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Dayakar Peddi[1], B. Suresh Reddy[2] and E. Revathi[3]

Abstract

The study examines the causal impact of adopting alternative rainfed agricultural systems on farm profits using a household survey of around 1100 farmers in Telangana, India. The study uses multinomial endogenous switching regression (MESR) model to assess the impact of alternative agricultural crop systems (i.e., conventional vs. millets) on agricultural performance while controlling for socio-economic, market, plot level, and village level characteristics. The result shows that the decision to adopt alternative crop choices is significantly affected by soil type, access to irrigation, social category, plot ownership, livestock and household income, distance from dwelling and access to road in study villages. The results of the model highlight that the institutional interventions played positive role in millet-based agriculture system practices and found that the estimated average treatment effect on treated (ATT) value of farm profit is significantly higher for farmers who received institutional interventions from DDS in the study area compared to who did not receive such interventions. Further, the results of the study indicate the potential of institutional support for the millet based agricultural system in rainfed areas of the country.

Keywords: Agricultural Systems, Causal Inference, SDG, India
JEL Classification: C83, D12, Q12, F61, O13

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Authors

1. Introduction

Farmers make their crop choices that maximize their profit. Crop choices are influenced by several other factors, including availability of seed, labor, climatic conditions, monsoon behavior, and access to irrigation, farmer experience, and soil characteristics (Pope, R. D., & Prescott, R. 1980: Kurukulasuriya, P., & Mendelsohn, 2007; Wang *et al.,* 2010; Rashid F.M., 2021). Empirical literature highlights that the Government policies or institutional factors also play a pivotal role via input and market prices (especially, minimum support prices) (Pingili *et al.,* 2017). In India, post green revolution, the Government agricultural policies are biased towards staple crops that inadvertently resulted in crowding out many crops including oilseeds, pulses, and minor cereals (Pingali, 2012; Ramaswami, B., & Murugkar, M, 2016; Pingili *et al.,* 2017). Moreover, these crops have been neglected by farmers over decades due to lack of technical advancement, access to market and price policies in the country (Pingili *et al.,* 2017). In this context it is pertinent to ask if institutional factors really matter for crop choice and farm profit? In the present analysis, we try to answer these questions regarding millet crops using cross sectional data collected through primary survey instruments in Sangareddy district of Telangana state in India.

Climate change is a major threat to agriculture and is expected to pose more challenges especially in rain fed areas (Birthal *et al.,* 2015). Further, estimations are projected that major cereals (i.e., rice and wheat) are more sensitive to climate change in future than minor cereals (i.e., sorghum and millets) (Birthal *et al.,* 2015; Barnwal & Kotani, 2013; Gupta *et al.,* 2014), leading to food supply imbalance and rising hunger and malnourishment (Saxena *et al.,* 2018). Tackling the dual problem of food and nutrition security is the biggest challenge to the policy makers in the present and future world, especially in the context of developing countries. However, scientific communities believe that minor cereals can play a major role in rainfed dominated areas of developing countries located in Sub-Saharan Africa and South Asian regions to mitigate hunger and nutritional security given climate projections (Padulosi *et al.,* 2015). Further, traditionally rainfed agriculture systems (especially, millet) adopt more diversified crops than conventional agriculture (i.e., maize, paddy, and cotton) systems. Empirical works pointed out that the livestock integration into agriculture is crucial in soil fertility management and farm production. Reddy (2009) emphasized that quantity and quality of livestock influences the soil fertility directly and indirectly.

There is a notion that conventional[4] or chemical agricultural cultivation offers a higher farm revenue than millet based agricultural farm cultivation. Therefore, farmers tend to shift towards conventional agricultural practices. But, development and access to technology for millet-based agricultural practices also have a potential to transform agriculture in rain fed areas in India. A large body of empirical literature on millet based cropping systems focused on the interlinkages between farm profit and climate change scenarios (Seo S. N., & R. Mendelsohn, 2008; Bezabih, M., & Di Falco, S. 2012), access to credit (Rashid F.M., 2021), crop insurance (Yu, J., & Sumner, D. A., 2018), plot-level characteristics, and socioeconomic characteristics of farmers (Pope, R. D., & Prescott, R. 1980; Nguyen *et al.*, 2017). Empirical works did not pay significant attention to the role of institutional support and its causal inference on farm profit at the ground level, for millet based cropping systems in rain fed agriculture in India. Therefore, the present study attempts to analyze the role of institutional support for crop profit in rainfed regions taking the case of Telangana State in India. The rest of the paper is organized as follows: Section 2 discusses the cropping pattern in Telangana State. The analytical framework and empirical strategies are provided in Section 3. Data and descriptive statistics are presented in Section 4, while estimated results and discussion are presented in Section 5. The final section outlines the study conclusions and policy implications.

2. Agricultural Practices in Telangana, India

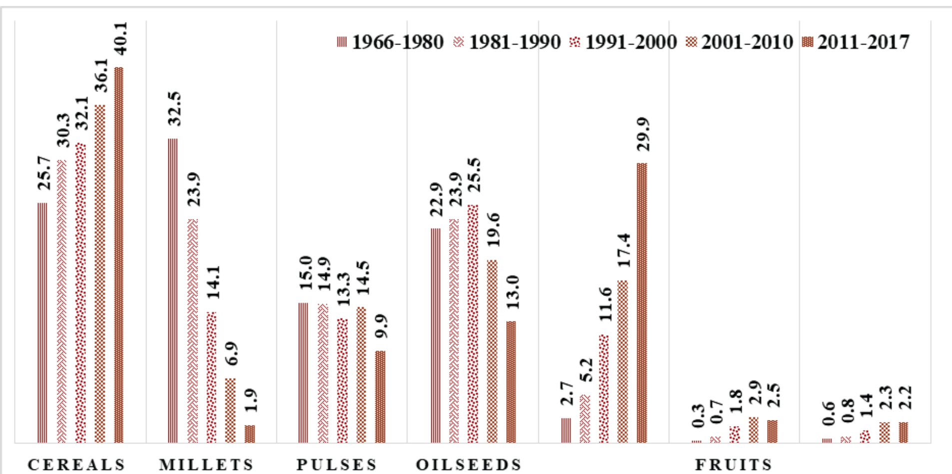
The data on agriculture cropping patterns and trends over a long period indicate that farmers in Telangana[5] tend to move towards conventional and mono-cropping across the state except for some patches of rain-fed regions in the state. Major cereals (i.e., paddy, maize, and wheat), minor cereals (i.e., sorghum, finger millet, pearl millet and small millets), pulses (i.e., chickpea, pigeon pea, minor pulses), oil seeds (i.e., groundnut, sesamum, rapeseed, safflower, castor, linseed, sunflower, soybean), commercial crops (i.e., cotton and sugarcane), fruits and vegetables are the dominant crops, covering more than 90 percent of the total cultivated area in Telangana (ICRISAT-TCI, 2017). However, the area under the major cereals, commercial crops, fruits, and vegetable crops significantly increased from 1966 to 2017 (ICRISAT-TCI, 2017), while the area

