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ORIGINAL RESEARCH

Parcelized Cut-and-Carry Agroforestry Systems for Confined Livestock

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Abstract

We characterize a parcelized land management system that does not meet traditional co-located agroforestry practices in the tropics. A cut-and-carry agroforestry system for confined livestock emphasizes land utilization as a source of fodder, cutting and carrying feed from parcels to paddocks near a farmer's home. It reduces feed cost by utilizing parcels under private, shared, and/or public ownership. Within cut-and-carry systems, we distinguish between those where parcels are managed as monocrops and traditional co-located agroforestry practices. Primary data for our case study were collected by surveying heads of household in Central Java, Indonesia, and analyzed following a capitals-based rural livelihoods framework. A sample of 122 farmers who managed parcels under co-located agroforestry practices was compared against 50 farmers who implemented parcelized monocropping. Overall, the adoption of cut-and-carry systems supports financial resiliency by limiting cash expenditures, facilitating income diversification, and producing assets that meet planned market opportunities and unforeseen cash needs. Survey results show that farmers who engage in parcelized agroforestry have more farming experience, higher farming income, are located at higher elevations, and live farther from the nearest local market. On-farm income among agroforestry cut-and-carry farmers was on average 11.1% higher than those using a cut-and-carry system but only adopting monocrop practices. Land as a biophysical capital asset under full private-ownership and at higher altitudes, and longer farming experience as a human capital asset, increased the likelihood of adopting parcelized co-located agroforestry practices. Membership in cash-crop cooperatives as a form of social capital asset was associated with a higher likelihood of managing land as parcelized monocrops.

Keywords Agroforestry · Woodlot · Smallholder · Logistic regression · Propensity score matching · Indonesia

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Introduction

Agroforestry has long been heralded as a land management system suitable to support rural livelihoods, adapt to a changing climate, diversify revenue sources, and cope with risk (McCabe 2013). In Indonesia, agroforestry has been actively promoted for over 30 years as a low-cost land use system beneficial to smallholder farmers. According to Sabrani and Saepudin (1994) bottomland agronomic systems that integrate tree planting with livestock are widely adopted and effectively contribute to farmers' enhanced income in Indonesia's Central Java region. Silvopastural practices have also been adopted in upland agriculture to promote soil conservation by planting nitrogen-fixing and fodder producing trees (e.g. *Gliricidia sepium* and *Calliandra calothyrsus*) in terrace systems. In addition to silvopastural practices (Alavalapati et al. 2004), home gardens (Sabastian et al. 2014; Roshetko et al. 2013), and riparian buffer strips (Anbumozhi et al. 2005) are the most commonly adopted agroforestry practices in Indonesia.

Agroforestry practices are frequently adopted within the same lot as in the case of silvopastures, intercrops or live fences, but their co-location is not necessary for land to be managed as an agroforestry system. Agroforestry systems can be parcelized as different practices may be implemented in separate lots—yet integrated over a larger landscape through resource management. Haines and McFarane (2007) defined parcelization as a rural landscape process of dividing a larger area of land into smaller lots. Partly because of parcelization, landscapes can be ecologically fragmented by having different land uses between plots and across ownerships. As suggested by Fujiwara et al. (2018) decisions to allocate particular management practices to different parcels are often driven by site conditions (e.g., topography, soil fertility) and land tenure considerations (e.g., individual- or group-ownership, leased). In addition, farmers' adoption of agroforestry practices, and tree planting decisions specifically, has been influenced by available agricultural technologies in response to declining soil quality and household labor supply, government policies, national reforestation programs, among other reasons (van Der Poel and van Dijk 1987; Nibbering1999).

In this manuscript, we describe a land management system that does not meet traditional co-located agroforestry characteristics. Our first objective is to offer a detailed characterization of cut-and-carry agroforestry systems that integrate land management between parcels. Our second objective is to, within cut-and-carry systems, identify differences between farmers engaged in parcelized agroforestry and monocrop practices. The manuscript starts by describing our case study area in Central Java's Gunung Kidul and characterizing parcelized smallholder cut-and-carry agroforestry systems for confined livestock. We outline our theoretical framework for data collection and analysis based on a capitals-based approach to appraise rural livelihoods. We relied on statistical analyses to determine statistically significant differences in cut-and-carry systems between landowner sub-groups adopting parcelized agroforestry and monocrop practices. We also assess the financial performance between these two sub-groups. We offer various insights regarding cut-and-carry systems and point to areas that merit future investigation.

Parcelized Cut-and-Carry Systems with Confined Livestock in Gunung Kidul

Gunung Kidul is one of five districts in the Yogyakarta region, with a population of 704,000 people located between latitudes 7° 460–7° 090 and longitudes 110° 210–110° 500 (Statistics of Gunung Kidul Regency 2016). The climate in the Gunung Kidul area is strongly influenced by the wet Northwest monsoon (November–May) and dry Southeast monsoon (June–October) with an average temperature between 24 and 26 °C (Sudiharjo and Notohadiprawiro 2006). Gunung Kidul has 18 subdistricts and 144 villages with distinct topographic areas receiving annual rainfall of 1500–2500 mm. Approximately 74% of the district has karsts soils, predominantly in the Sewu mountain range; Vertisols are dominant in the Wonosari plateau. Entisol and Alfisol soil types cover the Baturagung mountain range. Elevation ranges from 0 to 700 m above sea level (Statistics of Gunung Kidul Regency 2009). Its landscape is hilly along its northern, eastern and southern boundaries (Baturagung and Sewu mountain ranges) and relatively flat in its central zone (Wonosari plateau) with 71% of the district's area with slopes ranging from 2 to 40%. Our study focused on seven subdistricts including Karangmojo and Playen that represent lowlands (Wonosari), Nglipar and Semin that represent uplands (Baturagung mountain ranges) and Tepus, Panggang and Paliyan that represent mountainous (Sewu) areas (Fig. 1).

Gunung Kidul district is known for persistent deforestation, soil erosion, and widespread poverty (Nibbering 1999; Roshetko et al. 2013). Farming is the main contributor to the district's economy, providing 34% of gross income and most employment. Within the agricultural sector, food crops (e.g., maize and rice paddy) account for 64% of economic value, followed by forestry (27%), livestock (6%), plantation crops (2%), and fisheries (< 1%) (Rohadi et al. 2011). Sabastian et al. (2014) report that land use allocation in Gunung Kidul consists of dryland systems (45.3%), woodlots (17.3%), home gardens (17.1%), state forests (8.8%), wetland farms (5.3%), ponds (0.1%) and others (6.2%). Trees are planted scattered across fields and along contours in smallholder silvicultural systems in both dryland systems (kitren and tegalan) and home gardens (pekarangan).

