Title: Adoption constraints for small-scale agroforestry-based biofuel systems in India

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Adoption constraints for small-scale agroforestry-based biofuel systems in India

Abstract

Small-scale agroforestry-based biofuel production has recently been proposed as a strategy for rural poverty alleviation, but few empirical evidence is available on farmer adoption of such novel systems. This study describes adoption of oilseed tree mixtures on smallholdings in Hassan district, South India, and examines the impact of a biofuel extension program and farmer characteristics on adoption. Cross-sectional survey data and regression analyses addressing various forms of selection bias, are used. The findings reveal that tree cultivation is much more prevalent than oilseed collection, and that various activities of the biofuel extension program only stimulate the former. Low seed prices and high opportunity costs of labour are major factors impeding households to collect seeds from planted or wild oilseed species. The paper concludes that the program succeeds as an agroforestry program but not as a biofuel program. Similar challenges pertain to small-scale agroforestry systems as to jatropha-based plantation systems, although the former are a Low-Risk High-Diversity approach to build feedstock for the future.

Keywords: biofuel; oilseed trees; technology adoption; extension; value chains

1. Introduction

Liquid biofuel production has recently been proposed as a strategy for rural development in low-income countries (Demirbas and Demirbas, 2007). Smallholder communities could act as feedstock producers (and processors) in biofuel value chains, thereby generating income, employment, trade and energy at a local level (Ewing and Msangi, 2009; HLPE, 2013). In particular, much hope is set on biofuel systems that aim to minimize trade-offs between biofuel and food value chains (Ewing and Msangi, 2009). This hope has resulted in various government policies promoting widespread cultivation of non-edible oilseed trees for biodiesel production on marginal lands (Biswas and Pohit, 2013; Gunatilake et al., 2014; Sorda et al., 2010). Initial programs were mainly based on large-scale plantations of jatropha (*Jatropha curcas*) on wastelands, but seed yields proved to be limited and highly variable under low input regimes, resulting in a lack of economic viability and limited potential for poverty alleviation (Ariza-Montobbio and Lele, 2010; Kumar et al., 2012; Muys et al., 2014; van Eijck et al., 2014). Widespread project failures have caused global investment to plummet, leaving alternative cultivation approaches largely unexplored, even though they might still have considerable potential to realize the abovementioned aims (Achten et al., 2014; Sharma et al., 2016).

Small-scale agroforestry-based biofuel production for local use has been suggested as a possible alternative solution (Achten et al., 2010b, 2010a; Muys et al., 2014; Sharma et al., 2016; van Eijck et al., 2014). This approach carefully integrates oilseed trees within the existing farming system. By growing oilseed tree mixtures on field margins and scattered throughout the landscape, competition with crops is limited, while the trees thrive on and recycle nutrient and water residual streams (Jose et al., 2004; Malézieux et al., 2009; Rao et al., 1997). Although oilseed yields might be limited in these low input – high diversity – high resilience systems (Tilman et al., 2006), the trees bring along multiple other products, uses and co-benefits, which add to the viability of the approach. Agroforestry set-ups can introduce various ecosystem services, including soil quality improvement, biodiversity and water conservation, pest regulation, climate change mitigation and carbon sequestration, shading and hedging, labour and income diversification, risk mitigation, and increased farm resilience (Griscom et al., 2017; Jose, 2009; Malézieux et al., 2009). By combining species with different ecological niches, agroforestry systems aim to optimize spatial, temporal and physical resource use, and thereby overall system productivity (García-Barrios and Ong, 2004;

Jose et al., 2004; Vandermeer, 1989). This rationale has given rise to the World Agroforestry Centre's (ICRAF) Programme for the Development of Alternative Biofuel Crops, which aims to develop and support agroforestry-based biofuel projects throughout the tropics, and investigate their unexplored potential (Cardoso et al., 2017; Sharma et al., 2016).

One of the Programme's case studies is an agroforestry-based biofuel program implemented since 2007 in Hassan district, Karnataka state, India (Gowda et al., 2014; Lokesh et al., 2015). This biofuel program primarily focuses on extension through conducting awareness campaigns and training sessions on oilseed tree cultivation and biofuels. Furthermore, it distributes high-yielding tree seedlings among farmers and establishes biodiesel cooperatives within villages to streamline activities. The program also hands out small-scale oil-expelling equipment and provides various kinds of business support. Recent work by Bohra et al. (2016) and Lokesh et al. (2015) predicts that the promoted biofuel system could significantly increase the income, employment and energy security of farmers in Hassan district. This strongly contrasts with qualitative assessments of this biofuel program by de Hoop et al. (2016) and de Hoop (2017), which indicate that local farmers are generally not interested in the envisaged biofuel value chain, and that the biofuel program has very little impact on them. Farmers' opinions and practices are clearly not in line with the optimistic economic prospects. These prospects have induced the program managers to mainly evaluate the program in terms of provided extension and support activities, yet there remains a critical lack of quantitative insights on actual household adoption rates and determinants. The aim of this paper is to characterize, quantify and explain farmer perception and adoption of oilseed trees in Hassan district, using cross-sectional household survey data collected in 2015. The roles of extension, program implementation and farm(er) characteristics in the adoption process are analysed through an econometric approach.

This study contributes to the empirical evidence on farmer adoption of biofuel systems, in particular for agroforestry-based approaches using novel oilseed species. The contrast in expectations between program managers and farmers, as exemplified above, is common in agroforestry projects. Pattanayak et al. (2003) and Mercer (2004) report that despite the availability of novel and effective agroforestry projects, low adoption rates and rapid disadoption are widely observed. Farmers' utility from and behavior towards agroforestry-based innovations are shaped by a complexity of factors, and this requires better understanding (Mercer, 2004). On the one hand, program design, extension and diffusion may play a crucial role in stimulating adoption (Dalemans et al., 2018; Glendinning et al., 2001; Pattanayak et al., 2003). On the other hand, a wide range of farm and farmer characteristics may be (dis)adoption determinants, as discussed in both the seminal work of Feder et al. (1985) and the meta-analysis by Pattanayak et al. (2003). Although these articles survey the extensive empirical adoption literature, research on biofuel adoption is limited, for instance Axelsson et al. (2012), Montefrio et al. (2015) and Soto et al. (2015). In addition, existing studies usually focus on jatropha and monoculture set-ups. Despite the acclaimed potential of agroforestry-based biofuel systems in low-income countries (Baral and Lee, 2016; Fritsche et al., 2017; Korwar et al., 2014; Lokesh et al., 2015; Paelmo et al., 2014; Sharma et al., 2016), there is a lack of empirical evidence on farmer perception and adoption of these systems. This study provides such evidence from India, where minimizing trade-offs between biofuel and food value chains is particularly relevant (Biswas and Pohit, 2013). India has the highest absolute rates of undernourishment and poverty in the world (FAO et al., 2017; World Bank, 2016) and at the same time depends for over 70% to 80% of its oil demand on imports; a share projected to increase even further (IEA, 2015; Tuli and Gupta, 2017).

2. Methodology and Data

2.1. Research area

Hassan district in South India has a population of about 1.8 million, 79% of which lives in rural areas. This district is constituted by about 2600 villages, which are clustered into 38 administrative units termed hoblis (DCO, 2014). Its geophysical diversity is prevalent from the three agro-ecological zones (dry, transition, hill) characterized by a distinct rainfall gradient (Figure 1). Correspondingly, a wide variety of crops are cultivated, including various plantation crops such as coconut in the dry and transition zone, and coffee, pepper and cardamom in the hill zone. Most farmers are smallholders: 65% of the landholdings are smaller than 1 hectare, 89% smaller than 2 hectares (DAC&FW, 2017).