4 Conventional agricultural practices are defined as those related to cultivating mainstream crops like paddy, maize, cotton, and sugarcane, chilli based on intensive use of agro-chemicals to maximise agricultural production

5 Telangana state is carved out of undivided state of Andhra Pradesh on 2nd June 2014. It is located in southern part of India, and it is 11th largest state in India in terms of area.

under pulses, and oilseeds has significantly declined during the same period. Major cereals, commercial crops, fruits, and vegetables area in cultivation has increased from 141, 15, 2, and 3 thousand hectares in 1966-1980 to 256, 193, 15, and 11 thousand hectares in 2011-2017 periods respectively. In contrast the area under millets, pulses, and oilseeds decreased from 203, 86, and 161 thousand hectares in 1966-1980 to 12, 63, and 93 thousand hectares, respectively during the same period. However, the area under oilseeds increased from 1966-1990 to 1991-2000 and declined continuously thereafter. In terms of percentages (i.e., in area cultivated to the total cultivated area), area under cereals, commercial crops, fruits and vegetables has increased from 25.7%, 2.7%, 0.3% and 0.6% of total cultivated area in 1966-1980 to 40.1%, 29.9%, 2.5% and 2.2% in 2011-17 respectively. Data reveals that the growth in area of major cereals and commercial crops has significantly increased compared to other crops. However, growth in the area under millets, pulses and oilseeds crops has declined over the same period.

Figure 1: Crop wise Area Cultivation in Telangana during 1966-2017 Period (in % of Total Cropped Area)



Source: Data extracted from ICRISAT-TCI

2.1. The Deccan Development Society Interventions in Rainfed Agriculture Systems

The Deccan Development Society (DDS) has been playing a significant role among farming communities (i.e., millet based agricultural systems) of Sangareddy District in Telangana State. The DDS is a three and half decade old grassroots organisation (i.e., non-government organisation) working in about 75 villages with women's groups called Sanghams (village level associations of the poor) in Sangareddy District of Telangana, India. The 5000 women members of the Society represent the poorest of the poor in their village communities. Most of them are Dalits and Tribes, the lowest group in the Indian social hierarchy. The DDS initiated a set of interventions to improve millet cultivated farmers' livelihoods during Kharif 2020-2021 in rainfed district of Telangana. These interventions are at three levels- one, usage of increasing organic fertilizers (i.e., Mycorrhiza, Panchgavya, Bheejamrutham, Vermivash and Samrudhi Yeruvu) to improve soil fertility, second, extension services (i.e., technical advice throughout the cropping period), and third, support price to farmers when they fail to get it from the market. The present study attempts to understand the causal effect of these DDS interventions on farm level aggregate profits of surveyed farmers.

3. Methodological Framework

For this study we have adopted the framework suggested by Kassie *et al.* (2015, 2018); Tesfay (2020); Mohammed (2014); Biru *et al.* (2020); Ding and Abdulai (2020), Teklewold *et al.*, (2013); and Zegeye & Meshesha, (2022). Farmers choose to cultivate a variety of crops based on their expected benefits from the adoption of specific crop given farmer (adopters) constraints. Also, a farmer household decides to cultivate a single crop (i.e*.,* monocrop) or a set of crops (i.e*.,* multiple crops) based on the expected utility from adopted specific crop is higher than expected utility from other set of crops or its benefits. Estimating the impact of adoption of crop choice/system on farm outcome requires controlling for potential selection bias and unobserved heterogeneity. Empirical literature suggests to use instrumental variable regression to overcome this problem. However, this can only be attained if the selection process is based on time-constant unobserved heterogeneity. But time varying unobserved heterogeneity problem can be captured by endogenous switching regression (ESR) model (Kassie *et al.*, 2018; Zegeye & Meshesha, 2022). Following this, the estimations of the adoption of alternative crop choices and their impact on farm agricultural profits are modeled using multinomial endogenous switching regression model (MESR).

The MESR model is estimated in two stages. In stage one, farm households' decision to adopt alternative crop choices are estimated using *multinomial logit model (*MNL). The multinomial logit model accounting for unobserved heterogeneity is estimated to generate the inverse *Mills ratio* (Zegeye & Meshesha, 2022). In stage two, the impact of each crop choice on farm performance is estimated using ordinary least square with a selectivity correction term computed from stage one to reduce the bias from not accounting selection into the procedure of adoption decisions. The farm outcome equation is estimated for adopters and non-adopters separately controlling for the endogenous nature of crop choice adoption decisions. Unlike other impact evaluation models (i.e., ordinary least square (OLS), propensity score matching (PSM), inverse-probability-weighted-regression adjustment (IPWRA)), the MESR has potential in controlling the problems of endogeneity, inadequate counterfactuals, selection bias and unobserved heterogeneity (Bourguignon *et al.*, 2007). Crop choice adoption in this study refers to a farm household that adopts any of the alternative crop cultivation. It is equal to 0 for the adoption of conventional crops which we call as non-millet crops (NMC), 1 for the adoption of millets (MC), 2 for the adoption of millets with DDS interventions (MC-DDS)[6].

Farmers adopt alternative crops if the expected utility from adoption is higher than their counterfactuals. For example, the farmers aim to maximize their utility U_i - i.e., farm profit in our case, by comparing with alternative crop cultivation k. For the i^{th} farmer with J alternative choices, the choice of alternative crop choice k implies that $U_{ij} - U_{ik}$ for all other $k \neq j$. The expected utility of the farmer from adopting specific crop choice $j(U_{ij}^*)$ is a latent variable determined by observed plot level, socioeconomic and market access characteristics X_i and unobserved characteristics ϑ_{ij}.

$$U_{ij}^* = X_i\theta_j + \vartheta_{ij} \dots (1)$$

Where X_i refers to a set of observed explanatory variables such as plot level, socioeconomic and market access variables, θ is a vector of parameters to estimated ϑ_{ij} is error terms. Let A be an index that indicates the choice the farmer has made to adopt, such that;

$$A = \begin{cases} 0 \; if \; and \; only \; if \; U_{i0}^* > \max_{k \neq j}(U_{ik}^*) \; or \; \epsilon_{i0} < 0 \\ 1 \; if \; and \; only \; if \; U_{i1}^* > \max_{k \neq j}(U_{ik}^*) \; or \; \epsilon_{i1} < 0 \\ \dots \qquad\qquad\qquad\qquad\qquad\qquad \dots \\ j \; if \; and \; only \; if \; U_{ij}^* > \max_{k \neq j}(U_{ik}^*) \; or \; \epsilon_{ij} < 0 \end{cases} \dots (2)$$

6 In general, millet based agricultural system farmers adopt mixed cropping systems in each piece of land with millets (*i.e.,* dominant crops) pulses, jowar, bajra and green leafy vegetables. More details can be found in Dayakar and Kavi Kumar, 2022.