Farming systems in Gunung Kidul are stratified by elevation. Farmers in upland areas commonly practice agroforestry, cultivating upland rice (*Oryza sativa*), cassava (*Manihot utillisima*), maize (*Zea mays*), occasionally soybean (*Glicyine max*) and other crops (e.g., banana, ginger, curcuma). In upland areas farmers also plant trees such as mahogany (*Swietenia macrophylla*), teak (*Tectona grandis*) and acacia (*Acacia auriculiformis*). Farmers in low-land areas engage in commodity crops such as rice in paddy systems, cassava, maize, soybean and ground nuts (*Arachis hypogaea*). Seasonal weather variation affects farmers' decisions to plant cash crops. For instance, rice paddy is established during the March wet season and harvested in July. Cassava is planted in August and harvested after one year. Soybean or ground nuts are planted as a substitute of maize in alternate years. Instead of cassava, farmers also may choose to plant maize in December to be harvested in March/April the following year. In Gunung

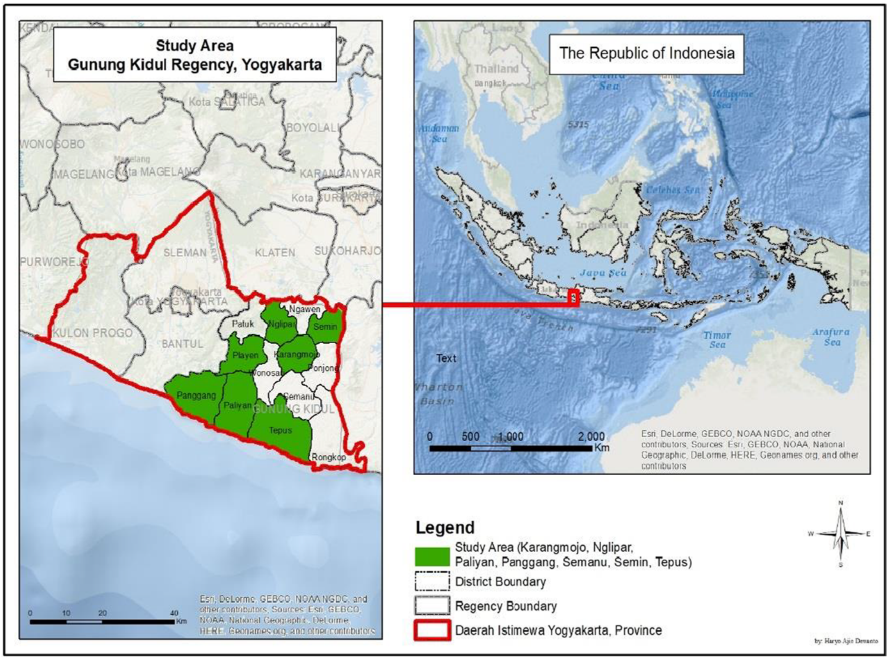

Fig. 1 Study area within Gunung Kidul District, Indonesia. Data source: Central Bureau of Statistics Republic of Indonesia (2016)

Kidul farmers have incorporated tree planting within agricultural crops as a form of capital accumulation (Rohadi et al. 2011) and to improve their livelihoods through low-input land management strategies (Roshetko et al. 2013). Socioeconomic and farm conditions determine the functions trees serve (Fujiwara et al. 2018). Common purposes include wood production, boundary demarcation, canopy for shade-demanding crops, protection against erosion, and shelter. Timber trees may be incorporated in various arrangements and densities in existing farm niches to better serve these particular functions. For instance, timber species are often intercropped or planted in dedicated woodlots (Sabastian et al. 2009).

Gintings and Lai (1994) define a cut-and-carry system as one adopting agrosilvopasture practices where livestock are stall-fed (paddock) with fodder collected from forests, home gardens, and along irrigation channels and even roadsides. In Gunung Kidul, a cut-and-carry system is commonly used to co-manage livestock (e.g., goat, beef cattle), forage, and cash-crops (e.g., maize, paddy, groundnut). Farmers adopt this system to minimize the cost of livestock feed and manage risk. The use of cut-and-carry systems can be found in other parts of the world such as in the Central Highlands of Mexico (Pincay-Figueroa et al. 2016) but their description in the extant literature is scarce. According to Rohadi et al. (2011) farmers commonly allocate 10% of their land to commercial timber stands (kitren systems), producing teak, acacia, and mahogany. Farmers also integrate timber into mixed upland cropping systems (tegalan) and home gardens (pekerangan). Land is frequently parcelized into two or three plots often including (a) a home plot where farmers plant vegetables, some forage, and an enclosure to keep livestock near their home, (b) an agricultural plot for cash crop production, and (c) a state-owned forest plot managed by farmers but publicly owned. The latter plot type is commonly planted with *Tectona grandis* and *Melaleuca* spp. Farmers who manage state forestland use the cut-and-carry system because of the inability to grow agricultural crops after the canopy has closed. Alternatively, they establish tree fences as a fodder source including *Calliandra calothyrsus*, *Gliricidia sepium* and *Leucaena leucocephala* and perennial grasses such as *Pennisetum purpureum*. Farmers cut forage and carry it to a paddock two to three times a day to meet livestock feed requirements. This is an integrated land management system as farmers incorporate livestock manure as organic fertilizer back into other plots (Fig. 2). It also includes diverse types of property right arrangements over different farm resources. The cut-and-carry system is utilized by farmers adopting parcelized agroforestry and monocrop practices.

Farmers in Gunung Kidul manage livestock as a savings and risk-management resource. They buy livestock when they have cash in excess of their immediate demands and sell livestock when in financial need. As a valuable financial asset, livestock is kept near homes as a precautionary risk measure. A profile of how farmers manage their livestock is presented in Table 1. Perdana et al. (2012) suggest that farmers in Gunung Kidul also manage teak as a savings resource that is retained as an asset of last resort after other disposable financial resources are exhausted. The preference for teak seems to be rooted in its initial fast growth and greater timber value than other species. Financial motivations are behind land allocation, too, contingent on tenure rights. For instance, most farmers keep livestock near their house where they enjoy full property rights. However, livestock-related agronomic