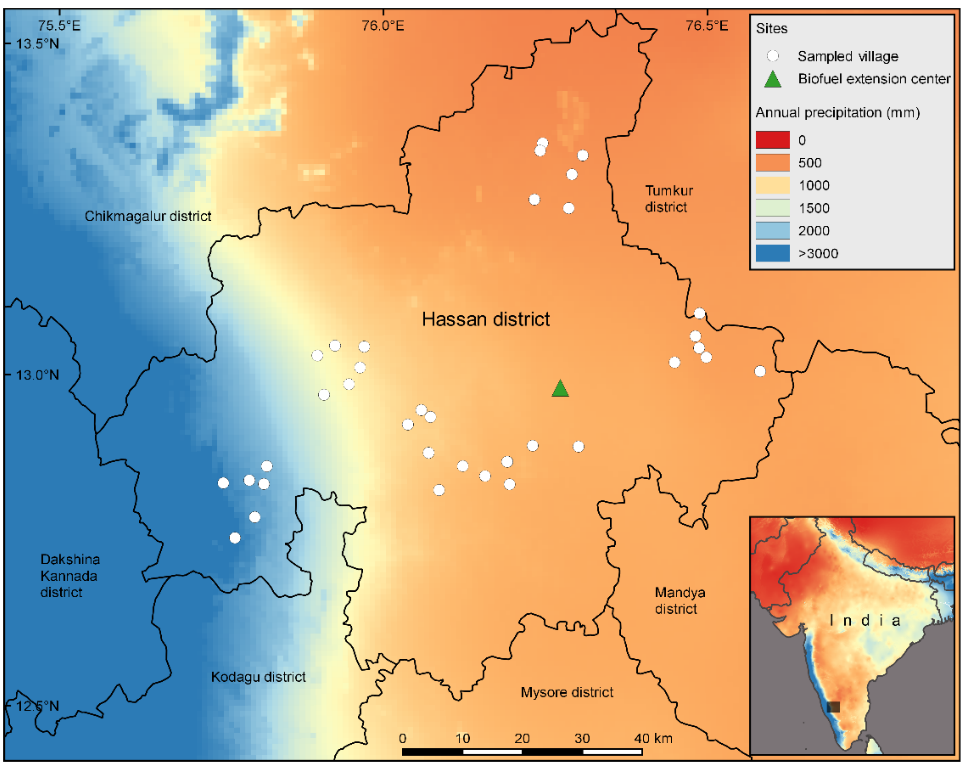

Figure 1. Map of Hassan district, Karnataka state, India. The map locates the biofuel extension center, sampled villages and rainfall gradient (Hijmans et al., 2005).

Within Hassan district, the Biofuel Program (BP) is being implemented since 2007 by a university – government partnership[1] (Gowda et al., 2014; Lokesh et al., 2015). This program (hereafter

[1] The Karnataka State Bio Energy Development Board and the University of Agricultural Sciences Bangalore.

referred to as BP) aims to establish oilseed tree mixtures on farms on field edges, in homegardens, and on fallow land, and on communal lands. It mainly promotes native oilseed tree species, which are adapted and non-invasive to local ecosystems, while local communities are, to varying extents, familiar with their cultivation and various uses (Gowda et al., 2014; Meena Devi et al., 2008; Neginhal, 2004). The principal species are pongamia (*Millettia pinnata*), neem (*Azadirachta indica*), mahua (*Madhuca indica*), simarouba (*Simarouba glauca*) and jatropha (*Jatropha curcas*). The BP provides extension and support on oilseed trees through a range of activities. First, the BP conducts biofuel awareness campaigns and training sessions (hereafter simply referred to as training sessions). These information and demonstration sessions focus on cultivation and uses of various oilseed tree species, and in particular on the biofuel value chain. They generally take place on-site in local villages, and by 2015 at least one training session had been conducted in half of the villages in the district. Furthermore, 290 training sessions had been organized in the central extension center for visiting groups. Second, the BP organizes planting programs throughout the district. By 2015, 1.55 million seedlings of various oilseed tree species had been distributed for planting. Third, by 2015 the BP had supported 470 villages in establishing biodiesel cooperatives (also called associations). These cooperatives should take the lead in coordinating biofuel activities in the community, including seed collection, storage, marketing, processing and use. Furthermore, they act as a meeting point for local farmers and the extension agency. Finally, the BP supports development of the downstream value chain. For pongamia and neem in particular there are many traditional uses of wood, leaves, fruits, seed cake[2] and seed oil. While seed oil can be blended in diesel or processed to biodiesel, it is traditionally used as a lamp fuel and for pesticidal, medicinal and industrial applications. Corresponding value chains exist, and oilseed collection on private and communal land is traditionally known as a secondary farm activity (Altenburg et al., 2009; de Hoop, 2017). The BP aims to develop a biofuel value chain in two ways. On the one hand, the BP provides business support through minimum oilseed support prices[3], on-farm pick-up, processing of oilseeds to biofuels, and redistribution of end products to local consumers. On the other hand, by 2015 the BP had distributed a small-scale oil expeller in 19 communities that expressed

[2] Seed cake is a by-product of seed oil extraction and has pesticidal, fertilizer and fodder applications.
[3] Oilseed prices have substantial spatial and temporal variations. Average support price levels in 2015 fluctuated around 20 INR/kg. INR = Indian National Rupee. 1 EUR = 74.2 INR in August 2015.

profound interest in engaging into the biofuel value chain according to the BP, to enable on-site extraction and use of seed oil and cake.

2.2. Data collection

To investigate farmer perception and adoption of oilseed trees in Hassan district, cross-sectional household survey data were collected in the period August – September 2015. A three-stage sampling was used. In the first stage, 1, 2 and 3 specific hoblis were selected in the hill, dry and transition zone, respectively, with the number of selected hoblis in the zones reflecting their share in the district population (Table 1). Purposeful selection was done in order to maximize the variation in BP extension and implementation within hoblis. In the second stage the villages in each hobli were stratified in four BP extension and implementation strata:

(1) villages where no BP activities had taken place ("control villages");
(2) villages where training sessions (and planting programs) had taken place, but no cooperative had been formed and no oil expeller had been distributed ("training villages")
(3) villages where training sessions and planting programs had taken place, a cooperative had been formed, but no oil expeller had been distributed ("association villages")
(4) villages where training sessions and planting programs had taken place, a cooperative had been formed, and an oil expeller had been distributed ("expeller villages")

Villages were randomly selected within these strata resulting in 6 sampled villages for each hobli (Table 1; Figure 1). In the third stage, in each village households were listed in a population census record and households without farm land or performing exclusively off-farm activities, were excluded from the sampling frame. The remaining households were ordered by address and eleven were selected through systematic sampling. This resulted in a final sample of 396 farm-households. For the analysis in this paper, 6 households are dropped due to incomplete or erroneous data, reducing the final sample to 390 households.

Household survey data were collected using a quantitative structured questionnaire, including closed- and open-ended questions based on adoption literature and focus group discussions with farmers held prior to the survey. The questionnaire included an extensive module to assess household knowledge, perception and adoption of five principal oilseed trees (pongamia, neem, mahua, simarouba and jatropha), and their participation in the biofuel value chain. In-depth data on household involvement in various BP activities were collected. This was supplemented with data on a wide range of farm(er) characteristics through detailed modules on household demographics, land and non-land assets, farm production and marketing, employment and income, and social capital.

Table 1. Characterization of the sampled hoblis (first sampling stage) and distribution of the sampled villages (second sampling stage).

Agro-ecological zone	Hobli	Annual rainfall (mm)[a]	Amount of sampled villages by stratum				Total per hobli
			Control	Training	Association	Expeller	
Dry	Nuggehalli	613	3	1	1	1	**6**
	Arsikere	709	0[b]	2	1	3	**6**
Transition	Halekote	737	1	1	1	3	**6**
	Kattaya	891	2	1	1	2	**6**
	Palya	1258	2	2	1	1	**6**
Hill	Hetthur	2477	2	2	2	0[b]	**6**
Total per stratum			**10**	**9**	**7**	**10**	

[a] Source: KSNDMC (2017); [b] A zero value indicates that there are no villages within this stratum for the corresponding hobli.

2.3.Definition of adoption

In most empirical studies adoption is conceived as the take-up of a specific technology or practice and correspondingly considered as a single binary choice. In this study, however, an explicit distinction is made between the adoption of tree cultivation (defined as the presence of at least one of the five oilseed tree species on the household's landholding) and the adoption of seed collection (defined as seed collection by the household from at least one of the five species in the past 12 months). This distinction is necessary because these species have multiple uses and co-benefits, implying that some households might cultivate trees but not for oilseed collection. Table 2 shows that even though the majority of households cultivate oilseed trees on their land, only 13% collect oilseeds. The various ecosystem services mentioned by respondents are listed in Table 3; 92% of the households mentioned at least one of these. In addition, it takes several years for these species to start yielding – ranging from three years for jathropha to nine years for mahua – implying that some households have trees but are still unable to collect seeds. If only households with mature trees are considered, the seed collection rate increases to 31% (Table 2). On the one hand, this indicates that having mature trees is a strong determinant for seed collection, although it is not a strict condition as 2.4% of households without mature trees collect oilseeds. Most oilseed tree species are native and wild trees are prevalent in the district, enabling households to collect seeds from communal lands and forests, while some households might also collect seeds from other households' private land. On the other hand, even conditional on tree maturity, still two out of three households do not collect seeds, which emphasizes the need to consider adoption as two separate choices. Species-specific adoption rates are presented in Table A.1.