The farmer i will adopt any crop of j with respect to adopting any other alternative crops k if it provides more expected utility than any other alternatives $k, k \neq j$, i.e, if and only if $\epsilon_{ij} = \max_{k\neq j}(U_{ik}^* > U_{ij}^*) > 0$. Assuming that ϑ_{ij} in equation (1) are independent and identically distributed with Gumbel (satisfy IIA assumption) the probability that farmer i with a set of variables X_i will adopt j can be specified using MNL model as

$$P_{ij} = P(\epsilon_{ij}(0|X_i = j)) = \frac{\exp(x_i\, \theta_j)}{\sum_{m=0}^{j} \exp(x_i \theta_i)} \ldots.(3)$$

3.1. Multinomial Endogenous Switching Model Specification

In the MESR model, farm profit function is estimated for adoption of each alternative crop choice separately controlling for the endogenous nature of crop choice adoption decisions. In the model specification, the base outcome for studying non-millet crop choice (NMC), is denoted as $j = 0$. Whereas for those who adopt alternative crop choice it is denoted as $(j = 1,2 \ldots m)$. The outcome equation for each possible regime j is, therefore, given as

$$\begin{aligned} &Regime\ 0\text{: } \pi_{i0} = Z_i\theta_0 + \eta_{i0} && if j = 0 \\ &\ldots && \ldots \\ &Regime\ J\text{: } \pi_{ij} = Z_i\theta_j + \eta_{ij} && if j = 1,2 \ldots, m \end{aligned} \quad \ldots(4)$$

Where π_{ij} are farm outcome (i.e., profit) of farmer i in regime j and $j(0,1,\ldots,m)$, Z_is is a set of exogenous variables included in X_i, and η_{ij} denotes error terms that capture the uncertainty faced by farmers and it is unobserved, and satisfies zero mean and constant variance. To get consistent estimates, one can consider the correlation between the error terms ϑ_{ij} from the selection equation estimated in stage one and the error term from the outcome equation η_{ij} (Bourguignon *et al.*, 2007). If the error terms ϑ_{ij} and η_{ij} are not independent and identically distributed, a consistent OLS estimation of parameters requires the inclusion of the selection correction terms of alternative choices in equation (4). The consistent estimates can be obtained by estimating the following set of models:

$$\begin{aligned} &Regime\ 0\text{: } \pi_{i0} = X_i\theta_0 + \beta_0\hat{\psi}_{i0} + \upsilon_{i0} \qquad if j = 0 \\ &\dots \qquad\qquad\qquad\qquad\qquad\qquad\qquad \dots \\ &Regime\ J\text{: } \pi_{ij} = X_i\theta_j + \beta_j\hat{\psi}_{ij} + \upsilon_{ij} \qquad if j = 1,2,\dots,m \end{aligned} \qquad \dots(5)$$

$$where\ \hat{\psi}_j = \sum_{j \neq k}^{J} \rho_j \left(\frac{\hat{P}_{ik} \ln(\hat{P}_{ik})}{1 - \hat{P}_{ik}} + \ln(\hat{P}_{ij}) \right) \qquad \dots(6)$$

Here, υ is the error term with an expected value of zero, ρ_j is the covariance between ϑ_{ij} and η_{ij}, ψ is the inverse *Mills ratio* computed from the estimated P_{ij} that the i^{th} farmer chooses of crop j. However, the computed inverse *Mills ratio* creates the problem of heteroscedasticity in equations (5) and (6) (Kassie *et al*., 2015). To overcome heteroscedasticity, we used bootstrapped standard errors. According to Asmare *et al*. (2019) finding an instrumental variable to solve the problems of selection bias, unobserved heterogeneity is overly complex and tedious. Hence, we have applied exclusion restrictions to assure the acceptability of MESR model and followed Parvathi and Waibel (2015), Asmare *et al*. (2019) and Belay and Mengiste (2021). The exclusion restriction is used to exclude explanatory variables which directly affects the selection variable but not the outcome variable. The main reason for this exclusion restriction is that the inverse Mills ratio is a non-linear function of explanatory variables in the MNL equation. Therefore, the second stage equation is identified due to the non-linearity. However, the non-linearity of the inverse *Mills ratio* is not normally tested. Hence, to make source of identification clear, empirical literature advice to have an explanatory variable in the selection equation and which is not included in the outcome equations (i.e., farm profit). Accordingly, we have used, access to road, ownership of the land, distance to dwelling, agri- assets and village dummies as selection instruments. The acceptability of these instruments is established by a simple falsification test. If the instrument is valid, then it will affect the choice adoption of crops, but it will not affect farmer outcome equation among households to choose alternate crops (Zegeye & Meshesha, 2022).

The MESR model allows users to compare the expected farm outcome of adopter of alternative crops with respect to the non-adopter (here NMC) and with their counterfactuals. We have computed conditional expectations for each outcome variable using equation 5.

The actual expected value of farm outcome for adopters:

$$E\left[\frac{\pi_{ji}}{j} = 1,2,..,m, X_{ji}, \psi_{ji}\right] = X_{ji}\theta_j + \beta_j\hat{\psi}_{ji} \qquad \text{... (7)}$$

The counterfactual expected value of farm outcome for adopters:

$$E\left[\frac{\pi_{0i}}{j} = 1,2,..,m, X_{ji}, \psi_{ji}\right] = X_{ji}\theta_0 + \beta_0\hat{\psi}_{ji} \qquad \text{... (8)}$$

The use of these conditional expectations allows us to calculate the average adoption effects on farm outcomes on adopters (ATT) and is defined as the difference between equations seven and eight as

$$ATT = E\left[\frac{\pi_{ji}}{j} = 1,2,..,m, X_{ji}, \psi_{ji}\right] - E\left[\frac{\pi_{0i}}{j} = 1,2,..,m, X_{ji}, \psi_{ji}\right] = X_{ji}(\theta_j - \theta_0) + \hat{\psi}_{ji}(\beta_j - \beta_0) \text{ ... (9)}$$

The first term on the right side shows the expected change of adopters' outcome if adopters had the same characteristics as non-adopters. The second term ψ_{ji} is the selection term that captures all potential difference among adopters and non-adopters. The actual expected value of farm outcome of non-adopters as

$$E\left[\frac{\pi_{0i}}{j} = 0, X_{0i}, \psi_{0i}\right] = X_{0i}\theta_0 + \beta_0\hat{\psi}_{0i} \qquad \text{... (10)}$$