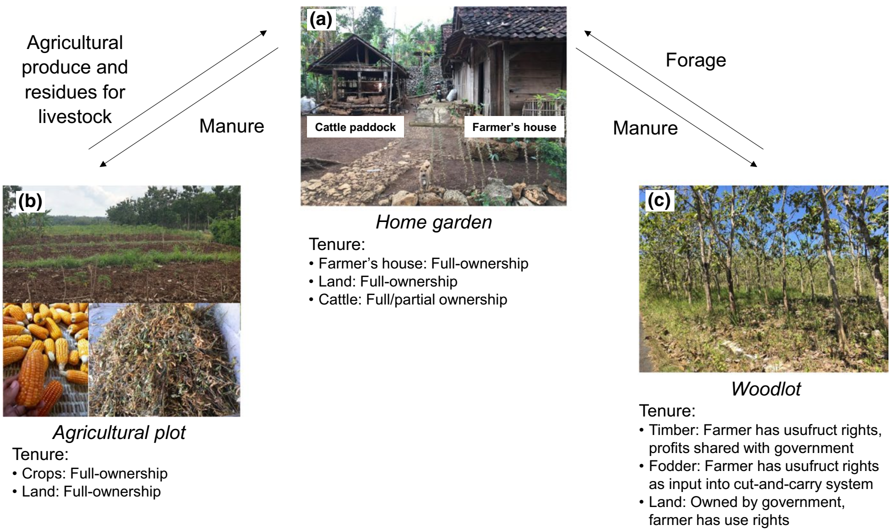

Fig. 2 Cut-and-carry system with **a** confined livestock, **b** cash crop, and **c** woodlot parcels. Photo credits: Authors

Table 1 Characteristics of livestock management systems in Gunung Kidul

Characteristics	Description
Type	Cattle, goat, sheep
Functions	Capital accumulation and liquidation, manure as organic fertilizer, farm work, protein source for human consumption
Ownership	Fully-owned livestock or partially owned livestock (managing under a particular shared agreement)
Paddock	In the garden near the farmer's house
Feed	Collect feed from farmer's own land but also from communal- and state-owned lands
Husbandry knowledge and skills	Knowledge obtained primarily from parents and other ancestors. Influenced by extension programs intended to improve productivity by introducing new technologies (e.g. artificial insemination)

activities on state forestlands are limited to fodder cut-and-carry because farmers do not have full property rights. Furthermore, feed necessary to complement livestock dietary needs is often sourced from home gardens, irrigation channels, and roadsides during the wet season (Gintings and Lai 1994). In the dry season animals are herded on arable lands, and are also fed hay and other crop residues such as corn stover.

Conceptual Framework

The adoption of land management practices is the result of a farmer's aim to maximize household wellbeing. The decision-making process of smallholder farmers is part of a strategy to balance livelihood objectives, possibilities, and constraints (Van Noordwijk et al. 2001). Farmers continuously select strategies that optimize expected utility derived from the land, trees, family labor, cash and other available resources to meet wellbeing objectives and minimize critical risk factors (Ellis 2000). Specific to agroforestry practices, socioeconomic characteristics such as family size, labor, social capital, land holding size, income, age, and experience reportedly have a systematic effect on the likelihood of their adoption (McGinty et al. 2008). Adesina and Chianu (2002) report that larger family sizes intrinsically provide more labor facilitating the adoption of commonly more labor-intensive agroforestry systems. Land availability can also influence a farmer's decision to adopt agroforestry practices (Adesina and Chianu 2002). Pattanayak et al. (2003) highlights the role of financial resources and infrastructure as cash availability and lesser road accessibility seem to influence farmers' adoption of agroforestry. Adesina and Chianu (2002) found farmer's age and experience to also be associated with the decision to integrate trees into farming systems. Pattanayak et al. (2003) further reported that experience and familiarity of farmers with general farming and tree planting were strongly associated with agroforestry adoption. In addition, Neupane et al. (2002) have suggested that membership in a local organization consistently had a significant and positive effect on farmers' willingness to adopt agroforestry practices.

We relied on a capitals-based approach to rural livelihoods to examine likely reasons associated with the adoption of agroforestry within cut-and-carry parcelized systems. A rural livelihoods' capitals-based approach offers the benefit of an established conceptual framework suited to the assessment of land management practices. Under this framework, rural livelihoods are comprised of five forms of capital: human, social, financial, natural, and physical (Ellis 1998). Human capital is a combination of knowledge, habits, behavior, and personality that contribute to economic benefits for an individual and/or community (Ellis 1999; 2000). Human capital also includes the health of an individual, household, and community in order to be able to harness other forms of capital (Smith et al. 2001). Coleman (2010) explains that human capital is created by changes to skillsets and capability to act. Human capital is often measured through education attainment (e.g., years of schooling), demographic (e.g., racial and ethnicity) and household characteristics. Social capital refers to relationships, institutions, and norms that shape societal interactions. It plays a significant role in the productivity of an individual, organization, and community (Ellis 2000; Baum and Ziersch 2003). The literature suggests that social capital is commonly gauged through the assessment of social structure, trust, norms, and social networks that facilitate collective action (Green and Haines 2002). Social capital may be proxied through participation in organizations, voluntary associations, newspaper readership but also by assessing individuals' involvement in public meetings, informal sociability, and trust (Ellis 2000). Social capital gains come through changes in relations among people to facilitate shared and coordinated actions (Coleman 2010). Financial capital assets include savings, income, investments, and access to credit. It can be measured through household income, property value, and investments, among other financial assets. Natural capital can be defined as stocks of natural resources that flow to produce ecosystem services sustaining rural livelihoods (Daly et al. 1994). Amongst smallholder farmers their most fundamental and constraining physical asset is land (Missemer 2018). Physical capital refers to the built environment, comprised of a residential housing, public buildings, business/industry, dams and levees, and shelters, among others. It also includes infrastructure that allows access to electricity, water, telecommunications, hospitals, schools, fire and police stations, and nursing homes. Physical capital can be measured by the number, quality, and location of housing units, business/industry, and infrastructure (Ellis 2000). In the context of this research, natural and physical capital assets were jointly captured through land size and ownership information. Henceforth, we jointly refer to these two forms of capitals as bio-physical assets.

Methods

Survey Instrument and Data Collection

A survey was developed to gather information about farm and land conditions, farming and market information, and farmers' socio-demographic characteristics. It was first developed in English translated into Indonesian and back to English to ensure consistency (Cai and Aguilar 2013). The survey was pre-tested in Karangmojo sub-district prior to deployment following a participatory rural appraisal technique inclusive of group discussions with farming leaders and field observations. The pre-test aimed to gather contextual information about farming background and preferences and to corroborate through observation that the commodities selected in the survey were commonly planted. Farm, farming and farmers' characteristics included in the final questionnaire were associated with elements of social, financial, human and bio-physical capitals as summarized in Table 2.