Examining adoption rates across villages stratified by degree of BP implementation, shows tree cultivation and maturity rates are only substantially higher in expeller villages (Table 2). However, this observation does not apply to seed collection rates, in particular when controlling for tree maturity. Remarkably, seed collection rates are substantially lower in association villages, and the households in these association villages are neither aware of the cooperative nor indicate they are members (Table 2). Further consideration of BP participation rates reveals only 18% of households have attended at least one BP training session (Table 2). This figure is substantially higher in expeller villages, while even some households in control villages have attended sessions in other villages or at the extension center. In contrast to the association villages, in the expeller villages cooperatives are more firmly established: 62% of the sampled households know them, and 26% are members. This does not apply to oil expeller use, which is only done by one household in the entire sample. About half of seed-collecting households in expeller villages is not even aware that the equipment is present, while the majority of the others state that they prefer to sell seeds over expelling oil[4]. In addition, of the fifty households collecting oilseeds, only one sells these directly to the BP, whereas the others sell them in local markets or to traders and other buyers.

Finally, in Table 4 adoption rates are compared between households that have attended at least one BP training session, and those that have not. Tree cultivation and maturity rates are significantly higher for the former. This seems to be the main driving factor for the significantly higher

[4] Some households further specified the reason for this, including 1) Selling is less risky; 2) Expelling is not profitable; 3) Oil cannot be sold in the village; 4) No need for oil.

unconditional seed collection rates for trained households; when controlling for tree maturity, the difference is still substantial but insignificant ($p = 0.215$).

Table 2. Adoption of oilseed trees and Biofuel Program participation rates across villages in the sample.

	Total		Control villages		Training villages		Association villages		Expeller villages	
Number of households	390		111		95		76		108	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Adoption rates										
Tree cultivation	0.60	(0.29)	0.57	(0.33)	0.42	(0.22)	0.56	(0.28)	0.81	(0.18)
Tree maturity	0.36	(0.23)	0.34	(0.28)	0.25	(0.17)	0.37	(0.28)	0.48	(0.17)
Seed collection, unconditional on tree maturity	0.13	(0.13)	0.16	(0.16)	0.11	(0.13)	0.04	(0.05)	0.18	(0.13)
Seed collection, conditional on tree maturity	0.31	(0.29)	0.38	(0.37)	0.36	(0.27)	0.07	(0.08)	0.36	(0.27)
Biofuel Program participation rates										
Training sessions	0.18	(0.21)	0.04	(0.06)	0.11	(0.10)	0.16	(0.23)	0.41	(0.20)
Cooperative awareness[a]	-		-		-		0.00	(-)	0.62	(0.28)
Cooperative membership[a]	-		-		-		0.00	(-)	0.26	(0.19)
Expeller use	-		-		-		-		0.01	(0.03)

Note: "Mean" refers to the mean adoption/participation rate at a village level, while "(SD)" is the rate's standard deviation across villages.
[a] Cooperative awareness refers to how many households know the biodiesel cooperative in the village, cooperative membership to how many households are member of it.

Table 3. Ecosystem services of oilseed trees mentioned by respondents.

Specific uses / benefits mentioned	Rates, for…					
	At least 1 species	Pongamia	Neem	Mahua	Simarouba	Jatropha
Uses						
Furniture / construction	**0.61**	0.07	0.56	0.04	0.00	0.00
Fertilizer	**0.55**	0.47	0.33	0.03	0.01	0.01
Solid fuel	**0.45**	0.43	0.12	0.08	0.00	0.00
Medicinal	**0.43**	0.04	0.40	0.00	0.00	0.01
Liquid fuel	**0.29**	0.27	0.09	0.04	0.00	0.06
Pesticide	**0.21**	0.03	0.19	0.00	0.00	0.00
Ceremonial	**0.19**	0.01	0.18	0.01	0.00	0.00
Industrial / marketing	**0.13**	0.11	0.08	0.01	0.00	0.01
Fodder	**0.02**	0.01	0.01	0.01	0.00	0.00
Food	**0.00**	0.00	0.00	0.00	0.00	0.00
Benefits						
Shade	**0.45**	0.37	0.24	0.05	0.00	0.00
Hedging & bordering	**0.44**	0.33	0.28	0.11	0.00	0.13
Reduce pests & diseases	**0.38**	0.02	0.36	0.01	0.00	0.02
Reduce erosion	**0.11**	0.07	0.07	0.02	0.00	0.01
Diversify income	**0.10**	0.05	0.09	0.01	0.00	0.01
Increase soil fertility	**0.09**	0.05	0.07	0.01	0.00	0.00
Increase biodiversity	**0.07**	0.03	0.06	0.02	0.01	0.00
Ornamental	**0.02**	0.01	0.00	0.01	0.00	0.00
Diversify labour	**0.01**	0.01	0.00	0.00	0.00	0.00
Diversify risk	**0.00**	0.00	0.00	0.00	0.00	0.00

Table 4. Adoption of oilseed trees among households that attended BP training sessions and non-trained households.

	Total	Trained households	Non-trained households	
Number of households	390	71	319	
Adoption rates				
Tree cultivation	0.60	0.80	0.55	***
Tree maturity	0.36	0.52	0.33	***
Seed collection, unconditional on tree maturity	0.13	0.21	0.11	**
Seed collection, conditional on tree maturity	0.31	0.41	0.28	

Note: Fisher's two-sided exact test is used to test differences in means for trained and non-trained households. Significant effects are indicated as follows: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

2.4. Econometric approach

In order to identify adoption determinants, with a particular focus on the role of BP activities, a regression-based approach is applied. This involves accounting for various types of potential selection bias.

2.4.1. Baseline model

As discussed in section 2.3, adoption of tree cultivation (Y_t) and adoption of seed collection (Y_s) should be explicitly distinguished and hence separately modelled. As these dependent variables are binary, a generalized linear model is defined:

Tree cultivation equation: $$Pr(Y_t = 1 \mid T, X_t) = g(T'\delta_t + X_t'\beta_t) \quad (1)$$

Seed collection equation: $$Pr(Y_s = 1 \mid T, X_s) = g(T'\delta_s + X_s'\beta_s) \quad (2)$$

in which the left-hand sides are adoption probabilities, T is a vector of BP treatment variables, X_t and X_s are vectors of control variables, δ_t, δ_s, β_t and β_s are coefficient vectors to be estimated, and g( ) is a link function.

The vector T includes three BP activities: training sessions, biodiesel cooperative formation and expeller distribution[5]. The first is modelled as a binary variable indicating whether at least one household member has participated in at least one training session in a village or in the central extension center (“BP training”). The latter two are modelled as binary variables indicating respectively whether a biodiesel cooperative has been formed in the household’s village (“BP association”), and whether an expeller has been distributed to the household’s village (“BP expeller”). These three treatment variables are hypothesized to have a positive effect on adoption probabilities.

To optimally estimate the BP treatment effects on adoption of tree cultivation, it should be taken into account that 42.5% of all households already cultivated trees before the BP started[6], and that

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[5] The other two BP activities, namely planting programs and oilseed business support, are not considered here. This is because farmer participation in a planting program is a result, rather than a predictor, of willingness to adopt tree cultivation. Receiving oilseed business support is similarly a result, rather than a predictor, of oilseed collection adoption.

[6] Species-specific tree cultivation rates in 2007 are presented in Table A.1

many of these trees might still be present today. For these households, BP treatments cannot make a difference for current adoption, except by influencing the decision whether to cut the trees or not. Therefore, tree ownership in 2007 is reconstructed ("Trees in 2007") based on recall data and added as a control variable in equation 1 to capture time-constant unobserved heterogeneity, but also interacted with BP treatment variables. The interaction terms prevent the described mechanism from "diluting" the real (or potential) effects of BP treatments.

A similar approach is applied to the seed collection equation. Table 2 indicates tree maturity is a strong determinant for seed collection. Potential BP treatment effects on tree cultivation, and hence on tree maturity, might therefore indirectly influence seed collection as well (also see Table 4). To estimate only the direct BP treatment effects on seed collection, tree maturity ("Mature trees") is added as a control variable in equation 2. Furthermore, it is also interacted with BP treatment variables. One can reasonably expect that many farmers with no mature trees simply do not have the ability (or permission) to collect seeds within a reasonable distance (only 2.4% collects, see Section 2.3), even if they are willing to. BP training is therefore simply unable to make a difference for these households. The interaction terms prevent this mechanism from "diluting" the real (or potential) effects of BP treatments.