The counterfactual expected value of farm outcome of non- adopters as

$$E\left[\frac{\pi_{ji}}{j} = 0, X_{0i}, \psi_{0i}\right] = X_{0i}\theta_j + \beta_j\hat{\psi}_{0i} \qquad \text{... (11)}$$

Further, the treatment effect of untreated for the farmers that did not adopt (ATU) can be calculated as the difference between equation ten and eleven:

$$ATU = E\left[\frac{\pi_{ji}}{j} = 0, X_{0i}, \psi_{0i}\right] - E\left[\frac{\pi_{0i}}{j} = 0, X_{0i}, \psi_{0i}\right] = X_{0i}(\theta_j - \theta_0) + \hat{\psi}_{0i}(\beta_j - \beta_0) \text{ ... (12)}$$

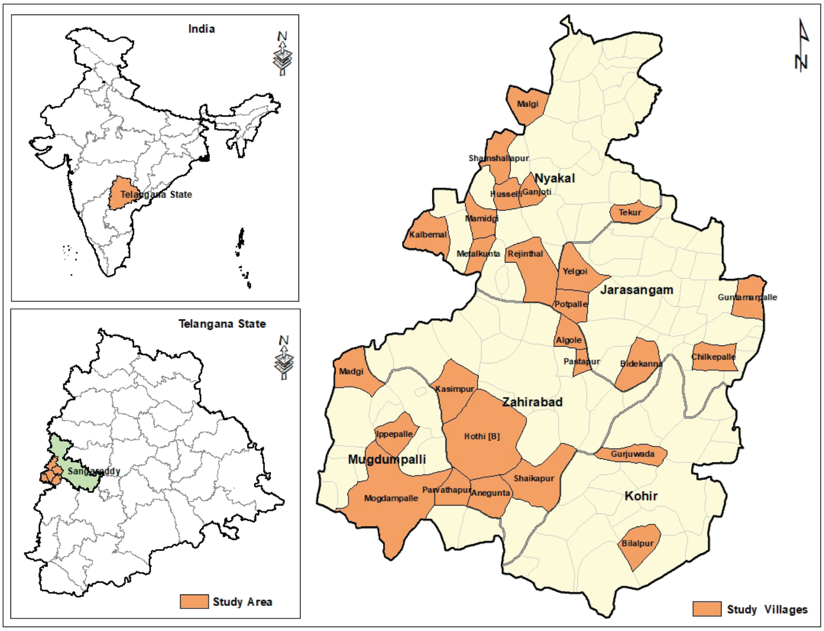
The first term on the right-hand side represents the expected change in the outcome of non-adopters if the characteristics of non-adopters had the same returns as of adopters, and the 2nd term. The second term ψ_{ji} is the selection term that captures all potential difference among non-adopters. The conditional expectation outcome also calculates the traditional heterogeneity which is difference between treatment effects on treated (ATT) and untreated (ATU). Further, the difference between equations 7 and 11 and 8 and 10 gives base heterogeneity for adopters and non-adopters respectively.

4. Data and Descriptive Statistics

4.1. Field Study and Data Sampling

The study area is a part of the Sangareddy district of Telangana state in India and lies approximately 120 kilometers northwest of the state capital Hyderabad. The area falls within the region which is highly vulnerable to drought with an annual average rainfall of 600 mm, over 80% of which is received during the monsoon season from June to September (GoT, 2020). The study area is dominated by rainfed agriculture and millets, cereals, pulses, maize and cotton are the main crops in Kharif season. A purposive sampling method was followed to select the study mandals and villages, to account for heterogeneity in villages in terms of crops and socio-economic characteristics. The study was conducted in 34 villages from five mandals of Zaheerabad mandal[7]. The data used in the study was obtained from a household survey of around 1100 farmers, who were categorized into three groups viz., non-millet crop farmers (NMC), millet crop farmers (MC) and DDS-millet crop farmers (MC-DDS).

Figure 2. Location of Study and Villages in Telangana State, India



7 More details on the study area and data collection process is provided in the Report titled 'An assessment of millet based agro biodiversity systems enriched with a mix of modern and traditional ecological practices', (Revathi E, B Suresh Reddy B and P Dayakar, CESS, 2022).

The survey was conducted from July 2020 to March 2021. In each village, the list of households has been compiled from agricultural department data sets. A simple random sampling approach has been followed to identify the households for a survey from a complete list of households in the village. Moreover, we have also conducted several focus group discussions (FGD) with different categories of sample farmers in some of the study villages to capture the issues in depth in the study area of the villages. Around 700 farmers are selected for DDS-Millet category across villages. We randomly collected the remaining farmers cultivating millets and other non-millet crops. Once we finalize the households, we have selected the major plot if they own more than one plot in the village or neighbor villages to minimize the complexity while analyzing[8].

4.2. Descriptive Statistics of Farm Level Characteristics and Socio-Economic Variables

Table 1 presents a summary of statistics of sample villages corresponding to (a) plot-level characteristics such as area of the plot, soil type, land quality, irrigation, and crop diversification; b) socioeconomic variables including age of the household head, sex of the household head, social status of the household, education of household head, number of working age people in the household, household and agricultural amenities and household income; (c) connectivity variables including distance of the plot to the house, access to the road, and distance to the market from the plot variables.

Table 1. Summary Statistics and Description of the Variables Used in the Analysis

Variable	**Variable measurement**	**Non-Millets**		**Millets**		**DDS-Millets**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Area of the plot	Total area owned (in acres)	3.4	6.2	2.0	1.7	2.2	1.6
Soil type	(Regadi=1; otherwise=0)	0.4	0.5	0.0	0.2	0.0	0.2
	(Suddaregadi=1; otherwise=0)	0.1	0.2	0.0	0.1	0.0	0.2
	(Garapa=1; otherwise=0)	0.1	0.3	0.1	0.3	0.1	0.3
	(ErraGarapa=1; otherwise=0)	0.5	0.5	0.8	0.4	0.7	0.5
	(Erraregadi=1; otherwise=0)	0.0	0.1	0.1	0.3	0.1	0.3

8 It is assumed that the farmers make more agricultural investment in bigger sized plots compared to small sized plots due to viable agricultural operations (Singha, 2019; Dayakar & Kavi Kumar, 2022). However, more than 50% of the surveyed farmers own single plot across villages.