We face-to-face surveyed a total of 172 farmers engaged in cut-and-carry systems. Among them 122 had adopted parcelized agroforestry practices and 50 were engaged in parcelized monocrop farming. The split reflects how a majority of farmers in our study region engaged in parcelized agroforestry. The distinction of two farmer groups was determined on where they obtain fodder or feed for livestock. Parcelized agroforestry farmers primarily obtain feed from forest areas, either from private or state forests. In contrast, parcelized monocrop farmers obtain feed from their own agricultural fields, primarily from border plantings of fodder plants or agricultural residues. The sampling recruitment process is outlined in Fig. 3. Primary household data were collected between May and July 2017. Questionnaires were collected in seven sub-districts: Karangmojo, Tepus, Semanu, Nglipar, Semin, Paliyan and Panggang.

Data Analysis

In addition to sample descriptive statistics, data analyses included a binary regression to identify systematic differences between monocrop and agroforestry farmers, and financial analyses to compare and contrast cut-and-carry characteristics between parcelized agroforestry and monocrop farming. We also explored the potential causation between parcelized agroforestry and higher farm revenues over monocrop farming. Descriptive statistics included measures of centrality and

Table 2 Survey sections, livelihood capitals, and selected farm and farmers characteristics

Section	Capitals	Characteristics (variables)
Farming and Market Information	Social	Cash-crop cooperative membership
	Social	Distance to nearest market
Farm and Land Characteristics	Human	Number of available farm laborers
	Financial	Livestock owned, measured in animal units
	Bio-physical/Financial	Land size
	Bio-physical/Financial	Land ownership
	Bio-physical	Elevation
	Financial	Commodity and timber crops
Farmer Demographic Characteristics	Human	Age
	Human	Head of household education
	Human	Farming experience
	Financial	On-farm income

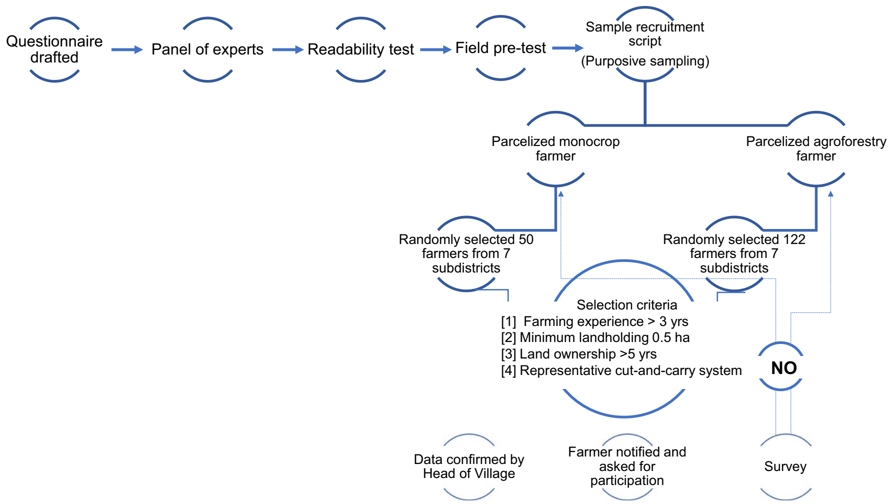

Fig. 3 Sampling recruitment process of survey respondents based on selection criteria of the farmers

distribution and differences in means of agroforestry and monocrop agricultural farmer groups. Logistic regression examined the relationship between selected covariates and the adoption of parcelized agroforestry. Here, the dependent variable was adoption of parcelized agroforestry (0: 'monocrop' farmers; 1: 'agroforestry' farmers) within cut-and-carry systems. The model included 12 explanatory variables (Table 3). Eight explanatory variables corresponded to farming information, market information, livestock, land size, number of family members who work on the farm, land ownership status, and land elevation. The other four (age, education, years of experience, and on-farm income) controlled for sociodemographic characteristics. We estimated odds ratios to ease interpretation of covariate association (Hosmer et al. 2013).

We implemented a propensity-score one-to-one matching to address the likely non-random nature of engaging in agroforestry, over monocropped, cut-and-carry farming and to examine its possible causal effect on higher on-farm revenue. It consists of a quasi-experimental statistical technique that mimics a randomization process through re-sampling (Dehejia and Wahba 2002) that has been applied in non-experimental causality studies in forest management (Song et al. 2014a, b). We first estimated the probability of a farmer to be in either cut-and-carry category using a logistic regression with the same explanatory variables as used previously but leaving out on-farm income as the outcome response. Our rationale for the selection of variables in the matching step was to control for systematic effects associated with farming and market information, and other resources intrinsic to the owner and her/his land, on the adoption of parcelized agroforestry. Propensity scores from the logistic regression were used to match agroforestry and monocrop farmers one-to-one to then estimate mean differences in on-farm income. All statistical analyses were conduced in Stata version 15.1.

Table 3 Dependent and independent variables used in logistic regression model to identify differences between parcelized agroforestry and monocrop practices within cut-and-carry systems

Variables	Description
Dependent	Cut and curry system practice adoption with: 1 = Parcelized agroforestry practices 0 = Monocrop commodity agriculture
Independent	
Farming and market information	Cash-crop cooperative membership: Respondent participates in cash crop cooperative: 1 = Member of cash crop cooperative 0 = Not a member of cash crop cooperative
	Accessibility to nearest market Distance from respondent house to market (minutes)
Farm and land characteristics	Number of farm laborers: Number of family members participation as farm labor 1 = Number of family members working as farm labor is more than one 0 = Number of family members working as farm labor is one
	Livestock owned: Number of animal units (AUs) owned by household, converted to the following categories in logistic regression 1 = More than 2 AUs 0 = 2 or fewer AUs
	Land size: Total area of land managed by household including private, shared and publicly owned lands
	Land ownership status: Categories denoting land ownership status Fully-owned: Lland is in full ownership by the respondent, household can harvest all production from the land Partially-owned: Land is owned by another party, household has the right to use and market produce based on established agreements Shared: Land is owned by more than two households, the cost and production from the land are commonly divided based on the number of individuals holding rights to the land Leased: Land has been leased from/to another person with agreement over how it is to be used
	Elevation Ordered categories capturing regency elevation 3 ≥ 300–700 m above sea level 2 = 200–300 m above sea level 1 = 0–200 m above sea level

Table 3 (continued)

Variables	Description
Farmer demographic characteristics	Age: Age of respondent (years)
	Head of household education: Ordered categories for highest degree of education earned by head of household 1 = Never attended school 4 = Senior high-school 2 = Elementary school 5 = Bachelor degree 3 = Junior high-school 6 = Other, higher education
	Experience: Respondent's farming experience (years)
	On-farm income (exchange rate 13.900 IDR = 1US$): Ordered categories denoting income obtained from farming: 1 = 501.000–1000.000 IDR ~ 36.04 – 71.9 US$ 2 = 1001.000–2.000.000IDR ~ 72.01–143.88 US$ 3 => 2.000.000 IDR ~ > 143.88 US$

