# Impact of adoption of hydroponic fodder production on pastoralist households' income in Borena, Ethiopia

**Sisay Bedeke Bedeke**
belaysisay@gmail.com

Wolaita Sodo University

**Tagese Melkato**
Wolaita Sodo University

**Melisew Dejene**
Hawasa University

**Tenaw Fentaw**
Addis Ababa University

**Article**

**Keywords:** Pastoralists, hydroponic fodder, adoption, propensity score matching, income, Ethiopia

**Posted Date:** June 12th, 2024

**DOI:** https://doi.org/10.21203/rs.3.rs-4268088/v1



**Additional Declarations:** No competing interests reported.

# Impact of adoption of hydroponic fodder production on pastoralist households' income in Borena, Ethiopia

**Sisay Bedeke Bedeke[*1], Tagese Melkato[2], Melisew Dejene[3], Tenaw Fentaw[4]**

[1,2]Department of Rural Development and Agricultural Extension, College of Agriculture, Wolaita Sodo University, Ethiopia

[4] Faculty of communication and Development, Hawasa University, Ethiopia

[5] Monitoring and Evaluation Office, Cordaid Ethiopia

[*]Corresponding Author: belaysisay@gmail.com …………………..

## Abstract

This study assesses the adoption of hydroponic fodder production practice and how the adoption impacts pastoralist household income in Borena, Ethiopia. A total of 211 pastoralist households were surveyed and interviewed to collect quantitative data. The data were analysed using econometric models, i.e., binary logistic regression model for adoption, the impacts of adopting hydroponic fodder were evaluated using propensity score matching (PSM), and descriptive statistics. The results of the binary logistic regression model showed that the probability of adopting hydroponic fodder was positively and significantly influenced by gender of the household head, herd size, frequency of contacts by development agents, educational level, participation in training on hydroponic fodder production, and pastoral cooperative membership. However, the possibility of hydroponic fodder being adopted was significantly and negatively impacted by the use of credit services. The PSM score suggested that, in comparison to the control groups, the adoption of hydroponic fodder significantly impacted income of the treatment households. Based on the findings of the study, we recommend that the government and interested parties need to concentrate on raising herd size, increasing the provision of education and the frequency of visit by pastoral development agents, training towards promoting cooperative membership, and raising awareness of local credit use. Overall,, the findings suggested that hydroponic fodder productions have a significant positive impact on pastoral households' ability to generate additional income.

***Keywords: Pastoralists, hydroponic fodder, adoption, propensity score matching, , income, Ethiopia***

## 1. Introduction

Pastoralism is a way of life among people living in the arid and semi-arid land areas in Ethiopia. This mode of life is mainly dependent on animal husbandry. It provides livelihoods for more than 12 million people, and contributes about 20% of the GDP through livestock sub-sector (Menghistu et al., 2020). However, current natural disasters prevailing in pastoral areas are characterized by rampant poverty, acute food and feed shortages as well as frequent droughts (Tofu et al., 2023). While there is a growing concern in Ethiopia's food insecurity situation, reports indicated that about 15% of its population were undernourished by 2020, which is predicted to rise more than 20% by 2025(Kassegn and Endris 2021), putting food security a high level risk (Ali et al. 2022). In the past decade, the price of cereals in Ethiopia, increased  by 27% given the growing demand for food and the rapid rise in food commodities (Ali et al. 2022). However, the rate of decline in food expenditure slightly varies among income levels. That is to say, while households from  high income groups allocate about 60% of their budget to food, households at the top end allocate only less than 50% (WFP 2020).

Inclusive disaster risk management for  pastoralists households in could consider  the promotion of innovative solutions that drive food security (Mendoza and Thelen 2008). As  majority of pastoralist households face burden from disaster risks and vulnerability to shocks, inclusive innovations are important to sustain their livelihoods (Berhanu et al., 2016; Moores and Hunters, 2018). Previous research by Tofu et al. (2023) in Northern Ethiopia indicated that innovative practices are one of the strategies to drive locally relevant solutions that could improve household income and food security. A study by Horton et al. (2023) affirms the importance of innovations as a critical strategy to improve fodder production. Improving the adoption of hydroponic fodder may help achieve a more efficient and sustainable ways to improve food security while reducing drought shocks (Horton et al., 2023; Gebru et al., 2022).

Hydroponics is a method of growing plants using nutrient solutions or water without soil. Different types of leafy vegetables and fodder could be produced using hydroponic systems (Shit 2019). The growing system could be open systems, where the nutrient solution or water is not recycled, and closed systems that utilize recycled excess water from growing systems. The open hydroponic systems are not practically feasible due to wastage of water and nutrients especially if mixed with irrigation water. The yield from hydroponic systems is significantly higher compared to the traditional methods of fodder production. Specifically, Naik et al. (2020) contends that production under hydroponics system yields 1000 times more than the conventional farming methods. The improved efficiency in fodder production enhances the efficiency of the entire supply chain. This implies that livestock yields such as milk and meat are sustainably supplied throughout the year despite the variability in weather conditions. This improvement in feed value chain may contribute to help pastoral households' income and food security (Arif et al. 2023).

Although the concept of hydroponic fodder production is relatively old, very few research  have been published (Ahamed et al. 2023; Upreti et al. 2022). Most research has been undertaken on nutritional aspects and operating costs regarding DM contents of fodder production compared with original grains. A study by TC et al. (2020) reviewed the nutritional elements of hydroponic fodder and their impact on productivity for milk and meat. The study also analyzed the water use efficiency in hydroponic production compared with open-field production. Other studies have reviewed the  fundamentals of hydroponic fodder production and rationality from water conservation, land use, and minimal use of chemicals and its benefits for animal production (Omollo et al. 2018). However, these studies have not considered the effect of hydroponic fodder adoption on pastoral household food security.

A number of studies have been conducted on factors determining households' participation in fodder production in Kenya (Upreti, Ghimire et al. 2022; Ahamed et al. 2023). For instance, in their study on factors influencing adoption of fodder production among smallholder farmers in western Kenya, Harerimana et al. (2023) reported that adoption of fodder cropping was limited by lack of quality seed resources, input-output market problems and lack of credit facilities, as well as limited extension services. Although a different study by Omollo et al. (2018) noted that adoption of Napier grass in the highlands of Kenya was influenced by farmer education level, farm size, years of experience in farming and membership in cooperative group. They noticed that access to credit facilities did not have any significant effect on adoption of this particular grass species. These studies have focused mainly on the drivers of adoption of hydroponic fodder production and how adoption impacts pastoral household food security (Omollo et al. 2018; Gunasekaran et al., 2019; Arif et al. 2023).

Given these gaps in knowledge, this study examines factors influencing the adoption of hydroponic fodder production and how such adoption impacts household food security in Ethiopia. In so doing, the study has made two important contributions. First, the study adds relevant value on existing knowledge addressing food security impacts of hydroponic fodder (Thornton et al. 2018). Second, the study contributes to existing research (Mekonnen et al., 2021; Teklewold et al., 2017; Tesfaye et al., 2020) by evaluating the level of hydroponic fodder adopters and non-adopters in response to different explanatory factors using Propensity Score Matching (PSM) (Tesfaye et al., 2020). The use of PSM is particularly important to account for potential unobservable heterogeneity, which may otherwise lead to suboptimal decision (Issahaku and Abdulai 2020).