Variable	Variable measurement	Non-Millets		Millets		DDS-Millets	
		Mean	SD	Mean	SD	Mean	SD
Land quality	Plot level soil quality 0= Poor; 1= Good)	0.6	0.5	0.5	0.5	0.7	0.5
Irrigation	Irrigation status (0=Rainfed; =Irrigated)	0.3	0.5	0.0	0.2	0.0	0.1
Level of crop diversity	(Low level; 1-4 crops)	1.0	0.1	0.9	0.2	0.6	0.5
	(Moderate level;5-10 crops)	0.0	0.1	0.1	0.2	0.4	0.5
	(High level; 11-17 crops)	0.0	0.0	0.0	0.1	0.1	0.3
Manure	Years of farmyard manure application	3.1	1.2	2.7	1.3	1.9	1.1
Socioeconomic variables							
Sex	Gender of the household (1=male;0=female)	0.7	0.5	0.8	0.4	0.7	0.5
Caste (Social status)	(1=SC&ST; 0=Otherwise)	0.6	0.5	0.8	0.4	0.9	0.2
	(1=BC; 0=Otherwise)	0.3	0.5	0.2	0.4	0.1	0.2
	(1=OC; 0=Otherwise)	0.1	0.3	0.1	0.2	0.0	0.1
Working age group	Number of people in the family	3.4	1.4	3.2	1.4	2.9	1.2
Agri assets	Agriculture assets index (1= High; 0=Low)*	0.0	0.1	0.0	0.1	0.0	0.1
Ownership	Land ownership (1 =Male; 0=Female)	0.6	0.5	0.8	0.4	0.6	0.5
Market access variables							
Distance	Distance to dwelling (in km)	1.7	1.0	1.5	0.9	1.8	1.2
Road	Road connectivity of the plot (1=yes; 0=no)	0.6	0.5	0.5	0.5	0.7	0.5
Distance to market	Distance to the market from the plot (in km)	13.7	5.6	15.1	7.1	14.7	7.3

Source: Authors' calculations based on field study data

***Note**: The Agri-assets index is constructed to capture the ownership of agricultural implements. The index values lie between 0-1, and one indicates farmer owns all required agricultural implements and zero means not the case. Here we have adopted methodology suggested by Farzana Afridi *et al.*, (2022) in order to construct the agricultural amenities index.

The average area owned by respondents was 3.4 acres for non-millets farmers and 2 and 2.2 acres for millet and DDS-millet farmers respectively more than 50 percent of farmers rated land quality is good[9]. *Erragarapa* (Red Sandy soil) and *Garapa* (Sandy soil) soils are predominant in surveyed villages. Primary data reveals that rainfed agriculture is predominant and none of millet cultivating farmers have access to irrigation in surveyed villages. In contrast, 30 percent of non-millet farmers had access to irrigation facilities. However, data reveals that many of the surveyed farmers have sown a higher number of crops on their farms. Table 1 highlights that DDS-millet farmers adopts diversified crops compared to non-DDS millet and non-millet farmers in each plot they owned. Interaction with farmers and field observations highlights that farmers have sown a greater number of crops in rain fed areas due to the climatic uncertainties and their food consumption patterns. The average age of respondents was 49 years and most of the surveyed farmers were from backward classes with a low level of education. Table 1 reveals that 90 percent of farmers are from schedule caste and schedule tribes and other backward classes in the surveyed villages. The average number of working people in respondent households is close to 3 with poor agricultural amenities across villages. The average distance from dwelling to the plot was 1.72 kilometers and, on average, the plots had poor road connectivity. The average distance to the market is nearly 15 kilometers. The owned per capita of livestock is higher with households who practice millet based agricultural systems compared to conventional (i.e., non-millet) crop farmers.

4.3. Cropping Patterns Adopted by Farming Households in Surveyed Villages

The rainfed agriculture practice is the dominant agriculture system across surveyed villages. Farmers cultivate a variety of crops grown on their fields including jowar, bajra, millets (including finger millet, pearl millet, foxtail millet, kodo millet, little millet), red gram, black gram, cowpea, horse gram, soybean, chilli, maize, ginger, cotton, and turmeric across the villages. One can witness that most farmers in the study villages practice millet-based agriculture rather than conventional agricultural cropping practices. Moreover, the outcome of group discussions with stakeholders and household level data suggests that more than 80% of farmers who practice crops have grown more than one crop on their small plots with a greater number of varieties.

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9 The quality of land variable is defined purely based on farmers' perception (not measured objectively) and categorized according to Likert scale. We have asked the farmers to scale (i.e., good, or poor) the quality of the selected plot vis-à-vis best quality of land in the village.

The costs and returns of farmers have been estimated. The total cost of cultivation is 12843 INR per acre for those who adopt non-millet crop choice while it was 11893 INR and 10218 INR per acre for the MC and MC-DDS farmers respectively. The share of labor cost is more than 70% of the total cost for millet-based cropping system whereas it is 39% for non-millet cropping systems. This shows that millet-based agricultural practices require more farm labor because of the diversified nature of its crops. A farmer from Potpalli village of Jarasamgam Mandal in Sangareddy district said that "the distribution of human labor spreads across the season in their millet cultivated farms due to diversified agriculture system. The time of sowing, weeding, and harvesting cultivated crops will not be the same days or weeks, hence, they must work across the season. There is a little scope for mechanization other than land preparation in millet-based agriculture systems." Further, farmers said that "millet or multi cropping system requires more family labor than mono or commercial crops cultivation in the region.

The seed cost constitutes more than 43% of total cost for non-millet agricultural practices, followed by fertilizers and pest respectively. This is because non-millet cultivated farmers mostly depend on markets for their seed and fertilizers whereas millet cultivated farmers use their own seeds. The seed cost constitutes around 12% of total input cost and fertilizers and organic fertilizers follows respectively for farmers adopting millet cultivation practices. On the other hand, organic fertilizers constitute around 15% of its total input cost followed by seed, fertilizers, and pesticide costs respectively for the millet farmers in the fold of DDS. Table 2 highlights that farmers who are under purview of DDS organization adopt more organic cultivation practices than other faming households in the study area. Hence, the organic input cost is higher when compared to other categories of farmers in the study villages. Moreover, literature highlights that the role of chemical fertilizer is minimal in millet cultivation (Gupta et.al., 2014).

Table 2. Summary Statistics for Full Sample, Non-millets, Millets, and DDS-millets

Variable	**Full sample**	**Non-Millets**	**Millets**	**DDS-Millets**
Number of observations	1086	175	216	695
Input Cost per Acre (In INR)				
Seed	1830 (*16.68*)	5571(*43.38*)	1433(*12.05*)	1012(*9.90*)
Organic	1173(*10.69*)	487(*3.79*)	534(*4.49*)	1544(*15.11*)
Fertilizers	492(*4.48*)	1285(*10.01*)	843(*7.09*)	183(*1.79*)
Pest	96(*0.87*)	471(*3.67*)	43(*0.36*)	18(*0.18*)
Labor	7381(*67.26*)	5028(*39.15*)	9038(*75.99*)	7459(*73.00*)
Total cost	10974	12843	11893	10218
Output Value per Acre (In INR)				
Fodder	636(*3.77*)	198(*0.78*)	623(*5.54*)	750(*4.57*)
Byproduct	172(*1.02*)	92(*0.36*)	90(*0.80*)	218(*1.33*)
UCF[10]	581(*3.45*)	154(*0.60*)	181(*1.61*)	813(*4.95*)
Grains yield	15459(*91.74*)	25072(*98.26*)	10352(*92.03*)	14626(*89.14*)
Total revenue	16850	25517	11248	16408
Profit	5875	12673	-645	6190

Source: Authors own calculations based on field study data; ***, **, *Significant at 1%, 5%, and 10% probability level respectively, values in parenthesis are in percentages.