Financial indicators were generated to gather insights into conditions associated with the adoption of parcelized agroforestry practices over lots managed as monocrops. We quantified differences in operational costs, income and net profit margins to assess the relevance of each component to cut-and-carry financial performance (Gittinger 1982; Monke and Pearson 1989). In both cases, profit margins were calculated as the difference between total revenues and costs (inputs, operations, labor, etc.) to assess how production and price of each commodity influenced final farm profitability. The costs of all inputs and operations in a year period are shown in Table 4. Within our estimates we considered a second scenario where farmers engaged in parcelized agroforestry sold livestock periodically (usually every 2–3 years as per our survey results) to assess its impact on profitability. This scenario was chosen because farmers engaged in agroforestry do not have regular annual income generated from commodity crops, hence, revenues from livestock are needed on a periodic basis to meet households' needs.

Under the cut-and-carry parcelized monocrop system, we estimated the annualized costs and revenues for each crop in dry and wet seasons. We did not consider repayment of capital, taxes or insurance, because farmers did not have any amortization of such payments for an entire year. This latter assumption was empirically supported by the fact that farm insurance and taxes are not mandatory in Indonesia. Farming taxes are not mandatory but farmers have to pay real estate (land and building) taxes every year. Real estate taxation is levied only on land that is under full private ownership commonly ranging from US$10 to US$35 per year. Although in 2013 the Indonesian government proposed legislation (Law No. 19) to protect farmers through agriculture insurance (Law No. 19/2013), most farmers are unaware of it and there is a prevalent lack of understanding regarding its implementation as observed during survey data collection.

Table 4 Farming costs of selected crops and commonly used inputs (US$/0.1 ha)

Input/crop	Paddy		Maize		Groundnut
	Field[a]	Forest/home garden[b]	Field[a]	Forest/home garden[b]	Forest/home garden
Seedling	2.59	4.64	1.10	0.65	–
Manure (as fertilizer)	8.60	3.11	58.42	54.32	5.17
Urea	4.65	2.87	3.96	2.16	0.31
Triple super phosphate	2.70	2.81	1.78	2.73	0.39
Zwazelzurre ammoniac	0.71	0.46	1.76	0.00	2.47
Ponska	1.47	1.44	3.19	0.00	0.54
Pesticides	1.65	0.38	2.01	0.00	0.64
Labor	6.44	6.76	9.53	0.94	0.00
Other (e.g. transportation cost, electricity, water, diesel)	2.88	0.06	4.03	0.17	0.64
Total costs	31.68	22.53	85.79	60.95	10.15

[a]Also called "sawah" is a wet-open parcelized area that surrounded by hedges, located in steep slope and need a large quantity of water for irrigation. On the field/*sawah* rice is grown in rainy season and different crop such as maize, soybean and peanut normally planted during dry season

[b]Home garden (*Pekarangan*) is a parcelized area that located close to settlement (house), it has no source of irrigation, managed non intensively either as agroforestry subsystem or monoculture. Sometimes "home gardens" are used as secondary field to grow maize, paddy, trees etc

Results

Descriptive Statistics

Responses from 172 farmers show that, on average, heads of household managing cut-and-carry parcelized agroforestry systems were 54.6 (SD = 12.1) years old, with 25.6 (SD = 13.4) years of farming experience (Table 5). On average, cut-and-carry agroforestry farmers had 1.9 AUs, two family members engaged as farm labor, and were more likely to live in higher elevations (> 200–700 m above the sea level) and a farther travel time to the nearest market (27.4 min). Heads of households engaged in parcelized monocrops were slightly older with an average age of 55.1 (SD = 11.8) years with 26.4 (SD = 14.3) years of farming experience. The number of livestock units owned by monocrop farmers was also higher (2.3 AUs) than agroforestry farmers. The former mostly lived at lower elevation areas (0–200 m above sea level) suggesting better access to markets (16.6 min travel distance to nearest market). Among monocrop farmers, 72% were members of a cash and crop cooperative. Regarding land size ownership, both agroforestry and monocrop farmers managed slightly more than 1 ha of land with partially-owned status (58.1%)—i.e. the land is owned by another party but the farmer has the legal right to use the land under certain conditions. A majority of farmers had parcelized land consisting of more than one plot. Most agroforestry farmers (70.3%) had two plots consisting of state-owned forest (74.6% of the total land area) and community forest (25.4% of total land area). Over a quarter of

Table 5 Descriptive statistics comparing cut-and-carry parcelized agroforestry and monocrop systems ($n = 172$)

Independent variable	Agroforestry ($n = 122$) Mean (SD)	Monocrop ($n = 50$) Mean (SD)
Farming and market information		
Cash-crop cooperative membership	0.26 (NA)	0.68 (NA)
Accessibility to nearest market	27.43 (16.10)	16.60 (12.82)
Farm and land characteristics		
Number of farm laborers	1.29 (.75)	1.16 (.42)
Livestock owned (number of AUs)†	1.89 (1.03)	2.33 (1.86)
Land size	1.07 (0.30)	1.18 (.422)
Land ownership status		
Fully owned*	0.22 (NA)	0.64 (NA)
Partially owned*	0.68 (NA)	0.30 (NA)
Leased*	0.09 (NA)	0.06 (NA)
Elevation		
Elevation 3*	0.27 (NA)	0.36 (NA)
Elevation 2*	0.34 (NA)	0.40 (NA)
Elevation 1*	0.37 (NA)	0.24 (NA)
Farmers demographic characteristics		
Age (years)	54.62 (12.15)	55.10 (11.78)
Head of household highest education	2.47 (.94)	2.76 (1.01)
Farming experience (years)	25.60 (13.36)	26.37 (1.86)
On-farm income	2.02 (0.22)	1.86 (0.45)

*Mean value denoting percent (%); *NA* not applicable for categorical variables

†AUs converted to categorical variable as per Table 3

commodity monocrop farmers (28.5%) had more than 1 plot of land consisting of agricultural fields (58.0%) and state forest (42.0%).

Both cut-and-carry parcelized agroforestry and monocrop farmers had an average family-size of four individuals with at least one member working on the farm.

On average, the head of the household of both groups had completed elementary schooling (at least 8 years of education). Farmers also engaged in off-farm income generating activities such as government employment, work as head of village, and traders. Off-farm income activities contributed an average annual income of US$94–US$500 or 9.5% to 37.5% of total income.