## 2. Methodology

### 2.1. Description of the study area

This study was conducted in pastoral areas of Borena zone of Ethiopia (Figure 1). Borena zone is located at 4°56'58.3"N and 38°12'32.9"E. Borena zone is among the 21 administrative zones in the Oromia Regional State of Ethiopia. The zone covers an area of approximately 95,000 km2, with an overall population density of six inhabitants per square Kilometre. According to (NMA 2020), the climate relies under a mean annual temperature of 19 °C and with a mean maximum and mini- mum temperature of 24.6 °C and 12.96 °C respectively (Worku et al. 2022). The rainfall has a bimodal distribution, with long rains occurring between March and June and short rains occurring between August and October. The elevation ranges from 1000 m above sea level on the plains to 1500 m in the highlands. In Borena, pastoralism is the dominant livelihood, and the people are generally referred to as cattle herders. The people are known for their strong bondage and social security networks of helping each other during hard times, including droughts. This zone is amongst the most severely drought-stricken and neglected areas in Ethiopia (Pouw et al., 2020). Livestock is a crucial source of food and income, as well as a symbol of pride and social status. The key inputs to livestock production, pasture, and water, are heavily dependent on rainfall conditions. The current drought in each zone has seriously aggravated the already high levels of chronic food insecurity in pastoral and agro-pastoral communities (Schoneveld, 2020).

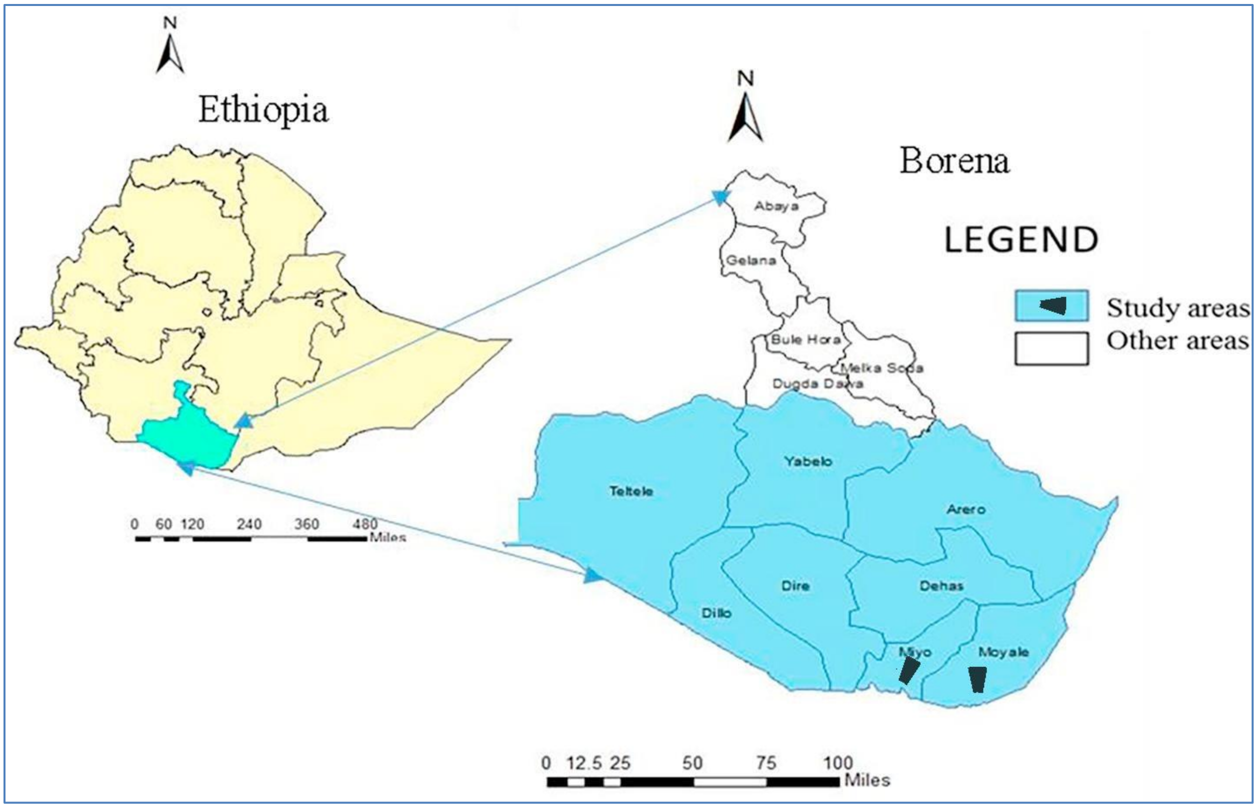


Figure 1: Map of the study area. Source: EthioGIS, 2023

## 2.2. Sampling Strategy

While applying survey research design, this study employed a multi-stage sampling technique to select sample units. First, two districts, Moyale and Miyo districts were selected purposively from the Borena zone . This is because both the selected districts are prone to frequent droughts and dry spells, poor access to fodder, a huge livestock loss as well as facing rapid soil degradation, all of which are resulting in acute food insecurity. To this end, pastoral households were expected to adopt hydroponic fodder as social innovation strategy to improve livestock productivity and ameliorate food security.

In the second stage, we obtained the lists of pastoral villages 23 in Moyale and 18 in Miyo and developed, the final sampling frame. Using a simple random sampling technique, two villages were selected from each district. The population list we got from each village was stratified into adopters and non-adopters of the hydroponic technology. In a third stage, an “optimum” total sample size required from the sampled village was determined using equation (1) as suggested by Kothari (2004):

$$n = \frac{z^2.p.q.N}{e^2(N-1)+z^2.p.q} \quad = \ 211$$

where n represents the optimum sample size, which was required to predict the population N significantly; z indicates the confidence level, which determines at 95% (z =1.96); p denotes the distribution of population attributes (p =0.5); q is 1– p; and e represents the desired level of precision (e = 5%). p value of 50% was assumed to increase the level of precision for the sample size and reduce variability of population attributes. The more heterogeneous the population, the larger the sample size required to obtain a given level of precision.

In the final stage, from each stratum, the required sample size was selected using systematic random sampling techniques. Accordingly, a total of 100 hydroponic fodder adopters and 111 non-adopter pastoral households were selected. By considering the ten (10) % non-response rate of the sampled households using the 95% confidence level, the sample size was increased to 211 household heads (Table 1).