Table 2 shows that fertilizer cost constitutes about 6 percent of total cost of cultivation whereas in case of NMC fertilizer constitutes 10 percent. The average aggregate returns from agriculture are 25517, 11248, and 16408 INR per acre among farmers who adopt NMC, MC, and MC-DDS agricultural practice respectively in the study area. More

10 Field level observations and household survey data highlights the presence of rich and diverse leaf-based uncultivated foods (UCF) across millet cultivated farming households in the study villages. Greens like Pundi (Hibiscus sps), Doggalikoora (Amaratnthus sps), Chennangi (Lagerstoemia parviflora), Soyikoora (Aurthum graveolus wild), Kodi juttu, Thotakura, GunuguKoora, Gormetikoora, Tummikoora, Lambadikoora, Doddupayili, Sannamdoggali and Chirudoggali are major uncultivated greens. These crops are available across season and farmers believe that they have good nutrition value.

than 90% of total revenue comes from grains yield followed by fodder, uncultivated food (UCF), and byproducts with 4%, 3.5%, and 1% respectively. However, most of the contribution comes from fodder and UCF to total pool of agricultural revenue for millet and MC-DDS farmers compared to non-millet farmers. Further, Table 2 reveals that farmers who adopt non-millet agricultural practices make an average profit of 12673 INR profit per acre while millet farmers make loss of 645 INR and MC-DDS farmers make 6190 INR profit respectively. The difference between MC and MC-DDS farm net profit is 6835 rupees per acre and clearly indicates that the DDS interventions played a significant role. Further, millet cultivating farmers adopt high level diversified cropping patterns. Nearly 35% of the sample farmers have grown more than eight crops in an average size of one acre land at a given point of time. On the other hand, the majority of conventional farmers (47%) were growing single crop in their piece (one acre) of land. Further, DDS-farmers grow a greater number of crops compared to other millet farmers and indicates that DDS encourages diversified agriculture in the study area (Figure A. 4). The reason cited by farmers for growing of variety of crops in the same piece of land is "their ability to extract nutrition with different depths and nutrient requirement of different crops is different so that there would not be specific nutrition deficiency, labor distribution spreads across the year, and *less* incidence of pests & disease". Diversity provides some protection from adverse price changes in a single commodity and better seasonal distribution of inputs (Cacek and Langer, 1986).

4.4. Outcome and Explanatory Variables

Profit per acre during the monsoon season in 2020-2021 period is considered a relevant outcome variable in the study area. Profit is estimated at an aggregate level for each selected farmer[11]. The aggregate level of net-revenue equals the total agricultural returns from all cultivated crops in the study area minus cost of cultivation of corresponding crops. The cost of cultivation is calculated at an aggregate level. The cost of cultivation includes cost of land preparation, seed, soil fertility input, chemical fertilizers, pest management,

11 where i represents farm plot and j represents crop category. Empirical literature considers yields rather than profits to avoid price and market sensitivity. However, we have taken aggregate profits as an outcome of interest because of two reasons: One is that the surveyed farmers cultivate a greater number of crops/mixed crops in a single piece of plot. Second, we can not compare yields of two different crops (example, cotton from conventional agriculture and millets).

weeding and harvesting costs[12]. These costs are collected crop-wise wherever possible or are collected farm-wise where there is no availability of data for crop-wise activity, for instance, land preparation. On the other hand, total agricultural returns are defined as aggregate value of grain yield, by-products including biomass (i.e*., Pottuporaka*), UCF, and fodder. We have estimated the value of the biomass per acre based on crop-wise physical output and multiplied with corresponding monetary terms[13]. The value of UCF per acre is calculated based on the value (i.e., kg per acre) of uncultivated crops consumed by farmers and multiplied with market value of corresponding uncultivated food crops during Kharif 2020-2021 period; the fodder value per acre is derived based on household survey data and outcome of FGDs. As stated in the above section the explanatory variables include, (a) plot-level characteristics such as area of the plot, soil type, land quality, irrigation, and crop diversification; b) socioeconomic variables including age, sex and education of the household head, social status of the household, number of working age people in the household, household and agricultural amenities and household income; (c) connectivity variables including distance of the plot to the dwelling, access to the road, and distance to the market from the plot.

5. Econometric Model Results

5.1. Determinants of Crop Choice

A multinomial logistic regression model was estimated to identify determining factors that influence farmers' decisions to adopt crop choices in the study area. The base outcome is adoption of non-millet crops (NM). Prior to the estimation we have performed different tests and the model fits reasonably well with the Wald test result; . We have performed Hausman test result for test of independence of irrelevant alternatives (IIA) assumptions which shows that all alternative crop choices are unique with respect to the variables in the model. The model results shows that decision to adopt alternative crop choices are significantly affected by plot-level characteristics such as soil type, access to irrigation, farmyard manure application; socioeconomic characteristics such as social

12 This study accounted only paid out cost for labour use and not accounted for family labour while aggregating the total cost across sampled farmers as farmers said reported that they allocate their labor of at least one hour in a day for crop and engage with other allied activities for the rest of the work day.

13 These monetary values are derived from market value of respective crop biomass in the study area.

category, education of the household head, plot ownership, livestock and households' income; distance to dwelling, and village level factors like market access, access to road. The coefficient of soil type is positive and significant for adoption of MC cultivation, implying that farmers are more likely to adopt MC choice if farm households have access to other than black soils. Sandy, red sandy, calcareous soil, and red clay soils are more suitable for millet cultivation. Further, the fertility of these soils is low compared to black soils. Results from empirical studies confirm that millets give better yields compared to other crops in less fertile lands (Gupta *et al.*, 2014; Dayakar, 2021). The coefficient of the access to irrigation is negative, implying that farm households that have access to irrigation are less likely to adopt millet based agricultural systems.