Logistic Regression and Propensity Score Matching

The logistic regression offered a systematic comparison of associations between covariates denoting livelihood capitals and the likelihood of adopting parcelized agroforestry practices within cut-and-carry systems (Table 6). Results show a model that was highly statistically significant ($p < 0.01$). The analysis shows that explanatory variables gives an improvement of over 43% from the null model including solely an intercept. Variables capturing accessibility to the nearest market and land ownership status showed strong statistical associations ($p < 0.01$) with the adoption of parcelized agroforestry. Absolute marginal effects show that farmers who had full land ownership status where 8.36 times more likely to engage in agroforestry practices than those with other tenure conditions (e.g. partially owned, leased or

Table 6 Results of logistic regression assessing the likelihood of parcelized agroforestry adoption, over monocropped parcels, within cut-and-carry systems ($n = 150$*)

Variable	Coefficient	Odds ratio	p value
Farming and market information			
Cash-crop cooperative membership	− 1.723	0.178	0.011
Accessibility to nearest market	0.099	1.104	< 0.001
Farm and land characteristics			
Number of farm laborers	− 0.371	0.689	0.586
Livestock owned	− 0.442	0.642	0.447
Land size	− 0.143	0.866	0.827
Fully-owned land ownership status†	2.123	8.360	< 0.001
Elevation 3‡	1.708	5.522	0.040
Elevation 2‡	1.677	5.349	0.045
Sociodemographic characteristics			
Age	− 0.011	0.988	0.655
Head of household highest education	− 0.813	0.443	0.141
Farming experience	1.329	3.778	0.065
On-farm income	1.779	5.928	0.032
Constant	− 7.929	< 0.001	0.003
Log-likelihood ratio (Prob > χ^2)	74.97 ($p < .001$)		
Pseudo-R^2	43.09		
− 2 Log likelihood	49.503		

*Fewer observations included in regression due to incomplete questionnaires

†As compared to base level of ‘other categories’ (partially-owned, shared and leased)

‡As compared to base level ‘Elevation 1’ 1 (0–200 m above sea level)

shared plots). In addition, elevation and on-farm income showed strong statistical associations at the 5% Type-I error level. For instance, medium and high elevations were associated with increased likelihood of agroforestry adoption by 5.52 and 5.35 times, respectively, over parcelized monocrop farmers. Higher income categories were also associated with the adoption of agroforestry practices. In contrast, cash crop cooperative membership, number of farm laborers, land size, having more than 2 AUs, and education had an inverse association with the likelihood of adopting agroforestry practices. Among the latter, membership in a cash crop cooperative was associated with odds ratio of farmers engaging in agroforestry practices being 82.8% lower than managing parcels as monocrops. Results show that the head of household's age and education attainment did not systematically differ between agroforestry and commodity agricultural farmers ($p > 0.10$).

The propensity score matching offered statistical evidence of the likely causality between the adoption of parcelized agroforestry and higher on-farm income levels than parcelized monocrops. Engagement in parcelized agroforestry significantly ($p < 0.001$) increased the likelihood of being in a higher income category by 14.0% (Coefficient for differences in means = 0.14; std. error = 0.044).

Financial Analysis

Total income per household was relatively small. Average on-farm income among parcelized agroforestry farmers was IDR 12 million/year, higher than on-farm income of monocrop farmers (US$ 840/year compared with US$ 756/year) in 2017. This difference is largely the result of different revenue levels from farming activities other than livestock; agroforestry systems prioritize agricultural crops and timber, while monocrops solely prioritize agricultural crops. Area-adjusted income from cash crops suggests farmers obtained US$103.82 in profit per 0.1 ha if they plant rice in irrigated fields. Profits were lower if irrigated rice was planted on woodlots or in home garden areas. On average, a farmer earned US$44.80 per harvest period. Yields and income from rice cultivation is affected by land and water characteristics and requirements, soil fertility, paddy infrastructure, tenure restrictions, and competition adjacent and associated crops (Roshetko et al. 2018).

Maize and ground nuts earned farmers around US$41.18 and US$98.78 of profits per 0.1 ha, respectively (Table 7). Revenue from livestock sales provided an additional 8.40 US$/month to farmers with parcelized agroforestry systems and 8.05 US$/month to monocrop farmers. Results of the financial analysis show that households that managed timber and livestock in agroforested parcels had 11.1% higher on-farm income than those under a monocrop system corroborating results from the logistic regression and propensity score matching.

Table 7 Cash-crop financial analysis for paddy, maize and groundnut farmed under agroforestry and monocrop practices (all values in US$)

	Agroforestry			Monocrop	
	Paddy (0.1 ha)	Maize (0.1 ha)	Groundnut (0.1 ha)	Paddy (0.1 ha)	Maize (0.1 ha)
Income					
Production	183.50	546.00	134.00	369.30	144.00
Price	0.37	0.19	0.81	0.37	0.19
Total income	67.33	102.13	108.94	135.50	27.45
Cost					
Seedling	4.64	0.65	0.00	2.59	1.10
Urea	3.11	54.32	5.17	8.60	58.42
Triple super phosphate	2.87	2.16	0.31	4.65	3.96
Zwazelzurre ammoniac	2.81	2.73	0.39	2.70	1.78
Ponska	0.46	0.00	2.47	0.71	1.76
Pesticide	1.44	0.00	0.54	1.47	3.19
Labor	0.38	0.00	0.64	1.65	2.01
Other (e.g. transportation cost, electricity, water, petroleum)	6.76	0.94	0.00	6.44	9.53
Manure	0.06	0.17	0.64	2.88	4.03
Total cost	22.53	60.95	10.15	31.68	85.79
Profit	44.80	41.18	98.79	103.82	−58.34

Discussion

Cut-and-carry agroforestry for confined livestock is a land management system used by farmers managing small-size plots. The extant literature describing this land management system is limited and a central aim of this study was to offer a detailed characterization of its features. As an alternative management approach, cut-and-carry agroforestry systems help minimize feed cost and utilize parcels under partial, shared and leased ownership. This system emphasizes the use of peripheral lands as source of fodder, cutting and carrying feed to a paddock near the farmer's house. A majority of farmers have parcelized land under full- or partial-ownership that allows the utilization of all holdings as sources of fodder. The implementation of cut-and-carry systems in Gunung Kidul also helps manage risks due of harvest failure by keeping livestock as an alternative income source in addition to timber. Nonetheless, we recognize that characteristics described in this manuscript represent conditions found in Indonesia's Gunung Kidul region and different practices are likely to occur in other regions. We offer our findings as a case study and stress the importance of continued research to better understand cut-and-carry systems and their prospective benefits to smallholders' resiliency.