Table 1. Sample size distribution by study woredas

| **Woreda** | **Sample villages** | **Non adopters** | **adopters** | **Sample per kebele** | | **Total sample** |
|---|---|---|---|---|---|---|
| | | | | **Non-adopters** | **Adopters** | |
| Moyale | Slam ber | 340 | 120 | 29 | 30 | 59 |
| | Arbille | 390 | 97 | 35 | 27 | 62 |
| Miyo | Milbana | 310 | 102 | 26 | 21 | 47 |
| | Silala | 280 | 104 | 21 | 22 | 43 |
| Total | | 1320 | 433 | 111 | 100 | 211 |

## 2.3. Data collection methods

In this study, we used survey methods to collect pastoralists' household level data on demographic and physical features, socio-economic attributes, hydroponic fodder production practices, drought shocks and food security. First, draft questionnaires were constructed based on the framework used by Arif et al. (2023) who suggest that the link between fodder production and food security is contingent upon access to capital assets on which households depend for their wellbeing. Questionnaires consisted of close-ended questions with the advantage of getting pastoralists households' strong views on their responses, and achieve ease of response and respondent comfort (Kothari 2004). Second, we invited experts to review the content of the draft questionnaires in order to ensure consistency and coverage. Following this, 8 enumerators (5 male and 3 female) were recruited for KoBo Toolbox, a free open-source tool for effective data collection. Third, we pre-tested draft questionnaires with the same group of respondents on two separate occasions, expecting only minor variation in responses. The pre-test was done with 9 (5% of the total sample) randomly selected household heads who did not participate in the final survey. Accordingly, those questions that deemed ambiguous, poorly phrased and too complex were revised. After data was gathered, the data management quality works including treating the missing data/values, avoiding outliers , and recoding some items were undergone. The survey was conducted during the period, June 2023 to September 2023.

## 2.4.Data Analysis

## Model specification

**Propensity Score Matching:** Evaluating the impact of a project on an outcome variables (e.g., income) using linear regression analysis can lead to biased estimate if the underlying process which governs selection into a project is not incorporated in the empirical framework. The assumption is that the effect of the hydroponic fodder production adoption project may be over (under) estimated if project participants are more (less) able due to certain unobservable characteristics to derive benefits compared to eligible non-participants (Austin 2011). A number of econometric methods were employed elsewhere to study the impact of hydroponic fodder adoption on welfare (Caliendo and Kopeinig 2008). One of such methods is the use of difference-indifference method that enables the evaluator a treatment and comparison group before and after a program (Alberto et al., 2018). However, this method needs baseline information, which is not sufficiently accessible in this case. To this end, the Propensity Score Matching (PSM) came out as a popular approach to estimate causal treatment effects. It is being increasingly applied for impact evaluation mainly because it is based on comparable observations which reduces the selection bias problem when there are two categories of response (Heckman 1976). The necessary steps when implementing PSM were:

**Step 1: Propensity Score Estimation:** For this study, a binary logistic regression model was used to estimate propensity scores and matching were then performed using propensity scores. In estimating the binary logistic regression model, the dependent variable is adoption, which takes the value of one if a household is adopter and zero otherwise. The mathematical formulation of the binary logistic regression model was:

$$\mathrm{Pi} = \mathrm{F(Zi)} = \mathrm{F}[\alpha + \sum(\mathrm{BiXi})] = [\frac{1}{1+e^{-[\alpha+\sum(BiXi)]}}] \tag{1}$$

Where: e represents the base of natural logarithms (2.718), $x_i$ represents the $i^{th}$ explanatory variable, $P_i$ is the probability that a household is being non-adopter given $x_i$, α and $\beta_i$ are regression parameters to be estimated.

Interpretation of the coefficients is understandable if the logistic model can be written in terms of the odds and log of odds (Hosmer and Lemeshow, 1989). The odds ratio is the probability that a household would be non-adopter ($P_i$) to the probability that it will be adopter ($1 - P_i$).

$$(1 - P) = \frac{1}{1 + e^{zi}} \tag{2}$$

And putting using natural logarithm:

$$Z_i = \mathrm{Ln}\left(\frac{P_i}{1 - P_i}\right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \text{---} + \beta_n x_n \tag{3}$$

Where: Zi represents is a function of explanatory variables $x_i$, α is the intercept, β's are the slope parameters in the model.

**Step 2: Choose Matching Algorithm**

In this study, we applied the nearest neighbor matching (NN). The NN is the most straightforward matching estimator. The individual from the comparison group is chosen as a matching partner for a treated individual that is closest in terms of propensity score. In addition, caliper matching method was used for the matching algorism. Applying caliper matching means that those individual from the comparison group is chosen as a matching partner for a treated individual that lies within the caliper (‘propensity range’) and is closest in terms of propensity score. A benefit of this approach is that it uses only as many comparison units as are available within the caliper and therefore allows for usage of extra (fewer) units when good matches are (not) available.

**Step 3: Check Over- lap/Common Support**

The Average Treatment effect on the Treated (ATT) and Average treatment effect on the Untreated (ATU) are only defined in the region of common support. Hence, an important step is to check the overlap and the region of common support between treatment and comparison group. Several ways are suggested in the literature, where the most straightforward one is a visual analysis of the density distribution of the propensity score in both groups. One of the methods to determine the region of common support more precisely is comparing the minima and maxima of the propensity score in both groups and the other one is estimating the density distribution in both groups. Common Support rules out the phenomenon of perfect predictability of D given X:

(Overlap) $0 < P(D = 1|X) < 1$ (9)

It ensures that persons with the same X values have a positive probability of being both participants and non-participants (Heckman et.al., 1999).

**Estimation Strategy**: Given that CIA holds and assuming additional that there is overlap between both groups (called `strong ignorability' by Rosenbaum and Rubin (1983)), the PSM estimator for ATT can be written in general as:

$$W^{PSM}_{ATT} = E_{P(X)/D=1}\{E[Y(1)/D = 1, P(X)] - E[Y(0)/D = 0, P(X)]\}. \qquad (10)$$

To put it in words, the PSM estimator is simply the mean difference in outcomes over the common support, appropriately weighted by the propensity score distribution of participants.

**Step 4: Matching Quality/Effect Estimation**

Since we do not condition on all covariates but on the propensity score, it has to be checked if the matching procedure is able to balance the distribution of the relevant variables in both the control and treatment groups. If there are differences, matching on the score was not (completely) successful and remedial measures have to be done, e.g. by including interaction-terms in the estimation of the propensity score. A helpful theorem in this context is suggested by Rosenbaum and Rubin (1983) and states that:

$X \ D|P(D = 1|X).$ (11)

This means that after conditioning on P (D = 1|X), additional conditioning on X should not provide new information about the treatment decision. Hence, if after conditioning on the propensity score there is still dependence on X, this suggests either misspecification in the model used to estimate P (D = 1|X) or a failure of the CIA ((Meskel et al. 2020).