Table 3. Factors Influencing Choice of Millet Crops: Estimates Based on Multinomial Logit Model

Variable	**Adoption of**			
	Millets		**Millets-DDS**	
	Coef.	P-Value	Coef.	P-Value
Plot level characteristics				
Total area owned	-0.063	0.16	-0.029	0.21
Soil type of the plot	0.495***	0.00	0.573***	0.00
Land quality of the plot (Good)	-0.076	0.76	0.435	0.12
Access to irrigation (Yes)	-2.077***	0.00	-2.787***	0.00
Farmyard manure application (No)	-0.190	0.12	-0.698***	0.00
Socioeconomic characteristics				
Sex of the household head (Female)	-0.201	0.55	-0.232	0.41
Caste of household (BC&OC)	-0.467**	0.03	-2.011***	0.00
Household head education (Yes)	-0.192	0.20	0.141	0.31
Access to agricultural amenities'	1.847*	0.06	2.550***	0.01
Plot ownership (Female)	-0.990***	0.00	0.044	0.86
Household income (High)	0.652***	0.00	0.207	0.29
Livestock owned	0.183***	0.00	0.221***	0.01
Market access variables				
Distance from the dwell	-0.122	0.25	0.153*	0.09
Access to road (No)	0.896***	0.00	0.284	0.23
Village	-0.014**	0.02	0.005**	0.02

Variable	Adoption of			
	Millets		Millets-DDS	
	Coef.	P-Value	Coef.	P-Value
Constant	1.253	0.30	2.269*	0.06
Diagnostic				
Observations	1069			
Wald chi2(28)	423.66			
Prob > chi2	0.000			
Pseudo R2	0.2927			

Note: The reference group for crop choice is non-millet crops; soil type is black; land quality is poor; access to no-irrigation; sex is male; cast is SC&ST; ownership is male; road is yes; ***, **, *Significant at 1%, 5%, and 10% probability level

This is because millet-based agriculture requires less water to grow compared to non-millet agriculture. The findings of this are in line with other works of Gupta et. al. (2014) and Dayakar et. al. (2022). Quantity and quality of livestock influences soil fertility management both directly and indirectly. The higher livestock (number) leads to more access to organic manure. The livestock component of the farming system is crucial to help maintain soil fertility (Reddy 2009). Farm households are more likely to adopt millet agricultural system if they own a greater number of livestock. Moreover, Table 2 reveals that farm households are less likely to adopt MC and MC under DDS if they do not have access to farmyard manure. In general, farmers use more organic fertilizers compared to NM crop practices. The coefficient of social status is negative, implying that if farm households belong to BC and OC social categories, then they are less likely to adopt MC and MC-DDS crops. Culture and traditional food consumption practices could be one of the determinants of crop choice on their farmlands. Further, some of the empirical works state millets as 'poor people's food'. In addition, the coefficient of agricultural amenities is positive and significant and indicates that if the farm households own a greater number of agricultural implements, they are more likely to adopt MC and MC-DDS cropping practices compared to NM crop practices. Further, the coefficient of plot ownership is negative, implying that if female farmers own land (i.e., legal entitlement) then they are less likely to adopt MC choice. On the other hand, if farm households have more non-farm income levels, then they are less likely to adopt MC cropping patterns.

Further, the coefficient of distance from the dwelling is positive, indicating that if the distance from dwelling is long then farm households are more likely to adopt MC choice compared to NM crops. Lastly, the coefficient of access to roads is positive, implying that farm households who do not have access to road connectivity are more likely adopt MC cropping systems. Farm households adopt commercial crops if they have access to road connection. Households having better access to the market and main road may sell (buy) agricultural outputs on time and with reasonable prices and could lower production cost and ensure on-time adoption. The findings are in line with the works of Belay and Mengiste 2021; Wordofa *et al.*, 2021 and Ayenew *et al.*, 2020.

5.2. Causal Impact of Crop Choice on Farm Profit

The impact of crop choice on agricultural profit was analysed using multinomial endogenous switching regression (MESR) model[14]. The estimated average treatment effect on farm agricultural profit is reported in Table 4. The results show that significant values of mills, rho, and sigma's, indicating that a failure to reject the hypothesis of sample selection bias and employing a MESR is the right choice (see A.1).

Table 4. Average Treatment Effects on Plot Level Agricultural Outcome

Outcome	**MESR Model**		**IPWRA Model**	
	ATT	P-Value	ATT	P-Value
In terms of rupees/acre				
Non-Millets (NMC) vs. Millets (MC)	1553	0.86	2562	0.61
Millets-DDS (DDS-MC) vs. Millets (MC)	7323***	0.00	7446***	0.00
Millets-DDS (DDS-MC) vs. Non-Millets (NMC)	6880***	0.00	6992***	0.00

Note*:* ***, **, *Significant at 1%, 5%, and 10% probability level; Source: Authors own calculations based on field study data.

The estimated model instruments are jointly validated as strong predictors of adoption but not for farm profit using the falsification test, the test result [F (13,497) = 0.689, Prob > F = 0.775)] proved that instrument is found to be highly insignificant driver for consumption at $P > 0.05$, (see Appendix A.2). This confirms the validity of the selected instrumental variables, and the model is adequately identified. Table 4 reveals that a

14 For robustness check, we have estimated the Inverse Probability Weighted Regression Adjustment (IPWRA) model to the MESR final ATT results and reported in Table 4 and A.3. However, we did not offer any discussion of the results of the model here.

significant difference in farm profits between MC-DDS adopters and NMC and MC farm households. The study found that the average treatment effect on treated (ATT) value for MC farm households is 1563 less per acre compared to household NMC farm profit (but not significant). The possible explanation could be that the availability and adoption technology for MC is low compared to other conventional crops like cotton, paddy, and maize. Further, these crops are neglected due to missing markets. On the other hand, profit for farm households significantly increased if they adopted MC-DDS cropping systems. The result shows that the average ATT value is INR 6880 (significant level at 1%) higher per acre compared to NMC adopted farmers. The result of the study found that the adoption of MC-DDS cropping pattern significantly and positively increased profit per acre. On the other hand, the average ATT value is 7323 (significant level at 1%) higher compared to MC farm profits. This finding confirmed the potential role (i.e., agricultural extension services, and market prices) of DDS institutions on farm average profits in the study area. The estimated results may be overestimated because of the missing intervention (for example, scientists and extension facilitators) cost of DDS. On the other hand, these estimated results accounted only for the benefits from the interventions, and we did not account for other benefits (for example, values of soil health and carbon sequestration) of alternative agricultural systems hence it is an underestimate. The caveat of the study is that it studied only one time period, panel data may capture better time-varying unobserved factors.

6. Conclusions and Policy Implications

This study examined the impact of farm outcome of alternative agricultural systems on farm profit in villages of Sangareddy district in Telangana, India. The results of the study lead to the following main conclusions. First, the multinomial logit estimation results revealed that farm households' decision to adopt alternative cropping systems are significantly influenced by plot-level characteristics (such as soil type, access to irrigation), socioeconomic characteristics (social category of the household, access to agricultural amenities, plot ownership, livestock, and household income), village level characteristics (access to market, road). Second, the average farm profits of adopters of MC-DDS crops are significantly high compared to adopters of alternative cropping systems.