From a sustainable rural livelihood capitals perspective our analysis sheds light on a number of matters. It is generally agreed that human capital has a direct and significant influence on farmers' decision to adopt innovative management practices (such as agroforestry) and technologies (Keelan et al. 2014; Mignouna et al. 2011). Franzel and Scherr (2002) explain that higher education has been associated with greater degrees of innovation and the adoption of agroforestry. Education is frequently noted to have a positive influence on farmers' adoption of new technology (Mignouna et al. 2011). Yongling (2004) posit that the lack of proper education can limit the capacity to distinguish between poor and good information. Results from our logistic regression show that farming experience was significantly and positively associated with the adoption of agroforestry practices. However, the age and education level of farmers had no significant association which is likely due to the fact that there were only slight differences between our two smallholder farmer groups—as a majority of farmers in Gunung Kidul have attained at least an elementary to junior high school education. Also related to human capital, farmers often allocate family labor to minimize farming costs (particularly the rearing of livestock). As a farm laborer in a cut-and-carry system, a family member is responsible for cutting and carrying fodder, feed cattle, manage trees, plant crops, clean paddocks and harvest timber and commodity crops, among other activities. The head of household does not pay wages to the family member; instead money is saved to meet other basic needs. Although it may be assumed that family labor is available the entire year, the need to earn more money at particular times leads family members to find off-farm jobs such as agricultural labor during the rainy season or casual employment in local towns in addition to net outmigration. However, the statistical association in our analysis was not significant which is likely a result of little variance between the two groups.

Regarding associations with social capital assets, we found that participation in a cash crop cooperative had a negative effect on the adoption of parcelized agroforestry practices. This association might be linked to how cash crop cooperatives emphasize information about markets and marketing of commodity crops. A more diverse farming system such as parcelized agroforestry inherently places a lower priority in such practices and, thus, was inversely associated with cash crop membership. Although farming information is commonly provided by the Indonesian government, farmers' land management decisions tend to be more directly influenced by information shared with fellow farmers, village leaders, and other peer groups. Martini et al. (2017) and Riyandoko et al. (2016) found that government extension services are inadequate to transfer agroforestry information and that farmer-to-farmer communication was the main channel used among smallholder farmers in central Java, Nusa Tenggara, and Sulawesi. Sunkar (2008) reported that farmers in Gunung Kidul undertake farming activities through inherited traditions, which have evolved over decades of experience, observation, and trial-and-error problem-solving. We posit that in our sample it was membership in cash crop cooperatives that facilitated information dissemination in regards to intensively managed monocrop farming having an inverse relationship with the adoption of parcelized agroforestry practices.

Regarding financial capital, our findings show greater profits were accrued by parcelized agroforestry farmers. The likely causality between parcelized agroforestry and on-farm income was corroborated in results from the propensity score matching. Sabastian et al. (2014) explain that in Gunung Kidul larger land holdings devoting a greater area to timber production are associated with higher on-farm income. Our research suggests that by reallocating household labor and managing livestock, within a cut-and-carry system, co-located agroforestry practices can generate more on-farm income than monocropped parcels. Likewise, those implementing parcelized agroforestry were able to generate more income from livestock activities. Even though agroforestry farmers had fewer AUs than monocrop farmers, yet similar husbandry practices, the former generated more revenues from livestock (~8.40 US$/month compared with 8.05 US$/month). We posit that greater profits might be the result of more efficient use of labor and other resources with fewer animals (e.g., farmers could provide healthier and more diverse diets by adding fodder from *Pennisetum purpureum*, *Gliricidia sepium Leucaena leucochepala*). On-farm average income among farmers practicing parcelized agroforestry was higher by about 11%, compared with those who managed parcels as monocrops, with statistical evidence of a causal effect. Farmers reporting higher off-farm income had a greater tendency to practice monocrop agriculture. Our data show that 77% of agroforestry farmers identified "farmer" as their main occupation and 11% had a secondary occupation, whereas among monocrop farmers 62% identified "farmer" as their primary job.

Adoption of parcelized co-located agroforestry practices was also associated with bio-physical capital assets. Comparing elevation, tenure rights, and travel distances to nearest market, farmers who owned land in higher altitudes, had land in full ownership, or experienced longer travel times had a greater likelihood of adopting parcelized agroforestry practices. We posit this happens because farmers (1) experience higher transportation costs from more remote plots, (2) a more challenging topography reflected in these variables can challenge the establishment of agriculture instead making tree planting more appealing, and (3) having full tenure rights can facilitate the establishment of long-term land practices. Longer travel times increase transaction costs and can reduce profitability of commodity crops often relying on thin profit margins. In the case of timber lots, although often experience greater profit margins, these are highly dependent on local supply chains where famers rely on traders or intermediaries to sell timber (Perdana and Roshetko 2015). Other site-specific characteristics such as soil fertility and topography can influence the adoption of farming practices on privately or leased lands. For instance, it is common for farmers to establish terraced landscapes and various silvicultural systems in lands of more difficult topography. Farmers in the Gunung Kidul region grow teak and acacia on steeper slopes, while mahogany has the best growth on gentle slopes (Sabastian et al. 2014). These trends are reflected on regional statistics as the higher altitude sub-districts of Paliyan and Panggang have the largest areas allocated to teak plantation at 2070 ha (40.0%) and 1546 ha (29.8%), respectively (Yogyakarta Department of Forestry 2017). Regarding land tenure systems and uses, teak plantations are often established within state-owned lands made available to smallholder farmers. This scheme gives smallholder farmers access to state land as part of the community-based forest management program implemented in Gunung Kidul. The government's Community Forest (Hutan Kemasyarakatan- HKm) scheme grants farmers 35-year usufruct rights to state forestland, with secured rights for forest products other than timber, and permission for timber production created through concession agreements with final profits co-shared with the government (Ota 2011). Due to limited rights to grow timber, farmers first produce agricultural crops on state forestlands when the canopy is still open and can harvest livestock fodder.