**Standardized Bias:** one suitable indicator to assess the distance in marginal distributions of the X-variables is the standardized bias (SB) suggested by Rosenbaum and Rubin (1985 as cited in Caliendo and Kopeinig, 2005). For each covariate X it is defined as the difference of sample means in the treated and matched control subsamples as a percentage of the square root of the average of sample variances in both groups. The standardized bias before matching is given by:

$$SB_{before} = 100.\frac{(\overline{X}_1 - \overline{X}_0)}{\sqrt{0.5.(V_1(X) + V_0(X)}} \tag{12}$$

The standardized bias after matching is given by:

$$SB_{after} = 100.\frac{(\overline{X}_{1M} - \overline{X}_{0M})}{\sqrt{0.5.(V_{1M}(X) + V_{0M}(X)}} \tag{13}$$

Where $X_1$ ($V_1$) is the mean (variance) in the treatment group before matching and $X_0$ ($V_0$) the analogue for the control group. $X_{1M}$ ($V_{1M}$) and $X_{0M}$ ($V_{0M}$) are the corresponding values for the matched samples. This is a common approach used in many evaluation studies. One possible problem with the standardized bias approach is that we do not have a clear indication for the success of the matching procedure, even though in most empirical studies a bias reduction below 3% or 5% is seen as sufficient.

**Step 5: Sensitivity Analysis**

**Unobserved Heterogeneity - Rosenbaum Bounds**

The estimation of treatment effects with matching estimators is based on the CIA that is selection on observable characteristics. However, if there are unobserved variables which affect assignment into treatment and the outcome variable simultaneously, a 'hidden bias' might arise. It should be clear that matching estimators are not robust against this 'hidden biases. Since it is not possible to estimate the magnitude of selection bias with non-experimental data, we address this problem with the bounding approach proposed by Austin (2011). The basic question to be answered is, if inference about treatment effects may be altered by unobserved factors. In other words, we want to determine how strongly an unmeasured variable must influence the selection process in order to undermine the implications of matching analysis.

**Failure of Common Support - Lechner Bounds**

Those individuals that fall outside the region of common support have to be disregarded. But, deleting such observations yields an estimate that is only consistent for the subpopulation within the common support. However, information from those outside the common support could be useful and informative especially if treatment effects are heterogeneous.

## 2.5.Definition of Variables and Hypothesis

### 2.5.1. The dependent variable of the model

**Adoption of hydroponic fodder (IWVs)**: This is a dummy variable taking the value of "1" if the pastoralist household adopted hydroponic fodder production and "0" otherwise. The effects of the use of hydroponic fodder were observed after three to four consecutive years of the varieties and increased productivity.

### 2.5.2. Outcome variable

**Household Income**: is the amount of income generated from the production of hydroponic fodder through direct selling and selling of livestock products.

#### 3.6.3. Independent variables

The explanatory variables in this study are those variables that influence adoption of hydroponic fodder production and its impact on milk income and household income. They are defined as follows:

**Age of household head:** This variable is a continuous variable defined as the period from birth to the time of the interview measured in years. According to the study by Amare and Simane (2018), it is assumed that as farmers age increases, the probability of adoption of hydroponic fodder is expected to increase However, some studies showed that younger farmers are quick and willing to take risks with the adoption of new technology (Jambo et al. 2021; Singha 2019). Therefore, the coefficients for this variable were hypothesized to influence adoption and household income differently.

**Sex of household head:** It refers to the sex of the household head, and it is a dummy variable that takes a value of 1 if the household head is male and 0 otherwise. It is hypothesized that male-headed households have a higher probability of adopting hydroponic fodder than female-headed households. Male-headed households have a greater opportunity to participate in different training programs and have a chance to obtain more information. Female-headed households are more involved with childcare and home management than with interactions outside of the home. According to (Kassie and Alemu 2021; Jambo et al. 2021b), male-headed households have a better chance to adopt hydroponic fodder and use improved technology since they easily gain new information and are risk-takers. Hence, sex of the household head was expected to positively affect the adoption of hydroponic fodder production practices.

**Family Size:** It is a continuous variable that is measured in adult equivalent and refers to the total number of family members multiplied by the adult equivalent that live together in a given household, taken in the standardized unit of equivalency. According to (Mugambi 2020), large families may have a greater chance of adopting hydroponic fodder production. In this study, family sizes were expected to have a positive effect on the adoption of hydroponic fodder applications.

**Educational level:** This variable is a continuous variable measured in years of formal schooling spent by household heads. The education level of the household head, which is one of the significant indicators of human capital have a positive effect on the adoption of hydroponic fodder. Educated farmers are believed to obtain, analyse, and evaluate information on different agricultural inputs and technologies. Each additional year of education for the household head increases the probability of adoption of hydroponic fodder varieties (Harerimana et al. 2023; Upreti et al. 2022). In light of this, it was expected to have a positive relationship with the adoption of hydroponic fodder.

**Market distance:** It is a continuous variable measured in kilometres. Market distance is one of the determining factors in the adoption of hydroponic fodder production. Better access to the market can influence the use of output and input markets and the availability of information. It was expected that pastoral households living near the market would easily access the market for their milk products, hence readily adopting and intensively using hydroponic fodder (Shit 2019; TC et al. 2020). Therefore, this study hypothesized that access to the market is positively related to adoption of hydroponic fodder.

**Total herd size**: This is a continuous variable that represents the herd size of the pastoral household in a tropical livestock unit (TLU). Livestock is considered an asset and prestige that could be used in the production process or exchanged for cash or other productive assets. As depicted by (Omollo et al. 2018), herd size is taken as an asset, so as pastoralists hold a number of livestock; they can easily generate an income that enables them to cover the required cost of production and milk marketing. Studies have argued that pastoral households with large herd size have an opportunity to earn more income, improve their food security states, and invest in different production and improvement technologies, such as hydroponic fodder varieties. Hence, this variable was hypothesized to have a positive relationship with the adoption of hydroponic fodder production to gain more milk yields and income.

**Use of credit (CREDT):** This is measured as a dummy variable taking value of 1 if the pastoral household obtained credit and 0 otherwise. Using credit improves the financial capacity of pastoral households to buy modern inputs, thereby increasing production, which is reflected in the market supply of hydroponic fodder (Ahamed et al. 2023b). Additionally, this credit helps households to spend on other income-generating activities, which increases the households' probability of accumulating more household assets and necessary to boost milk yields and household income. Therefore, this variable was expected to have a positive influence on the adoption of hydroponic fodder.

**Pastoral Development Agents (PDA):** It is a dummy variable, which takes a value "1" if the household was involved in contact with PDAs and 0, otherwise. Farmers visited by PDAs are believed to be exposed to different, new, and updated information. Pastoralists who are repeatedly visited by PDAs are expected to influence the adoption of hydroponic fodder varieties more positively than those who are rarely visited. Arif et al. (2023) revealed that access to improved fodder production practices is related to access to pastoral development services. Therefore, this variable was expected to have a positive influence on the adoption of hydroponic fodder.

**Participation in non-herding activities:** This was used as a dummy variable, which takes a value "1" if the pastoral household was involved in non-herding activities and 0, otherwise. Non-herding activities generate additional sources of income for households but needs extra budget to run the non-livestock activities. Non-herding activities is income earned from working daily labor, trade, motor bicycle, bicycle, formal job, informal job, and handcrafts etc. That is, all activities associated with work, whether waged or self-employed, are located in pastoral areas. Households may obtain income from different sources, which may drive the adoption of hydroponic fodder since they can be used to buy different inputs. According to (Gunasekaran et al. 2019) and (Upreti et al. 2022), households with higher incomes are more likely to enjoy better adoption and improve their capacity to adopt agricultural innovations. Therefore, this variable was expected to have a positive relationship with the adoption of hydroponic fodder practices.