The results, after controlling possible covariates, confirm that the institutional presence (in the form of DDS intervention) significantly improved the average profit of the MC-DDS farmers in the surveyed villages. From a policy perspective, the results of the study emphasize that the policymakers should encourage and support the agricultural practices for not only major cereals but also minor cereals in similar rain-fed areas. The support to millet crop systems needs to be multifarious, in terms of helping conserve seed germplasm, maintaining livestock for FYM, agriculture extension, technology, and support prices. The support to the millet agriculture system in rain-fed areas contributes to achieving multiple Sustainable Development Goals (SDG 2, 11, 13, 15).

Appendix

A1. Multinomial Endogenies Switching Regression Results

Variable	Non-millets		Millets		DDS-Millets	
	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
Plot level characteristics						
Total area owned	-927	0.802	0.439	0.679	-1771	0.424
Soil type of the plot	-3562	0.116	-278	0.815	473	0.375
Land quality of the plot	3420	0.9	-20300	0.198	2875	0.823
Access to irrigation	-2077	0.819	24803**	0.035	-6356**	0.05
Plot level crop diversification	-1923	0.852	-374	0.884	619	0.728
Years of farmyard manure application	681	0.838	-301	0.716	-822	0.726
Socio economic characteristics						
Sex of the household head	-982	0.918	-5956	0.477	5850	0.262
Caste of household	-15772	0.884	24049	0.604	266	0.997
Household head education	2735	0.701	-5485	0.449	177	0.963
Access to agricultural amenities'	-73082	0.386	-6331	0.846	15763	0.558
Plot ownership	-13032	0.421	-14315	0.573	-4054	0.44
Household income	-15482***	0.001	2453	0.149	519	0.831
Market access variables						
Distance from the dwell	-1988	0.822	-4149	0.439	899	0.776
Access to road	5869	0.601	8693	0.441	-9497	0.182
Village	496	0.401	-365	0.324	37	0.573
_m0	-49960	0.349	10778	0.911	-141029	0.214
_m1	-36551	0.78	34947	0.394	-52046	0.275
_m2	-74335	0.716	-5253	0.929	-40006	0.326
Sigma2	4.17e+09	0.684	7.99e+08	0.937	7.27e+09	0.573

Variable	**Non-millets**		**Millets**		**DDS-Millets**	
	Coef.	P-Value	Coef.	P-Value	Coef.	P-Value
rho0	-0.7733	0.12	0.38133	0.745	-1.654198**	0.046
rho1	-0.5658	0.589	1.236422**	0.035	-0.6105	0.199
rho2	-1.1506	0.502	-0.1859	0.866	-0.4693	0.267
Constant	73458	0.787	-26342	0.664	-15652	0.785

Note: ***, **, * *Significant at 1%, 5%, and 10% probability level*

A.2. Falsification Test Results for Robustness Check

Variable name	**Coefficient**	**Std. Err.**	**P- Value**
Sex of the household head	1671.25	10571.60	0.88
Education of the household head	5693.49	4399.90	0.20
Caste of household	2958.87	6147.61	0.63
Access to road	11319.17	7713.21	0.14
Plot ownership	-4444.79	9658.47	0.65
Distance from the dwell	-6007.01	4159.91	0.15
Village dummy	204.55	25632.67	0.52

Figure A.3. Distribution showing overlap between non-millets, millets, and DDS-millet Farming

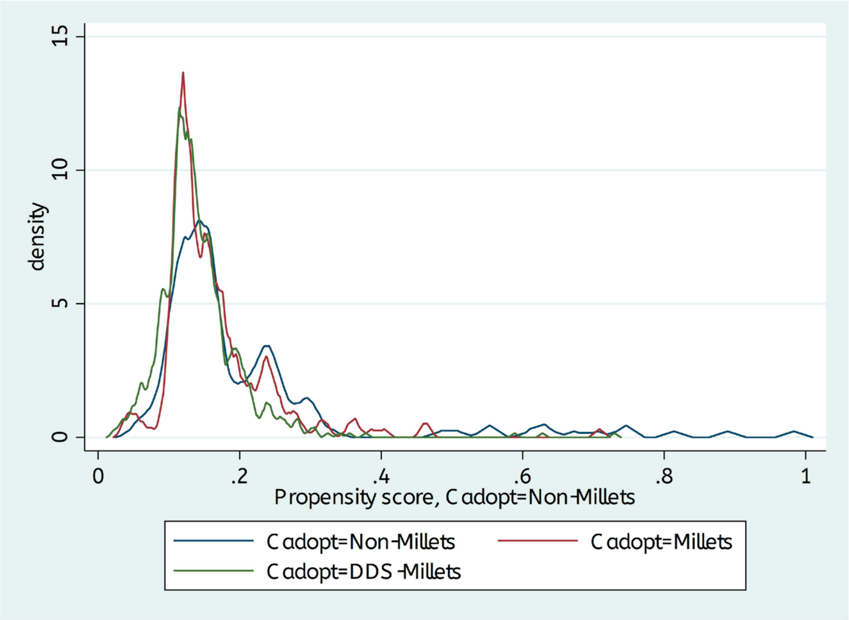
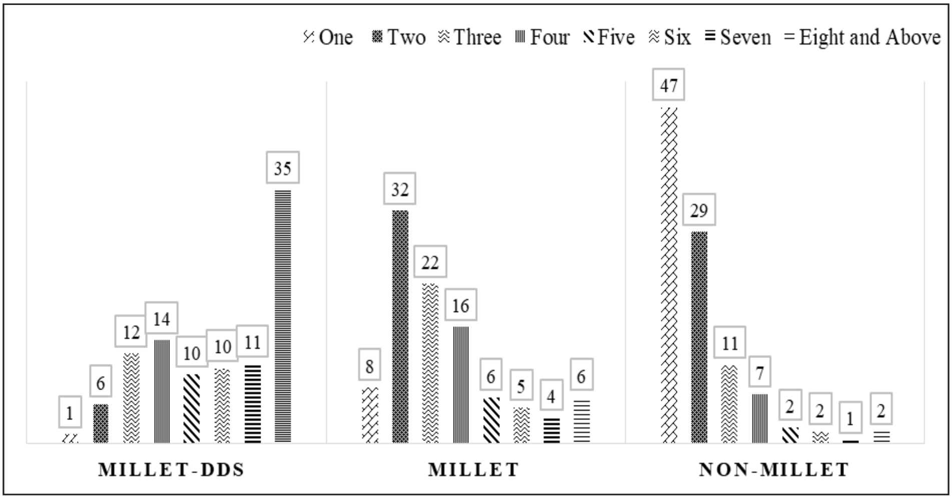


Figure A.4. Distribution of average number of crops grown by sample farmers



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