Other control variables in both equations include farm characteristics potentially acting as drivers or barriers to adoption. Human capital is quantified by indicators for the gender, age and educational level[7] of the household head, and by the amount of labourers and dependents in the household. Physical capital is measured by the total landholding size. Wealth is measured by a principal component based index of household assets and living standards, with higher values indicating more assets / higher living standards. The amount of tropical livestock units is also used as a control variable. Furthermore, two variables related to natural oilseed tree occurrence are included: a respondent-reported variable indicating whether wild oilseed trees occur naturally on their land ("Natural tree occurrence"), and the amount of parcels in the landholding ("Amount of parcels"). Finally, to account for potential unobserved cluster effects resulting from the sampling approach, cluster fixed effects are added (Imbens and Wooldridge, 2007). These unobserved cluster effects are most likely present at the hobli level, given the large agroclimatic, and

[7] Indicator that equals one if the household head completed at least 8 years of schooling.

correspondingly socioeconomic, variability at this level (see section 2.1). Therefore, hobli dummies are added as cluster fixed effects.

2.4.2. Endogeneity of BP treatment variables

The baseline model assumes exogeneity of all regressors. However, each of the three BP treatment variables is potentially endogenous in the adoption equations. In order to address this endogeneity, alternative models are specified and estimated.

BP training: self-selection bias

With regard to BP training, participation in training sessions is voluntary, and one could reasonably assume that farmers who are willing to adopt self-select into the treatment. This would lead to self-selection bias. This potential bias is addressed with an instrumental variable approach, which is a valid approach in case only cross-sectional data are available and conditional on finding an instrument that is relevant – highly correlated with the probability of program participation – and exogenous – not influencing the probability of tree cultivation and seed collection other than through program participation – conditional on the set of control variables.

The following variable is used as an instrument for participation in BP training: the fraction of adult household members who are member of a village organization or group ("Group membership"). Group membership is likely positively correlated with training participation, but is plausibly exogenous if it has no residual effect on the probability of tree cultivation or seed collection. This requires further explanation on how training sessions are organized in villages and in the extension center. With regard to the former, extension workers first pay one or a few visits to a village, to have preliminary interactions with some villagers on a potential future training session. Subsequently, a date is fixed, and they visit most households to inform them, leaving a pamphlet behind. Finally, the training session is organized. However, it should be noted that this procedure is not strongly formalized, and that the BP – or at least some extension workers – also strongly relies on villagers informing each other, given the scale it works on. Information on the organisation of training sessions is likely diffused among others through village groups. In addition, the villagers who are initially addressed are in practice often acquaintances of the local extension workers or prominent village members, such as village group leaders[8]. With regard to training sessions in the extension center, these are usually organized for invited groups, rather than for occasional visitors. Among the sampled households that visited the extension center, 62% did this together with fellow villagers or in a group they are member of, whereas 43% paid an individual visit.

As a result, group membership may play an important role in determining household awareness about training sessions and by consequence participation probability. When households in non-control villages were asked why they did not participate in village training sessions (Table 5), the majority claimed no training session was organized, or that it might have been but that they were unaware. Even though this may partly result from the fact that training sessions in some villages have taken place years ago, it clearly shows that information diffusion is key to participation. Similarly, the majority of households is unaware about the existence of training sessions in the extension center. Importantly, for both types of training only a minority mentions reasons relating to lack of interest, indicating self-selection bias is potentially limited.

Table 5. Reasons stated for not participating in trainings organized by the Biofuel Program.

Reasons for …	… not participating in village trainings		… not visiting extension center	
	Rate in control villages	Rate in other villages	Rate in control villages	Rate in other villages
No training organized	0.60	0.42	-	-
Not aware about potential training	0.29	0.31	0.64	0.58
Not informed about training	0.00	0.02	0.02	0.01
No opportunity	-	-	0.03	0.04
No time / Too busy Other constraints	0.01	0.07	0.17	0.23
Not interested (various reasons)	0.04	0.11	0.09	0.14
Absent	0.01	0.02	0.00	0.00
Unclear	0.06	0.05	0.05	0.00
Number of households[a]	107	212	107	212

[a] This includes households that neither participated in village trainings, nor visited the extension center. Among the other 71 households, 61 participated in village trainings, while 37 visited the extension center.

[8] In a study on microfinance diffusion in Karnataka state, Banerjee et al. (2013) find that extension workers target village group leaders for informational meetings to maximize subsequent information diffusion in the community. Furthermore, they show that this information is effectively gradually passed through these leaders' networks, but that a household's subsequent adoption decision is not influenced by adoption decisions of its network.

BP association and BP expeller: simultaneity bias

BP association and, in particular, BP expeller are likely endogenous, because they are only implemented in a later stage and reserved for villages that have proven (extensive) interest in tree cultivation and oilseed collection. Causality might therefore run in two directions and lead to simultaneity bias: presence of a cooperative or expeller might not only influence adoption but is also a result of it. Since the dependent variable (adoption) is the exact criterion for assigning the treatment, it is extremely hard to address this bias in a cross-sectional analysis. In order to test the robustness of the results for this potential simultaneity bias, village dummies (= cluster fixed effects) are included in the adoption regressions. This removes regressors that have no within-village variation, like BP association and BP expeller, from the model. It obviously implies that their effect is not estimated anymore.

2.4.3. Note on the tree maturity condition: sample selection bias

It has already been argued in Section 2.4.1 that only few households without mature trees might have the ability (or permission) to collect seeds within a reasonable distance. If abstraction is made of the 2.4% that effectively does it, tree maturity becomes a strict condition for seed collection. Correspondingly, adoption of seed collection can be considered a two-stage sequential process, in which the seed collection choice (stage two, Y_s) is unobserved for farmers without mature trees (stage one, Y_m). The seed collection equation in the baseline model (= equation 2) is then transformed as follows:

Selection equation: $$Pr(Y_m = 1 \mid T, X_m) = g(T'\delta_m + X'_m\beta_m) \qquad (3)$$

Structural equation:

If $Y_m = 0$: Y_s is unobserved

If $Y_m = 1$: $$Pr(Y_s = 1 \mid T, X_s) = g(T'\delta_s + X'_s\beta_s) \qquad (4)$$

in which the left-hand sides are adoption probabilities, T is a vector of BP treatment variables, X_m and X_s are vectors of control variables, δ_m, δ_s, β_m and β_s are coefficient vectors to be estimated, and g( ) is a link function.

This interpretation is primarily useful because it suggests potential sample selection bias. One could reasonably argue that farmers who are willing to collect oilseeds put on average more effort into cultivating trees to this end. In this case the subsample of farmers having mature trees ($Y_m = 1$) is not random, leading to sample selection bias in the structural equation. To assess this potential bias a sample selection model is used (Heckman, 1976). This model generally requires at least one selection variable that determines tree maturity in equation 3, but not seed collection conditional on having mature trees in equation 4. "Natural tree occurrence" and "Amount of parcels" (see Section 2.4.1) are used, as they relate to natural oilseed tree occurrence[9]. In addition, "Trees in 2007" (see Section 2.4.1) is expected to strongly determine tree maturity, but not to have any residual effect on seed collection.

2.4.4. Model specification and estimation

Four related models are specified. The first is the baseline model (= LPM), as described in section 2.4.1. Second, its hobli fixed effects are replaced by village fixed effects (= LPM-FE) to account for potential simultaneity bias (see section 2.4.2). Third, the LPM-FE model is estimated using an instrumental variable approach (= CFM) to additionally account for potential self-selection bias (see section 2.4.2). The two-stage residual inclusion estimation – also termed control function estimation – is used instead of the more common two-stage least squares estimation. This is because it flexibly allows to interact the potentially endogenous BP training with "Trees in 2007" (in equation 1) and "Mature trees" (in equation 2), and for a robust test of its exogeneity. Fourth, the seed collection equation is estimated with a sample selection model (= SSM), as described in section 2.4.3.

Adoption probabilities are usually estimated using the normal cumulative distribution function as link function, resulting in the probit model. However, in this study the four models are estimated as linear probability models[10] – using the identity function as link function – because of three reasons. First, adding cluster fixed effects is problematic in the probit model due to the incidental parameters problem (Greene, 2002; Wooldridge, 2010). In addition, the probit model drops clusters in which the dependent variable does not vary, from the estimation. Second, the above model specifications, which include many interactions of binary variables, lead to more unstable estimates in the probit model. Third, even though bivariate probit models can be applied (Greene,

[9] One would assume that both natural tree occurrence and amount of parcels – when controlling for total landholding size – increase the probability of having trees – and by extension mature trees – on the farm, but that for the subsample of farmers having mature trees, they do not determine the probability of seed collection.