**Access to training on hydroponic fodder**: It was a dummy variable that is 1 if a pastoral household have access to training on hydroponic fodder production and 0 otherwise. Training is one of the means by which pastoralist households acquire new knowledge and skills. Attending training is expected to positively influence farmer's fodder adoption behaviour (TC et al. 2020). Hence, it was expected to positively influence adoption of hydroponic fodder production practices.

**Membership to pastoral cooperatives:** This is a dummy variable that represents "1 if a pastoralist household was a member of cooperatives and "0 otherwise. Membership to cooperatives allow pastoral households to easily access inputs at an affordable price that is pertinent to increasing livestock production, and pastoral households can easily adopt improved fodder technologies (Shit 2019). Therefore, membership to cooperatives was expected to have a positive relationship with the adoption of hydroponic fodder practices.

## 3. Results and Discussions

### 3.1. Descriptive results

Table 2 shows the results of the descriptive statistics for the continuous explanatory variables. The average age of the household heads was 49.02 years. The average age of adopter households was 48.15 years and its standard deviation was 7.16 and also, the average age of non-adopter households was 49.73 years with a standard deviation of 7.95. The mean value of education of sample households was 5.23 grades. The mean education level for adopter households was 5.7 grades and its standard deviation was 3.42 and also, the mean education level for non-adopter households was 4.84 grades and its standard deviation was 3.94. The average livestock holding of adopters was 4.78 while the average livestock holding for non-adopter households was estimated at 4.31 TLU. That means there was statistical mean difference between adopters and non-adopters in terms of livestock holding not significance level. The survey result indicates that livestock holding was relatively the same in both adopters and non-adopters but adopters have slightly showed more extended livestock holding than non-adopters.

Table 2: Descriptive statistics results for continuous explanatory variables, N=211

| Variables | Adopter (n=100) | | Non-Adopter (n=111) | | Total (n=211) | | T-test |
|---|---|---|---|---|---|---|---|
| | Mean | St.dev | Mean | St.dev | Mean | St.dev | |
| Age | 48.16 | 7.16 | 49.73 | 7.95 | 49.02 | 7.60 | 1.67** |
| Family size | 3.44 | 1.56 | 3.58 | 1.47 | 3.52 | 1.51 | 0.750 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Education level | 5.70 | 3.42 | 4.84 | 3.94 | 5.23 | 3.74 | -1.87** |
| Market distance | 7.69 | 4.61 | 6.96 | 4.423 | 7.29 | 4.51 | -1.3216 |
| Livestock ownership | 4.78 | 1.30 | 4.31 | 1.479 | 4.52 | 1.41 | -2.7660 |

Source: Own survey result, 2023

***and ** indicate significance at 1% and 5% probability levels respectively.

Table 3 shows the results of descriptive statistics of the categorical explanatory variables. From the total sample respondent households 78 % were male headed households and the rest 22 % were female-headed . From the male headed households, 90.75% were found to be adopters of hydroponic fodder and the remaining 67.5 % were non-adopters. Out of the female-headed households, 9.25 % were adopters and 32.5% were non-adopters. From the total sample respondent households, on average 61% participated in training while 39% of their counterparts did not. From households that participated in training, 74.1% were adopters and the remaining 33.7% were non-adopters. On the other hand, from the households who did not participate in training, 5.9% were adopters and the remaining 66.3% were non adopters of hydroponic fodder. The chi-square test of association result shows that there is a statistically significant association between participation in training and adoption of hydroponic fodder at a 1% significance level.

Table 3: Descriptive statistics results for dummy explanatory variables, N=211

| **Variables** | | **Adopter (n=100)** | | **Non-Adopter (=211)** | | **Total (n=2011)** | | $\chi^2$ **–test** |
|---|---|---|---|---|---|---|---|---|
| | | **No** | **%** | **No** | **%** | **No** | **%** | |
| Sex | Male | 108 | 90.75 | 98 | 67.5 | 206 | 78 | 20.46*** |
| | Female | 11 | 9.25 | 47 | 32.5 | 58 | 22 | |
| Use of credit | Yes | 112 | 94.1 | 53 | 36.5 | 165 | 62.5 | 92.41*** |
| | No | 7 | 5.9 | 92 | 63.5 | 99 | 37.5 | |
| Contacts extension agents | Yes | 108 | 90.7 | 58 | 40 | 166 | 62.9 | 72.1*** |
| | No | 11 | 9.3 | 87 | 60 | 98 | 37.1 | |
| Off/Nonfarm activities | Yes | 79 | 66.3 | 81 | 55.8 | 160 | 60.6 | 3.03* |
| | No | 40 | 33.7 | 64 | 44.2 | 104 | 39.4 | |
| Participating in training | Yes | 112 | 94.1 | 49 | 33.7 | 161 | 61 | 99.9*** |
| | No | 7 | 5.9 | 96 | 66.3 | 103 | 39 | |
| Membership to cooperative | Yes | 96 | 80.6 | 72 | 49.6 | 168 | 63.6 | 27.17*** |
| | No | 23 | 19.4 | 73 | 50.4 | 96 | 36.4 | |

Source: Own survey result, 2023.

*****,** and ***** indicate significance at 1%, and 10% probability level respectively.

## 3.2.Econometric Results

This section presents the results of the binary logistic regression model used to analyse the variables affecting the adoption of hydroponic fodder production. Propensity matching score was used to determine how the adoption of hydroponic fodder impacts pastoralist's households' income. Data from adopter and non-adopter households were used in the estimation, and the dependent variable has a value of 1 in the case that the pastoralists' household has adopted hydroponic fodder and 0 in the other case.

### 3.2.1. Factors affecting the adoption of hydroponic fodder

Table 4 presents the results of binary logistic regression model that used to determine the factors affecting the adoption of hydroponic fodder. The sample households' hydroponic fodder adoption decisions was used as the dependent variable in the binary logistic regression model. The model contained a total of eleven explanatory variables, including five continuous and six dummy instrumental variables. Seven of the eleven explanatory variables that include the age, level of education, contacts with pastoral development agents, herd size, use of credit, participation in training on hydroponic fodder, and pastoral cooperative membership were determined to have significant effect on adoption of the hydroponic fodder. It indicates that the probability of adoption increased with the magnitude of each variable's positive impacts for every unit increase in any of these variables.

