for phân vi sinh production is peat, although phân vi sinh quality reportedly declines when non-manure substitutes are used. The company prefers to purchase manure when local farmer demand is low (later in the year), because bulk purchase prices are lower. Two manure purchase transactions, reported in 2013 from a trader in AC commune, Phú Yên, averaged 1,750 $m^3$/transaction at a purchase price of \$31.43/$m^3$. The company normally purchases manure once in January or February and again in July for an annual total of 4,000 to 5,000 $m^3$. Purchase prices range between \$28.57/$m^3$ \$34.29/$m^3$, with highest prices early in the year. The second purchase is used to make phân vi sinh for the following year.

The Khánh Hòa company purchased manure on a contractual basis from a trader in Phú Yên for use as a soil amendment in establishment year rubber trees. Prior to application, manure was composted for two months. Quality, a criterion for contract termination, was inspected. A single 2013 purchase transaction was reported in October from a Phú Yên trader for 200 $m^3$ at a price of \$30.95/$m^3$. The trader provided transportation (200 km, one way), which was included in purchase price.

Both companies fertilized with phân vi sinh at an average rate of 1.8 kg/tree per yr (810 kg/ha). The Khánh Hòa company fertilized establishment year rubber trees with 10 kg composted manure/tree (4.5 Mg/ha) and 0.3 kg phân vi sinh (135 kg/ha). Additional annual fertilizer rates used for established rubber trees were 0.35 kg urea/tree (157.5 kg/ha), 0.35 kg NPK/tree (157.5 kg/ha), 0.35 kg $K_20$/tree (157.5 kg/ha), and 0.45 kg $P_2O_5$/tree (202.5 kg/ha).