[10] In case of the SSM, this applies to the structural equation, as the selection equation is inevitably estimated with a probit model. Since the latter does not allow cluster fixed effects, these are not included in both equations.

2012), correcting for self-selection bias is generally difficult in nonlinear models, especially if the endogenous variable is also discrete (Imbens and Wooldridge, 2007; Wooldridge, 2014).

The clustered sampling approach should also be taken into account when calculating the standard errors. Even though the use of cluster fixed effects may substantially decrease the possibility of within-cluster error correlation, it does not necessarily remove it entirely (Cameron and Miller, 2015). As a result, although heteroscedasticity-robust standard errors will be reported, these might still be biased. Since the amount of clusters is relatively low (6 if clustered on hobli level, 36 if clustered on village level), it is inadvisable to use cluster-robust standard errors, which are only asymptotically valid (Cameron and Miller, 2015). Therefore, wild cluster bootstrapped t-statistics (with 100,000 residual resamples) are used to account for cluster effects (Cameron et al., 2008; Cameron and Miller, 2015; Esarey and Menger, 2016) and the corresponding p-values are reported (= p-btrap; "bootstrapped p-values") along with the p-values based on heteroscedasticity-robust standard errors (= p; "robust p-values").

3. Results

3.1. Regression diagnostics

The results of the baseline model (LPM), the village fixed effects model (LPM-FE) and the second stage of the control function model (CFM) for the tree cultivation equation and for the seed collection equation are provided in tables 6 and 7, respectively. The results of the sample selection model (SSM) are presented in table 8. This subsection discusses various regression diagnostics for the CFM and the SSM. The effects of treatment and control variables are discussed in the next two subsections, respectively.

In the first stages of the CFM, "Group membership" proves to be a relevant instrument for BP training, both in the tree cultivation (p = 0.002) and seed collection (p = 0.004) equation. Full estimation results of these first stage regressions are given in Table A.2. In the second stages, the coefficient of the first stage residuals is insignificant for tree cultivation (Table 6) but significant at 5% with bootstrapped p-values for seed collection (Table 7). This indicates that self-selection bias is likely present in the seed collection equation but not in the tree cultivation equation. Consequently, the adoption of tree cultivation is discussed based on the LPM-FE estimates, and seed collection based on the CFM estimates.

In the SSM (Table 8), "Trees in 2007" and "Natural tree occurrence" prove to be suitable selection variables, as they are significant in the selection equation but not in the structural equation (p = 0.138 and p = 0.832, respectively). "Amount of parcels" is unsuitable, as it is insignificant in both equations. More importantly, the null hypothesis that there is no correlation between the errors, is not rejected (p = 0.839). In other words, the estimation results indicate that sample selection bias is not present. Therefore, the seed collection equation could be independently estimated on the subsample of 141 households with mature trees. This would avoid some of the strong assumptions of the SSM and the complications to simultaneously account for treatment variable endogeneity (Wooldridge, 2010). Nevertheless, estimating it on the full sample of 390 households while including "Mature trees" as a regressor (Table 7), is preferred because of increased statistical power.

Table 6. Estimates for tree cultivation adoption (Y_t): baseline model (LPM), village fixed effects model (LPM-FE) and 2nd stage of the control function model using group membership as instrument (CFM).

	LPM				**LPM - FE**				**CFM – 2nd stage**			
	β	(SE)	p	p-btrap	β	(SE)	p	p-btrap	β	(SE)	p	p-btrap
Gender of HH head (1 = male)	-0.067	(0.055)	0.226	0.255	-0.017	(0.059)	0.773	0.772	-0.018	(0.059)	0.760	0.759
Age of HH head (years)	-0.001	(0.002)	0.576	0.590	0.000	(0.002)	0.979	0.979	0.000	(0.002)	0.997	0.997
Education of HH head	**0.105**	**(0.042)**	**0.013**	**0.019**	**0.114**	**(0.040)**	**0.005**	**0.009**	**0.113**	**(0.040)**	**0.005**	**0.012**
Number of HH dependents	0.005	(0.026)	0.841	0.837	0.004	(0.026)	0.882	0.887	0.000	(0.030)	0.997	0.997
(Number of HH dependents)^2	0.002	(0.004)	0.536	0.528	0.002	(0.004)	0.599	0.603	0.003	(0.005)	0.554	0.567
Number of HH labourers	0.061	(0.063)	0.334	0.388	0.108	(0.066)	0.104	0.135	0.106	(0.066)	0.110	0.154
(Number of HH labourers)^2	-0.009	(0.010)	0.325	0.413	-0.016	(0.010)	0.115	0.194	-0.016	(0.010)	0.115	0.197
Exploited land (10^{-1} acres)	-0.009	(0.100)	0.927	0.921	0.046	(0.104)	0.661	0.608	0.047	(0.105)	0.652	0.603
(Exploited land)^2 (10^{-1} acres)^2	-0.004	(0.027)	0.894	0.886	-0.022	(0.029)	0.450	0.389	-0.025	(0.031)	0.430	0.430
Tropical livestock units	**0.063**	**(0.025)**	**0.012**	**0.014**	**0.070**	**(0.024)**	**0.004**	**0.003**	**0.067**	**(0.027)**	**0.013**	**0.016**
(Tropical livestock units)^2	**-0.007**	**(0.003)**	**0.032**	**0.072**	**-0.008**	**(0.003)**	**0.015**	**0.088**	**-0.008**	**(0.004)**	**0.083**	**0.099**
Assets and living standards index	**-0.016**	**(0.008)**	**0.049**	**0.075**	-0.014	(0.009)	0.115	0.119	-0.015	(0.009)	0.110	0.129
Natural tree occurrence (1 = yes)	**0.265**	**(0.051)**	**0.000**	**0.000**	**0.286**	**(0.047)**	**0.000**	**0.000**	**0.291**	**(0.052)**	**0.000**	**0.000**
Amount of parcels	**0.034**	**(0.014)**	**0.015**	**0.027**	**0.037**	**(0.015)**	**0.015**	**0.022**	**0.035**	**(0.019)**	**0.066**	**0.090**
Trees in 2007 (1 = yes)	**0.449**	**(0.063)**	**0.000**	**0.000**	**0.403**	**(0.052)**	**0.000**	**0.000**	**0.399**	**(0.055)**	**0.000**	**0.000**
BP training (1 = yes)	**0.218**	**(0.087)**	**0.012**	0.167	**0.228**	**(0.087)**	**0.009**	**0.099**	0.311	(0.323)	0.337	0.453
Trees in 2007*BP training	**-0.295**	**(0.109)**	**0.007**	**0.096**	**-0.322**	**(0.103)**	**0.002**	**0.037**	**-0.322**	**(0.104)**	**0.002**	**0.036**
BP association (1 = yes)	-0.004	(0.065)	0.955	0.968								
Trees in 2007*BP association	0.075	(0.079)	0.344	0.350								
BP expeller (1 = yes)	**0.157**	**(0.091)**	**0.086**	0.231								
Trees in 2007*BP expeller	-0.154	(0.101)	0.131	0.191								
1st stage residuals									-0.085	(0.313)	0.785	0.835
Constant	0.075	(0.130)	0.565	0.602	0.004	(0.151)	0.978	0.976	0.017	(0.152)	0.912	0.915
Cluster fixed effects	(Hobli fixed effects)				(Village fixed effects)				(Village fixed effects)			
R^2	0.569				0.631				0.631			
Amount of observations	390				390				390			

Table 7. Estimates for seed collection adoption (Y_s): baseline model (LPM), village fixed effects model (LPM-FE) and 2nd stage of the control function model using group membership as instrument (CFM).