Table 4: The binary logistic regression results of adoption of hydroponic fodder

Number of obs =211 Log pseudo likelihood = -25.716924
Prob > chi2 = 0.0000 Pseudo R2 = 0.8585

| Variables | Coef. | Std. Err. | Z | P>\|z\| | Marginal effects |
|---|---|---|---|---|---|
| Age of the household head | 0.1477882 | 0.0829336 | -1.78 | 0.132 | 0.0042625 |
| Sex of the household head | 2.76157 | 1.031402 | 2.68 | 0.018 | 0.0796482 |
| Family size of the household | 0.1857279 | 0.3740051 | 0.50 | 0.677 | 0.0053567 |
| Educational level of the household | 0.2142069* | 0.1145939 | 1.87 | 0.069 | 0.0061781 |
| Market distance from home | 0.087634 | 0.1070622 | -0.82 | 0.441 | 0.0025275 |
| Herd size of the household | 0.7925495*** | 0.3431889 | 2.31 | 0.001 | 0.0228584 |
| Access to credit service | -4.4135*** | 1.043154 | -4.23 | 0.000 | 0.1272926 |
| Contact with Pastoral DA | 2.406305 | 0.9485143 | 2.54 | 0.014 | 0.0694018 |
| Non-livestock income | 0.4523271 | 0.8157734 | -0.55 | 0.670 | 0.0130459 |
| Participation in training | 6.233607*** | 1.654433 | 3.77 | 0.001 | 0.1797874 |
| Membership in Pa cooperative | 2.732039*** | 0.9367287 | 2.92 | 0.000 | 0.0787965 |
| Cons | 12.08865 | 5.271604 | -2.29 | 0.003 | |

***, ** and * indicate significance at less than 1%, 5% and 10% probability level, respectively, Source: own survey result, 2023

**Education level (EDUC):** the findings revealed that educational level of the household head has a positive and significant effect on the probability of adoption of hydroponic fodder at less than 10% probability level. A one year increase in level of education is associated with a 0.62% increase in the predicted value of adoption of hydroponic fodder, holding other variables constant. It also indicates that literate farmers are more likely to adopt hydroponic fodder than illiterate farmers. This could be due to the fact that farmers are likely to have greater information access and are more likely to be aware of new technologies. This suggests that as household education rises, so could the adoption of hydroponic fodder. This finding is in line with the findings of (Arif et al. 2023) and (Ahamed et al. 2023b) that found positive association between household heads' education and technology adoption.

**Herd size**: Herd size is found to affect the likelihood of adoption of hydroponic fodder positively ($p < 0.01$) . The marginal effect indicated that a TLU increase in livestock ownership is associated with a 2.29% increase in the predicted value of the adoption of hydroponic fodder, holding other variables constant. It indicates that rural households with larger livestock holdings are more likely to adopt hydroponic fodder. A possible explanation for this could be that households with more livestock incomes make more investments overall than households that have less livestock incomes and more likely to engage in more loan arrangements and payback records. This result is consistent with the study by (Mugambi 2020), who found that larger livestock households are more likely to adopt hydroponic fodder.

**Use of credit:** The model result shows a significant negative impact of access to credit on farmers' adoption of hydroponic fodder ($p < 0.01$) at less than 1% significant level (Table 6). The marginal effect explains that if the household uses credit, his/her probability of adoption of hydroponic fodder would be 12.73% lower than a household head which do not have access to credit, all other variables are held constant. The possible explanation for this could be that credit users are those who are poorer and they might get the credit for their other basic needs. This was confirmed by previous studies conducted ((Upreti et al. 2022 ; Gunasekaran et al. 2019; Agius et al. 2019).

**Participation in training on hydroponic fodder:** The model result indicates that training participation is positively correlated with the adoption of hydroponic fodder ($p < 0.01$) . The result of the reduced regression shows that households that took part in the training of hydroponic fodder are more likely to allocate a significant amount of their land to these varieties than are households that did not participate. Keeping other things in the model constant, households that took part in the training showed a 17.98% increase in the adoption of hydroponic fodder as compared to those that did not. This is in line with previous studies by (Berhanu et al. 2016), and (Shit 2019), that found training as having a positive influence on the rate and intensity of new technology adoption.

**Membership in pastoral cooperatives:** Membership in co-operatives positively and significantly influenced the probability of adoption of hydroponic fodder ($p < 0.01$) . Other variables held the constant, farmers who have the opportunity to be members of cooperatives are more likely to adopt improved hydroponic fodder technologies by a factor of 7.88% compared to their non-adopters. This variable showed that farmers who had the opportunity to be members of co-operatives were more probability to adopt hydroponic fodder technologies than those farmers who had not. By implication membership in cooperatives is more likely to help farmers access inputs at an affordable price and to share experience that is relevant to enhance agricultural productivity facilitating for farmers to adopt hydroponic fodder. This result concurs with (Agius et al. 2019; Upreti et al. 2022) who found that facilitating for producers to membership of a cooperative with the necessary information helped them to assess the usefulness of the technology, share an experience and, as a result, for adoption .

### 3.2.2. Impact of hydroponic fodder adoption on household income

Using an estimated propensity score to determine whether adopters and non-adopter households shared support, the propensity score distribution for each household in the treatment and control groups was determined. The distribution of the sample households about the determined propensity scores is shown in Figure 2. Furthermore, the distribution of the propensity scores for all sample households (for those in the treatment and control groups are shown in the figure 2 to have kernel density distributions that are relatively similar to a normal distribution. While most of the households in the control group are located on the lower side of the distribution, the majority of the treatment households are located partially on the upper and partially on the right side of the distribution.

### 3.2.3. Matching of adopter and non-adopter

To determine the common support region, treatment and control household groups were matched. According to (Asrat et al. 2022), the basic criteria for determining the common support region is to eliminate all observations whose propensity score is greater than the maximum and smaller than the minimum propensity scores in the opposite group. In other words, this means eliminating all observations that fall outside of the overlapped region.

As shown in Table 5, the estimated propensity scores for treatment sample households range from 0.000281 to 0.953 with a mean of 0.4028, while the control group range from 0.000360 to 0.952 with a mean of 0.4900. Therefore, in the vicinity of, the common support assumption is encountered [0.00036–0.952] for the sampled households. Therefore, households having an estimated propensity scores higher than 0.952 and lower than 0.00036 are not taken into consideration for the matching efforts.

Table 5: Distribution of estimated propensity scores

| Group | Observations | Mean | St.dev | Minimum | Maximum |
|---|---|---|---|---|---|
| Adopter | 100 | 0.4028 | 0.333 | 0.000281 | 0.953 |
| Non-adopter household | 111 | 0.4900 | 0.345 | **0.000360** | **0.952** |
| Total household | 211 | 0.450 | 0.342 | 0.000281 | 0.953 |
| Overlap region (208) | | | | **0.000360** | **0.952** |

Source: Survey data (2023).

The distribution of the propensity score and common support region are shown in Figure 2 below. The propensity score distribution of adopter households is shown in the upper half of the histogram, while the propensity score distribution of non-adopter households is shown in the bottom half.