In the Gunung Kidul area, farmers treat livestock as a savings and risk management financial asset. Hence, it is logical that farmers keep livestock near their homes as a safety precaution. They buy livestock when they have cash-in-hand beyond immediate financial demands and sell it when in need. Timber trees are kept for savings in case for emergency cash situations. Farmers sell either livestock or timber trees anytime when they need cash; whether livestock or timber tree, they do not consider the best time to sell the standing asset to obtain the greatest financial return. Their main concern is to not experience a dramatic financial loss and obtain just enough money as immediately needed; which often results in smallholder farmers receiving below market prices from teak traders (Perdana and Roshetko 2015). Timber sale is often preceded by a sequence of liquidated assets. For instance, Perdana et al. (2012) found that Gunung Kidul farmers manage teak trees as financial reserves that are retained until other disposable assets such as motorcycles, jewelry and electronic devices have been sold. How farmers decide to fulfill their cash needs can be classified into three categories. First is that of high-stake financial needs, where farmers need a major sum of money for a specific purpose (e.g., to pay medical costs, construct/renovate house, buy a motorcycle or land). Farmers sell more than one goat/sheep, cattle or timber tree to cover this financial burden. A second category is that of medium financial needs. This category includes payments for schooling or to buy feed/fodder for livestock. Farmers usually sell goats/sheep and agricultural crops like maize and ground nut to obtain money for such demands. Paddy is the only product seldom sold by farmers as it is used as a staple food. Last, are small financial needs to fulfill basic daily demands. Farmers sell either poultry (e.g., a chicken, duck) and/or agricultural commodities (e.g. maize and ground nut) to cover such expenses.

Our results suggest that having full tenure over land made landowners more likely to implement parcelized agroforestry practices. This finding corroborates results from Roshetko et al. (2008) who reported that secure land and tree tenure rights are prerequisites for the development of smallholder agroforestry systems in Indonesia. Both categories of cut-and-carry farmers placed the paddock and livestock at the parcel where they have full, or most and well-defined, tenure rights. It was often the case that they were co-located in the plot where the household resided. As woodlots are in public jurisdiction, farmers utilized them for feed collection and not active livestock management, although on occasion they may graze on them. Farmers have adapted to, and a cut-and-carry system has partly emerged from, the array of property rights inherent to various farming resources ranging from land, to timber and livestock, and fodder (Barbieri and Aguilar 2011).

Table 8 Synthesis of salient advantages and disadvantages of parcelized cut-and-carry system for confined livestock production

Advantages	Disadvantages
Reduces livestock feed costs by sourcing forage from woodlots and agricultural plots	Requires adequate financial and land capitals for confined livestock* in paddock
Improves financial resilience from farm diversification, magnified under parcelized agroforestry	Demands labor often multiple times a day for fodder collection and livestock management—alternatively, requires paying labor costs for conducting the same activities
Reduces risk through farm diversification	Requires time-bound management as animals need to be feed 2–3 times a day and pen needs to be cleaned daily
Maintains and grows livestock* as a non-perishable marketable product and financial instrument	Demands more time allocated to accessing various farm plots than larger farms, farmers often rely on motorcycles
Tailors land use to plot-specific bio-physical and land tenure conditions along suitable agronomic practices	Requires access to private, public and community-shared lands to source adequate fodder resources to effectively reduce feed costs
Maximizes productivity of marginal and underutilized peripheral farming niches (understories, terrace walls, borders, roadways) and underutilized vegetation for fodder	Requires in-depth farming knowledge and experience to manage multiple land uses, often limiting adoption by younger farmers
Reduces dependence on external farm outputs as many fodder crops grow from natural regeneration	Needs adequate understanding and current information of multiple markets, not relying on farming cooperatives
Recycles manure for organic fertilizer and compost to enhance annual crop production	Requires at least one or two plots for forage fodder—although some farmers also have it in their back/front yard or near the shelter)
Lowers demand for investments in a larger herd size accommodating farmer's available resources including labor and capital	
Integrates well with annual and perennial cropping systems whether in a co-located agroforestry system or not	

*We place greater emphasis on cattle as the main form of livestock asset managed under this system

Table 8 offers a synthesis of the apparent advantages and disadvantages identified from our characterization of cut-and-carry systems and particularly the adoption of parcelized agroforestry over monocrop lots. Our synthesis is offered from a smallholder farming perspective and, although comprehensive, is not deemed to be exhaustive as this is an area that warrants additional investigation. Various policy implications stem from our characterization. We stress that cut-and-carry systems adopted as parcelized agroforestry:

(1) offer an alternative to promote diversified and financially resilient farming—when management and usufruct of under-utilized public lands are granted under conditions that sustainable agronomic practices that are socially-acceptable by local communities;

(2) enhance on-farm revenues which are greater when it occurs in conjunction with co-located agroforestry practices—that can be supported through easier capital access to invest in livestock and dedicated woodlots;

(3) demand a greater degree of farming and market knowledge—for which public extension and education programs might be necessary to support younger and lower-income farmers.

Conclusions

A cut-and-carry system integrates natural resource management over a landscape dominated by small-size parcels by cutting and carrying fodder to a paddock, and when animal manure is returned to the fields. Financial management is central to the adoption of cut-and-carry systems for confined livestock. The adoption of a cut-and-carry system supports farmers' financial resiliency by limiting cash expenditures (e.g. lower livestock feed expenditures) and facilitating income diversification (e.g. allocating land to different uses) that can help meet planned and unexpected cash demands. Farmers treat livestock and timber trees as savings and risk-management resources. Cut-and-carry systems in Gunung-Kidul have also partly emerged from the array of property rights associated with different farming resources (e.g., land, timber livestock, fodder) in private and shared ownership.

Within parcelized cut-and-carry agroforestry systems we distinguished between one land management approach where agroforestry practices are co-located in a traditional fashion often as wind breaks or tree fences, and another where agricultural and forestry practices may be implemented on specific parcels, such as cash monocrops and timber lots, yet integrated across land holdings. Face-to-face surveys conducted with farmers engaged in parcelized agroforestry and monocrop cut-and-carry systems determined that the former had more farming experience, greater on-farm income, with parcels located at higher elevations, and farther from the nearest market. Within our two categories of cut-and-carry farmers, those adopting parcelized co-located agroforestry had larger on-farm income—about 11% higher than agricultural farmers on a per-hectare basis. More diversified income sources likely contributed to this difference.

The adoption of parcelized co-located agroforestry was strongly associated with bio-physical livelihood assets. Specifically, farmers with land under full-ownership were 8.3 times more likely to adopt parcelized agroforestry over monocropped parcels; possibly facilitated by the ability of long-term planning that support tree planting. Having land at greater altitudes increased the odds of engaging in parcelized co-located agroforestry about 5 times over the implementation of monocrops. More challenging topography can be a deterrent to the adoption of monocrops that often required more intensive and often mechanized management. Longer travel distances to market also made farmers more likely to engage in parcelized agroforestry. Associated higher transportation costs can discourage the planting of commodity crops that often have to be brought timely to local markets at very thin profit margins. It was a social capital asset, as captured by membership in a cash-crop cooperative, that showed the greatest association with the likelihood of engaging in monocropped parcels; it decreased the odds of parcelized agroforestry by over 83%. Sharing of agronomic knowledge and market information likely contributed to the planting of commodity crops in monocropped systems.

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