	LPM				**LPM - FE**				**CFM – 2nd stage**			
	β	(SE)	p	p-btrap	β	(SE)	p	p-btrap	β	(SE)	p	p-btrap
Gender of HH head (1 = male)	-0.038	(0.050)	0.450	0.409	-0.016	(0.054)	0.765	0.748	-0.009	(0.054)	0.871	0.862
Age of HH head (years)	0.000	(0.001)	0.896	0.899	0.000	(0.002)	0.936	0.927	0.000	(0.002)	0.927	0.919
Education of HH head	-0.046	(0.035)	0.189	0.129	-0.049	(0.041)	0.237	0.143	-0.045	(0.041)	0.279	0.181
Number of HH dependents	-0.033	(0.022)	0.136	0.137	-0.022	(0.026)	0.402	0.439	-0.001	(0.028)	0.981	0.981
(Number of HH dependents)²	0.004	(0.004)	0.342	0.393	0.003	(0.004)	0.501	0.567	-0.001	(0.005)	0.804	0.813
Number of HH labourers	**-0.102**	**(0.055)**	**0.063**	**0.099**	-0.075	(0.063)	0.233	0.248	-0.065	(0.062)	0.299	0.308
(Number of HH labourers)²	0.013	(0.008)	0.112	0.104	0.010	(0.009)	0.302	0.278	0.009	(0.009)	0.316	0.291
Exploited land (10^{-1} acres)	0.005	(0.094)	0.961	0.963	-0.048	(0.098)	0.623	0.660	-0.064	(0.099)	0.522	0.564
(Exploited land)² (10^{-1} acres)^2	-0.025	(0.027)	0.358	0.392	-0.011	(0.029)	0.709	0.732	0.005	(0.030)	0.855	0.860
Tropical livestock units	0.020	(0.017)	0.227	0.287	0.017	(0.018)	0.351	0.361	0.028	(0.019)	0.147	0.143
(Tropical livestock units)²	-0.002	(0.002)	0.154	0.207	-0.002	(0.002)	0.271	0.228	**-0.006**	**(0.003)**	**0.050**	**0.062**
Assets and living standards index	**-0.026**	**(0.008)**	**0.002**	**0.006**	**-0.022**	**(0.009)**	**0.014**	**0.010**	**-0.018**	**(0.010)**	**0.062**	**0.039**
Natural tree occurrence (1 = yes)	-0.018	(0.033)	0.589	0.527	-0.044	(0.036)	0.218	0.142	**-0.071**	**(0.039)**	**0.074**	**0.041**
Amount of parcels	0.012	(0.015)	0.422	0.566	0.009	(0.017)	0.586	0.700	0.025	(0.019)	0.180	0.321
Mature trees (1 = yes)	**0.348**	**(0.068)**	**0.000**	**0.002**	**0.287**	**(0.053)**	**0.000**	**0.000**	**0.325**	**(0.057)**	**0.000**	**0.000**
BP training (1 = yes)	-0.042	(0.027)	0.115	0.103	-0.035	(0.039)	0.362	0.210	**-0.483**	**(0.286)**	**0.093**	**0.026**
Mature trees*BP training	**0.231**	**(0.104)**	**0.027**	**0.092**	**0.174**	**(0.095)**	**0.068**	0.156	**0.173**	**(0.095)**	**0.069**	0.154
BP association (1 = yes)	**-0.036**	**(0.020)**	**0.079**	0.120								
Mature trees*BP association	**-0.202**	**(0.085)**	**0.018**	**0.020**								
BP expeller (1 = yes)	0.029	(0.037)	0.438	0.399								
Mature trees*BP expeller	0.061	(0.100)	0.545	0.405								
1st stage residuals									**0.460**	**(0.285)**	0.108	**0.035**
Constant	0.210	(0.134)	0.117	0.178	0.181	(0.157)	0.249	0.251	0.120	(0.157)	0.445	0.427
Cluster fixed effects	(Hobli fixed effects)				(Village fixed effects)				(Village fixed effects)			
R^2	0.301				0.338				0.342			
Amount of observations	390				390				390			

Table 8. Estimates for the sample selection model (SSM), with tree maturity (Y_m) as selection equation, and oilseed collection (Y_s) as structural equation.

	Selection equation – Tree maturity			**Structural equation – Seed collection**		
	β	(SE)	p	β	(SE)	p
Gender of HH head (1 = male)	-0.375	(0.231)	0.104	-0.110	(0.135)	0.415
Age of HH head (years)	0.010	(0.008)	0.210	-0.001	(0.003)	0.732
Education of HH head	0.304	(0.227)	0.180	**-0.166**	**(0.083)**	**0.045**
Number of HH dependents	0.147	(0.139)	0.288	-0.033	(0.050)	0.503
(Number of HH dependents)²	-0.014	(0.020)	0.481	0.003	(0.008)	0.685
Number of HH labourers	0.170	(0.345)	0.623	-0.163	(0.121)	0.178
(Number of HH labourers)²	-0.027	(0.053)	0.612	0.028	(0.019)	0.134
Exploited land (10^{-1} acres)	0.494	(0.733)	0.501	-0.042	(0.172)	0.808
(Exploited land)² (10^{-1} acres)^2	0.016	(0.241)	0.947	0.024	(0.045)	0.601
Tropical livestock units	**0.320**	**(0.145)**	**0.027**	**0.131**	**(0.059)**	**0.027**
(Tropical livestock units)²	**-0.056**	**(0.019)**	**0.003**	**-0.025**	**(0.011)**	**0.022**
Assets and living standards index	-0.002	(0.047)	0.961	**-0.053**	**(0.016)**	**0.001**
Natural tree occurrence (1 = yes)	**0.409**	**(0.228)**	**0.073**			
Amount of parcels	-0.076	(0.097)	0.435			
Trees in 2007 (1 = yes)	**2.627**	**(0.221)**	**0.000**			
BP training (1 = yes)	0.356	(0.256)	0.163	**0.150**	**(0.084)**	**0.075**
Constant	**-3.169**	**(0.740)**	**0.000**	**0.665**	**(0.269)**	**0.013**
Cluster fixed effects		(not included)			(not included)	
Amount of observations		390			141	

Finally, robust and bootstrapped p-values indicate the same variables to be significant – with exception of some treatment-related variables – and generally only differ to some extent in terms of the corresponding significance levels. Therefore, they will only be explicitly distinguished in case their implications differ substantially.

3.2. Treatment effects

The effects of BP association and BP expeller are only estimated in the baseline models (Tables 6 & 7). BP association does not significantly influence tree cultivation, while it has a negative effect (significant at 10% with robust p-values) on seed collection adoption. This negative effect is strongest for households with mature trees. On the contrary, BP expeller does not significantly influence seed collection, while it has a positive effect (significant at 10% with robust p-values) on tree cultivation for households without trees in 2007. Even though there is a high probability of simultaneity bias in these baseline models, of which the direction is difficult to predict due to correlation among regressors (Wooldridge, 2012), these findings suggest that advanced BP interventions only have a marginal to no impact on adoption. These findings are in line with the statistics in Section 2.3, showing that BP associations are widely non-functional and BP expellers hardly used.

The effect of BP training also differs for tree cultivation and seed collection adoption. First, the LPM estimates reveal significant effects of tree ownership in 2007, BP training and their interaction on tree cultivation (Table 6). As hypothesized, for households without trees in 2007, BP training significantly increases the probability of having trees today (significant at 5% with robust p-values), whereas for households that already had trees in 2007, BP training has no significant effect on that probability[11]. These findings are even more strongly supported by the LPM-FE model[12]. Second, the LPM indicates BP training also has a significant positive effect on seed collection, as hypothesized only for households with mature trees[13] (Table 7). However, when taking self-selection into account as advised by the diagnostics in Section 3.1, the CFM shows that BP training even has a negative effect, although it is only significant for households without mature trees[14]. As expected the estimate of the SSM is in line with the LPM (Table 8), as both models

[11] Main + interaction effect: -0.078. p = 0.216; p-btrap = 0.207.
[12] For households that already had trees in 2007, main + interaction effect: -0.094. p = 0.144; p-btrap = 0.127.
[13] Main + interaction effect: 0.189. p = 0.059; p-btrap = 0.127.
[14] For households with mature trees, main + interaction effect: -0.310. p = 0.280; p-btrap: 0.118.

ignore potential endogeneity. More specifically, it also suggests a significant positive effect of BP training on seed collection probability, for households with mature trees.

3.3. Control variables

Several control variables drive adoption of tree cultivation and seed collection. Household head schooling has a positive effect on tree cultivation (Table 6), which could stem from better insights into the benefits of agroforestry-based innovations[15] and increased ability to realize them (Pattanayak et al., 2003). Yet, education has a negative effect in the SSM (Table 8), which likely relates to the labour intensity of seed collection and an increased opportunity cost of labour for better educated households. The positive but decreasing effect of livestock on tree cultivation (Table 6) as well as on seed collection in the SSM (Table 8) could relate to the fact that trees provide shade, hedging and fodder, as well as to the finding that households with more livestock depend more on farming as an income source. Asset ownership decreases the probability of tree cultivation (the effect is only significant in the LPM, Table 6) and the probability of seed collection (Table 7). The finding that wealthier households are less likely to cultivate trees and in particular to collect seeds, probably relates to their higher opportunity costs of land, capital and especially labour (see further in Section 3.4). It suggests that oilseed collection still remains at best a secondary farm activity with limited profitability.