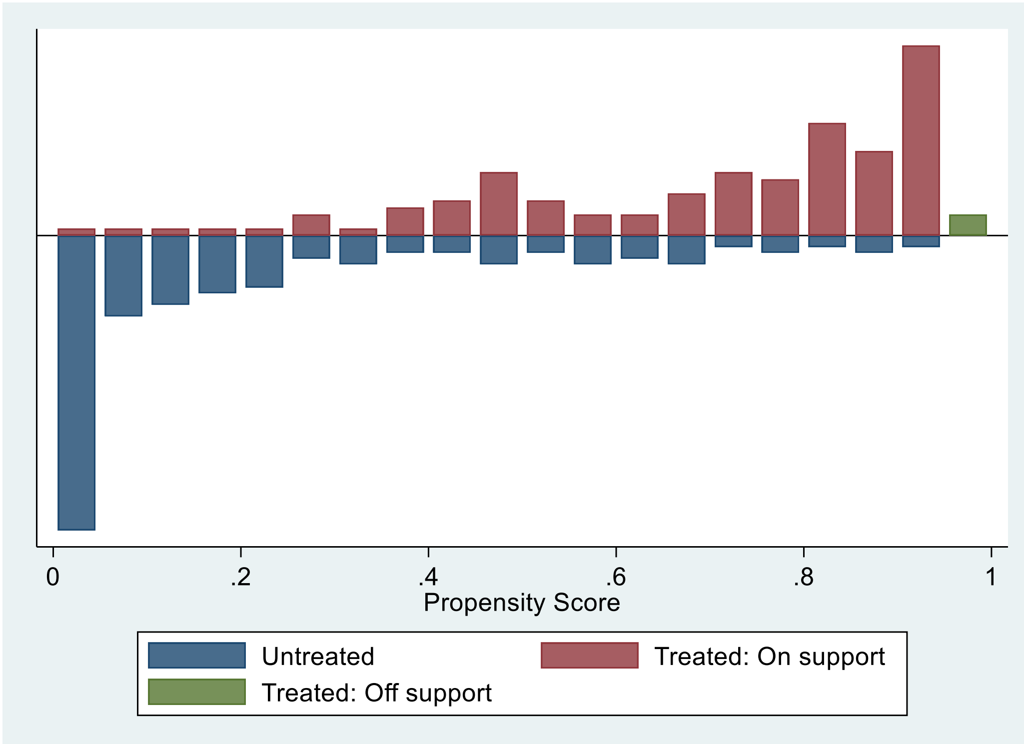


Figure 2: Propensity score distribution of after matched sample.

Source**:** Own computation based on survey data, (2023)

The observations in the adopter and non-adopter groups that have a suitable comparison are indicated by the red (treated on support) and green (treated off support), respectively, whereas the observations in the non-adopter group that do not have a suitable comparison are indicated by blue (untreated) color.

### 3.2.4. Choice of matching Algorithm

Using the radius caliper, kernel bandwidth, and closest neighbor matching techniques, the matching algorithm was selected. Four factors are taken into consideration when choosing an estimator: the number of matched sample sizes, pseudo-$R^2$, mean bias, and the balancing test (number of insignificant variables). Similarly, the best estimator of the data was determined to be a matching estimator that generates a high matched sample size, more insignificant variables, small mean bias between 3 and 5, and a low pseudo-$R^2$ value. As a result, it was found that the best estimator for the data at hand on the impact of hydroponic fodder adoption on household income of the sample households was the kernel matching with bandwidth 0.01 (Table 6).

Table 6: Performance of matching estimators

| Matching estimators | Number of insignificant variables after matching | Pseudo-$R^2$ after matching | Matched sample size | Mean bias |
|---|---|---|---|---|
| NN matching | | | | |
| Nearest neighbor 1 | 7 | 0.060 | 261 | 13.5 |

| | | | | |
|---|---|---|---|---|
| Nearest neighbor 2 | 7 | 0.057 | 261 | 13.3 |
| Nearest neighbor 3 | 7 | 0.053 | 261 | 14.0 |
| Nearest neighbor 4 | 7 | 0.047 | 261 | 12.9 |
| Nearest neighbor 5 | 7 | 0.049 | 261 | 12.9 |
| Caliper matching | | | | |
| Radius 0.01 | 7 | 0.055 | 226 | 12.6 |
| Radius 0.05 | 7 | 0.060 | 261 | 13.5 |
| Radius 0.1 | 7 | 0.060 | 261 | 13.5 |
| Radius 0.5 | 7 | 0.060 | 261 | 13.5 |
| Radius 1 | 7 | 0.060 | 261 | 13.5 |
| Kernel matching | | | | |
| Bandwidth 0.01 | 7 | 0.030 | 261 | 4.5 |
| Bandwidth 0.05 | 7 | 0.043 | 261 | 11.9 |
| Bandwidth 0.1 | 7 | 0.042 | 261 | 12.1 |
| Bandwidth 0.25 | 7 | 0.032 | 226 | 9.5 |
| Bandwidth 0.5 | 7 | 0.081 | 261 | 14.0 |

Source: Survey data (2023).

### 3.2.5. Testing the propensity score and covariate balance

After choosing the best performing matching algorithm the next task is to check the balancing of propensity score and covariate using different procedures by applying the selected matching estimator. As indicated earlier, the main purpose of the propensity score estimation is not to obtain a precise prediction of selection into treatment, but rather to balance the distributions of relevant variables in both groups. The balancing powers of the estimations are ascertained by considering different test methods such as the reduction in the mean standardized bias between the matched and unmatched sample, equality of means using t-test and chi-square test for joint significance for the variables used. Similarly, t-values in Table 7 shows that before matching seven of chosen variables exhibited, there was statistically significant differences while after matching almost all of the covariates are balanced.

Table 7: Propensity score and covariance balancing test

| Variable | Unmatched Matched | Mean Treated | Control | %bias | %reduct Bias | t-test T | p>\|t\| |
|---|---|---|---|---|---|---|---|
| Age of the household | U | 48.16 | 49.738 | -20.8 | | -1.68* | 0.095 |
| | M | 50.192 | 45.176 | 45.3 | -17.3 | 2.13 | 0.036 |
| Sex of the household | U | 0.90756 | 0.67586 | 59.3 | | 4.69*** | 0.000 |
| | M | 0.86538 | 0.75191 | 31.5 | 46.9 | 1.41 | 0.162 |
| Family size of the household | U | 3.4454 | 3.5862 | -9.3 | | -0.75 | 0.453 |
| | M | 3.5 | 2.9051 | -7.6 | 17.6 | -0.39 | 0.698 |
| Educational level of the household | U | 5.7059 | 4.8414 | 23.4 | | 1.88* | 0.062 |
| | M | 5.1731 | 4.0442 | -30.3 | -29.5 | -1.40 | 0.164 |
| Market | U | 7.6975 | 6,96 | 11.9 | | 0.96 | 0.336 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| distance | M | 8.0577 | 7.9271 | 57.5 | 82.3 | 3.14 | 0.002 |
| Herd size | U | 4.7899 | 4.3103 | 34.4 | | 0.32 | 0.750 |
| | M | 4.7692 | 4.8897 | -8.7 | 74.9 | -1.83 | 0.071 |
| Contact PD | U | 0.90756 | 0.40 | -25.7 | | -9.93*** | 0.000 |
| | M | 0.86538 | 0.81496 | 11.6 | 90.8 | 0.62 | 0.536 |
| Non-livestock | U | 0.66387 | 0.55862 | -21.6 | | -1.74* | 0.082 |
| | M | 0.55769 | 0.83315 | 5.3 | 75.5 | 0.25 | 0.802 |
| Membership in Pa Cooperative | U | 0.80672 | 0.49655 | 68.6 | | 5.48*** | 0.000 |
| | M | 0.82692 | 0.76592 | 13.5 | 80.3 | 0.77 | 0.445 |