The control variables that were added to optimally estimate BP treatment effects, have main effects as hypothesized in section 2.4.1: tree ownership in 2007 (Table 6) and current tree maturity (Table 7) indeed positively influence probabilities of tree cultivation and seed collection, respectively. Natural tree occurrence and, to a lesser extent, amount of parcels also positively influence tree cultivation, as they increase the probability of natural tree presence. Finally, in the CFM, natural tree occurrence has a negative effect on seed collection (Table 7). This may be surprising at first sight but it should be re-emphasized that tree presence is already controlled for through “Mature trees”. Under this condition, wild mature trees are more likely maintained for their multiple uses and co-benefits instead of for seed collection, than planted mature trees[16].

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[15] There are indeed positive correlations between the education indicator and various measures of knowledge of ecosystem services (cfr. Table 3), ranging between 0.18 and 0.20.

[16] Note that this argues against the use of “Natural tree occurrence” as a selection variable in the SSM, although it is insignificant in the structural equation of the model itself, see Section 3.1.

3.4. Stated reasons for (not) adopting

Respondent answers to the open-ended question on why they are willing, or not willing, to plant trees, shed further light on the findings above (Table 9). Even though the BP approach targets underutilized lands and involves minimal management practices, most stated reasons for non-willingness to plant biofuel trees relate to costs outweighing benefits or high opportunity costs: 16% of households not willing to plant state the income or profits are too low, and 38% indicate a high opportunity cost, of land (19% "Lack of land"), labour (13% "No time/ too busy" and 1% "High labour wages"), or water (6% "Lack of water"). A general and not further specified disinterest is reported by 32% of households. Other substantial reasons include non-suitability of particular species in particular areas, as well as lack of knowledge on biofuel trees. On the other hand, households' willingness to plant biofuel trees is generally related to the various uses and co-benefits the trees offer (64%) and to diversifying income sources (38%). Some households indicate that a lack of planting material is withholding them from planting.

Table 10 lists reasons why households do not collect seeds (open-ended question). Lack of profitability clearly proves to be the fundamental reason. Among those who have mature trees, 12% mentions this explicitly, while 59% specifies high labour costs and 30% describes it more generally stating they are not interested. These are also principal reasons when considering the entire subsample of non-collecting households. Although half of them states lack of mature trees as a key reason, it remains to be seen whether the presence of mature trees can effectively induce collection, as currently this only happens for one out of three farmers (Table 2). Other substantial reasons include lack of market or market information, and lack of knowledge on biofuel trees.

Table 9. Reasons stated for being willing or not willing to plant trees.

Reasons for **not being willing** to plant trees	Rate	Reasons for **being willing** to plant trees	Rate
Not interested / Not important	0.32	Various uses & co-benefits (see Table 3)	0.64
Lack of land	0.19	Additional / Diversified income	0.38
Not profitable or competitive No (or marginal) income No (or few) uses or benefits	0.16	Willing, but lack of planting material	0.08
No time / Too busy	0.13	Minimal inputs required	0.03
Not suited to the region	0.11		
Lack of knowledge	0.08		
Lack of water	0.06		
Planted but died	0.05		
Risk (no immediate or assured profits)	0.03		
Competition with crops	0.02		
High labour wages	0.01		
Number of households[a]	201	Number of households[b]	148

[a] This includes households that stated for at least one biofuel species – among those they did not have – they are not willing to plant it.
[b] This includes households that stated for at least one biofuel species – among those they did not have – they are willing to plant it.

Table 10. Reasons stated for not collecting seeds.

Reasons for …	… not collecting from any mature trees - Rates	... not collecting from any species - Rates
No (mature) trees	-	0.50
No time / Too busy Too laborious High labour wages	0.59	0.38
Not interested / Not important	0.30	0.26
Not profitable or competitive No (or marginal) income No (or few) uses or benefits Low prices	0.12	0.08
Lack of market or market information	0.10	0.02
Lack of knowledge	0.08	0.06
Seeds gone to waste, or collected/stolen by others	0.08	0.02
Low yield/few trees	0.04	0.01
Tree has other uses	0.02	0.01
Number of households	93	328

4. Discussion

The results show that while the majority of households cultivate oilseed trees, seed collection rates are generally low. In addition, BP activities stimulate cultivation, but not collection. Furthermore, there is minimal oil expeller use and seed selling to the BP. Therefore, it could be stated that the Biofuel Program is succeeding as an agroforestry program, but not as a biofuel program. Profitability proves to be the key limiting factor to adoption, in particular for seed collection and processing. This implies that new agroforestry-based biofuel systems face the same constraints and challenges as earlier biofuel programs based on jatropha plantations (Ariza-Montobbio and Lele, 2010; Kumar et al., 2012; Soto et al., 2015; van Eijck et al., 2014). Profitability is likely compromised from both supply and demand sides.

From the supply side, it is clear that adoption of these practices inevitably involves opportunity costs of land, labour and capital (also see Baka and Bailis (2014), Borman et al. (2013), Faße et al. (2014), Findlater and Kandlikar (2011)). This is also confirmed by focus group discussions held prior to the survey, and described in the qualitative assessments of the BP by de Hoop et al. (2016) and de Hoop (2017). First, even so-called "underutilized" lands have value, perhaps most obviously as a place to grow other useful trees[17]. Second, even though tree management practices are very limited, seed collection is labour intensive, in particular for species with small seeds such as neem. Low returns to labour can jeopardize biofuel value chain development, especially in areas where labour shortage is more common than employment shortage. The results challenge the widely used argument of biofuel value chain development being a valid rural employment strategy. Third, vitality of young trees in particular is threatened by drought, and seedling survival is usually low without irrigation (BP data; de Hoop, 2017; Narayanaswamy, 2009), but water is often a scarce resource serving many purposes within the household. These opportunity costs may still be limited for tree cultivation, and especially if extension is supplemented with free distribution of superior seedlings, households might plant biofuel trees. In addition, households likely often bear with these costs as the trees offer multiple uses and co-benefits, among which seed oil use as a liquid fuel is remarkably only ranked eighth (Table 3). This may induce households to cultivate trees as a potential future income source and hence as a risk-coping strategy, which contrasts with the

[17] As an example, some respondents mention they prefer other trees, such as silver oak (*Grevillea robusta*), teak (*Tectona grandis*) and various fruit trees, over biofuel trees.

common notion of perennial-based systems as long-term investments with revenue lags and associated risks (Alexander et al., 2012; Khanna et al., 2017; Kumar et al., 2012). The agroforestry approach effectively combines low inputs and risks with increased diversity and resilience (Tilman et al., 2006), which stimulates its adoption (Pattanayak et al., 2003). de Hoop (2017) similarly observes that most farmers have some space available to plant a couple of free seedlings for experimentation and diversification. However, with respect to the program's biofuel component, adoption of seed collection is strongly constrained by too high opportunity costs of labour. It should be noted though that this constraint might apply less to landless farmers, and that including them in the survey might increase seed collection rates to some extent. Processing rates of the distributed small-scale oil expellers are also low, thereby limiting profitability of decentralised value addition and local consumption. Due to these barriers, the BP has not succeeded in changing seed collection behaviour of local farmers, as also highlighted by de Hoop (2017).

From the demand side, low seed prices limit the profitability of seed collection. Even though real oilseed prices have risen by 10% to 40% from 2010 to 2015, and tripled from 2005 to 2015[18], this has not led to an equally large rise in adoption figures: since 2007 tree cultivation has increased from 43% to 60%, and seed collection from 6% to 13%[19]. Fossil fuel prices remain very volatile and have experienced steep falls in recent years (IEA, 2017; Tuli and Gupta, 2017). In absence of fiscal support, this creates downward pressure on oilseed prices in biofuel value chains (Kumar et al., 2012; Pohit and Biswas, 2017). With low seed prices, seed collection is mainly practiced by less-endowed households. Furthermore, even for collecting households it generally remains a low-ranking activity with very limited revenues: annual amounts and revenues are below 100 kg and 2000 INR[20], respectively, for the majority of households. This strongly restricts the scale at which potential biofuel value chains can operate. While low collection amounts mainly result from the fact that current on-farm feedstock production is still limited, it remains to be seen whether substantial feedstock increases proportionally stimulate collection rates and hence value chain upscaling. In the end, while the BP has distributed tree seedlings district-wide and stimulated biofuel tree cultivation, it has not succeeded in establishing a viable market. This is illustrated by

[18] Based on nominal pongamia seed prices reported in the survey and registered by the BP, and inflation rates reported by CSO (2018) and OEA (2018).
[19] Based on recall data.
[20] This only includes annual collection amounts and revenues from own mature trees. Few households also collect from other trees but there are no corresponding data. INR = Indian National Rupee. 1 EUR = 74.2 INR in August 2015.

the fact that almost all seed-collecting households sell to other buyers (see also de Hoop (2017)), and by other households' statements that lack of markets and market information form a barrier to adoption. The biofuel value chain remains largely underdeveloped and one cannot reasonably expect feedstock supply to expand, if feedstock demand is not simultaneously developed (Achten et al., 2014; Shinoj et al., 2010).

Apart from low profitability, other reasons may further explain limited BP impact. First, BP implementation may not have been intensive enough to effectively stimulate adoption (also see Basinger et al. (2012) and Glendinning et al. (2001)). In an effort to cover as many villages as possible with limited resources, the BP inevitably implemented only one or few activities in most of them, and these might have taken place years ago. Not only does this further contribute to lack of markets and marketing information, it also explains why several households mention a lack of knowledge and of planting material, as well as unawareness about training sessions, even in non-control villages. Furthermore, it could explain why advanced BP activities have barely to no impact. Lack of continued on-site support and promotion has led to biofuel cooperatives that are widely non-functional and probably simply not operational (anymore), and further explains why barely any seeds are sold to the BP or locally processed. Therefore, it may be preferable for the BP to refrain from a strategy of reaching as many villages as possible, to intensify activities in village clusters for specifically targeted farmers. Second, the fact that expeller distribution does not promote seed collection, while it does stimulate tree cultivation, may result from particular program features and strategic behaviour. With respect to tree cultivation, expeller villages usually had more planting program occasions than other villages, which allowed more opportunities for households to acquire seedlings. With respect to seed collection, de Hoop et al. (2016) point out that farmers' expressed interest in the BP as a means to increase their social status, knowledge and financial access, not because of a genuine intent to engage in the biofuel value chain. Showing interest could lead to receiving an expeller, which they similarly did not intend to use right away – as also revealed by this study. Interest in expellers was rather driven by curiosity, pride and potential future benefits (de Hoop et al., 2016). Third, whereas many respondents mentioned low profitability as primary adoption barrier (Table 10), more complex or sensitive reasons might remain unstated.

In the long run, on-farm feedstock will likely build up as trees are increasingly adopted and maturing. This is further substantiated by evidence of limited tree cutting, although the opposite is reported by de Hoop (2017), indicating that tree cutting dynamics should be further investigated. Yet, strengthening or redesigning the biofuel value chain (Dalemans et al., 2018), as well as favourable evolutions of relevant economic parameters and policies, fuel pricing in particular, will be of vital importance to increase the economic viability of seed collection, and to validate program continuation (de Hoop et al., 2016). The findings in this paper show one must acknowledge that even in small-scale, low-input systems, opportunity costs of land, labour and capital play a crucial role. Profitability studies that explicitly ignore these costs, such as the one on the BP by Bohra et al. (2016), may therefore strongly overestimate the potential of these systems. Better insights into current and future profitability – under various scenarios – are required to understand the long-term potential of the Biofuel Program in Hassan district India in particular, and of agroforestry-based biofuel systems in general.

5. Conclusion

This study provides empirical evidence on farmer adoption of agroforestry-based biofuel systems. For a case study in Hassan district, India, farmer perception and adoption rates are described, and the roles of a biofuel extension program and farm characteristics are quantified through various econometric models.

The data reveal that while 60% of farmers cultivate oilseed trees, oilseed collection is substantially less practiced, as two out of three farmers with mature trees do not collect seeds. The determinants driving adoption of tree cultivation differ from those driving adoption of seed collection. Not only is tree cultivation much more prevalent than seed collection, the activities of the biofuel extension program only stimulate the former. The program succeeds as an agroforestry program, which is likely driven by rather limited opportunity costs, free seedling distribution programs, and farmers' valuation of oilseed trees' multiple uses and co-benefits. However, the program does not succeed as a biofuel program, because of high opportunity costs of labour, low oilseed prices and a poorly developed value chain, resulting in poor profitability.

This study shows that despite their well-considered rationale, agroforestry-based biofuel programs also have to overcome several barriers. Profitable biofuel value chains can only be developed if these programs intensively address both supply and demand sides. Although they were partly developed as a response to the failure of jatropha monocultures, these programs face the same principal pitfalls. Consequently, they should be promoted very carefully, conditional on rigorous and comprehensive evaluations. Further research is warranted to clarify under which conditions, if any, these systems can be environmentally beneficial, economically viable and socially inclusive, and consequently part of a diversified set of innovations towards sustainable rural development. Nevertheless, this study proves one clear advantage of the agroforestry approach based on native species. Despite the current lack of biofuel profitability, the approach involves low risk and offers multiple ecosystem services, in contrast to jatropha monocultures (Ariza-Montobbio and Lele, 2010; Borman et al., 2013). As a result, on-farm biofuel feedstock is being built up in the region. This will enable biofuel value chains to quickly develop in case market conditions and policies do get opportune.

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8. Supplementary materials

Table A.1. Adoption rates for the individual oilseed tree species in the sample.

	Pongamia	Neem	Mahua	Simarouba	Jatropha	Overall
Adoption rates						
Tree cultivation	0.41	0.38	0.05	0.01	0.09	0.60
Tree maturity	0.25	0.19	0.03	0.00	0.02	0.36
Seed collection, unconditional on tree maturity	0.11	0.03	0.01	0.00	0.00	0.13
Seed collection, conditional on tree maturity	0.37	0.15	0.25	0.00	0.10	0.31
Tree cultivation in 2007	0.29	0.24	0.03	0.00	0.02	0.43

Table A.2. Estimates for the first stage regressions – with BP training as dependent variable – of the control function models.

	Tree cultivation				**Seed collection**			
	β	(SE)	p	p-btrap	β	(SE)	p	p-btrap
Gender of HH head (1 = male)	0.000	(0.049)	0.992	0.990	0.004	(0.049)	0.941	0.922
Age of HH head (years)	0.000	(0.002)	0.969	0.978	0.000	(0.002)	0.970	0.978
Education of HH head	0.010	(0.045)	0.822	0.822	0.007	(0.045)	0.880	0.883
Number of HH dependents	**0.046**	**(0.028)**	**0.095**	**0.032**	**0.045**	**(0.027)**	0.101	**0.034**
(Number of HH dependents)²	**-0.010**	**(0.004)**	**0.029**	**0.012**	**-0.009**	**(0.004)**	**0.031**	**0.011**
Number of HH labourers	0.029	(0.072)	0.691	0.638	0.027	(0.071)	0.704	0.649
(Number of HH labourers)²	-0.002	(0.011)	0.885	0.866	-0.001	(0.011)	0.894	0.875
Exploited land (10^{-1} acres)	0.004	(0.109)	0.973	0.975	-0.008	(0.110)	0.941	0.942
(Exploited land)² (10^{-1} acres)^2	0.022	(0.032)	0.492	0.609	0.022	(0.032)	0.481	0.592
Amount of tropical livestock units	0.023	(0.025)	0.360	0.443	0.019	(0.025)	0.443	0.523
(Amount of tropical livestock units)²	**-0.007**	**(0.003)**	**0.037**	**0.095**	**-0.006**	**(0.003)**	**0.063**	0.102
Assets and living standards index	0.007	(0.010)	0.509	0.544	0.007	(0.010)	0.491	0.528
Natural tree occurrence (1 = yes)	-0.057	(0.038)	0.139	0.114	-0.059	(0.038)	0.120	**0.090**
Amount of parcels	**0.034**	**(0.020)**	**0.092**	**0.093**	**0.035**	**(0.020)**	**0.075**	**0.084**
Trees in 2007 (1 = yes)	0.050	(0.049)	0.312	0.440				
Mature trees (1 = yes)					0.071	(0.047)	0.135	0.201
Group membership	**0.313**	**(0.102)**	**0.002**	**0.009**	**0.303**	**(0.103)**	**0.004**	**0.011**
Constant	-0.202	(0.154)	0.189	0.177	-0.187	(0.154)	0.224	0.221
Cluster fixed effects	(Village fixed effects)				(Village fixed effects)			
R^2	0.364				0.366			
Amount of observations	390				390			