Source: Own survey result (2023)

*** and * indicates significant at 1% and 10% significance levels, respectively.

Table 8 presents the findings of the covariate balancing test, which compares the unmatched and matching algorithms for statistically significant differences. Some variables were significantly varied between the two respondent groups during matching. However, some of these significant variables were conditioned to be insignificant, indicating the variables between treatments and control that were balanced. The hypothesis that both groups have the same distribution of variables after matching is supported by the low pseudo-$R^2$ and the insignificant likelihood ratio tests (Table 8). The results clearly showed that the matching technique was capable of balancing the traits of the comparison groups that are treated and controlled. It was used to compare the observed outcomes for treatments with those of a comparison group sharing common support to assess the impact of the adoption of hydroponic fodder among groups of households with comparable observed characteristics.

Table 8: Chi-square test for the joint significance of variables

| Sample | Pseudo $R^2$ | LR $chi^2$ | p>$chi^2$ |
|---|---|---|---|
| Unmatched | 0.412 | 149.66 | 0.000 |
| Matched | 0.030 | 6.66 | 0.757 |

Source: Own survey result, 2023

According to all of the tests mentioned above, the matching algorithm used is, on all levels, the best one for the available data. As a result, the kernel matching bandwidth (0.01) matching method was found to be the best estimator in this study, and the ATT estimate was subsequently performed using this best choice estimator.

### 3.2.6. Sensitivity of the estimated average treatment effects (ATT)

Table 9 portrays a summary of the results' robustness and matching quality. Fair matching quality is shown by the mean standardized bias (40.9%) reducing from 33.6% before matching to 4.5% after matching with a lower pseudo-R2 value. Moreover, the cases lost to common support limitations are rather low (1.136% of the all sample), and the mean bias after matching falls within the acceptable range of 3-5%.

Table 9 additionally showed the sensitivity analysis that was conducted using the Rosenbaum bounding approach. The CIA, or selection based on observable characteristics, acts as the foundation for estimating treatment effects with matching estimators. However, a "hidden bias" might appear if there are unreported factors that influence both the outcome variable and the allocation to treatment at the same time. We used the bounds approach to solve this issue because non-experimental data cannot be used to evaluate the magnitude of selection bias (Upreti et al. 2022). The level of significance was not affected by an increase in the crucial gamma level (p-value 7E-06-5E-03). This showed that the p-critical values had significance for the outcome variable estimated at various gamma-critical value criticality levels, which further indicated that significant factors affecting adoption and hydroponic fodder yields were taken into consideration for the study. Therefore, our impact estimates (ATT) represent the true effect of adoption on hydroponic fodder income per hectare and are not subject to unobserved selection bias.

Table 9: Sensitivity analysis of the estimated ATT

| | $SB_{Before}$ (%) | $SB_{After}$ (%) | % (SB) reduction | Cases lost to CS | Pseudo-$R^2$ | Critical values of gamma (Γ) |
|---|---|---|---|---|---|---|
| Adopter/Non-adopter | 33.6 | 4.5 | 40.9 | 3 (1.136%) | 0.030 | 7E-06-5E-03 |

Source: Own survey estimation (2023)

According to Dehejia (2002), sensitivity analysis is the final diagnostic that is performed to check the sensitivity of the estimated treatment effect to small changes in the specification of the propensity score; this is a useful diagnostic on the quality of the comparison group. Moreover, sensitivity analysis was undertaken to detect the identification of a conditional independence assumption (CIA) that was satisfactory or affected by the confounder. This indicated that the estimated ATT was robust to the specific failure of the CIA. Table 10 reveals the sensitivity analysis of the outcome ATT values of hydroponic fodder income to the confounder variables. As it was clearly realized from the table, the significance level was unaffected even if the gamma values were relaxed to any desirable level, which shows that ATT was insensitive to external change. Therefore, the CIA remained significant, the results were not sensitive to the confounders, and there are no external confounders that affect the result calculated for ATT.

### 3.2.7. Average treatment effect on the treated (ATT)

The estimated average treatment effect (ATT) of sample households revealed that the adoption of hydroponic fodder had a significant positive effect on the hydroponic fodder yields of the smallholder farmers in the treatment groups. The results showed that adopting hydroponic fodder caused average positive differences in hydroponic fodder income between adopters and non-adopters (unmatched). As the table below depicts, the ATT estimate using kernel matching bandwidth with the nearest (0.01) summarized the results of these variables . In contrast to the control (untreated) groups, the treatment groups' average treatment effect on their treated (ATT) hydroponic fodder yields earned 36 points per hectare (see Table 10). In contrast, the control groups' 30.41 point rating showed that there existed an effective significance level. In other words, the average hydroponic fodder yields for the treatments were greater than that of the control groups. The outcomes revealed that smallholder farmers who adopted hydroponic fodder had a favourable and statistically significant difference in their yields compared to those who did not. The tendency for adoption decisions explains the difference.

Adoption of hydroponic fodder by households frequently contributed to a 15.5% increase in the treatment group households' hydroponic fodder outcome over the control group. Frequently results in an average 15.5% increase in treated households' hydroponic fodder yields compared to control groups. Therefore, it is reasonable to conclude that the impact analysis of households' on hydroponic fodder income benefits the households in the study's area. Overall, the findings support the results of previous research on the impact of improved fodder technology adoption by (Harerimana et al. 2023), (Tofu et al. 2023), (Mugambi 2020) and (Arif et al. 2023).

Table 10: Average treatment effects estimated for household hydroponic fodder yields

| Outcome variable | Sample | Treated | Control | Difference | S.E | T-Stat |
|---|---|---|---|---|---|---|
| Household | Unmatched | 35.83 | 34.68 | 1.149 | 1.035 | 1.11 |
| Income | ATT | 36 | 30.41 | 5.58 | 1.987 | 2.93*** |

*** indicates significant at less than 1% probability level. Source: Own survey (2023)

Farmers during the focus group discussion explained the role that hydroponic fodder cultivation plays in contributing to their agricultural transformation. Therefore, the results estimated above are in line with the situations reported already by adopter farmers in the cultivation of hydroponic fodder and highly benefit from the agricultural development that adoption of hydroponic fodder promotes for smallholders.

## 4. Conclusions and implications

The most crucial factor in achieving higher agricultural productivity and improved income for Ethiopian smallholders is thought to be the application of improved agricultural technologies. The purpose of this study was to contribute to the knowledge gap about the variables that impact the yields of hydroponic fodder among pastoral households residing in a moistor deficit context, taking the Borana pastoralists as a microcosm. A multistage sampling strategy was adopted to choose 264 farmers from the sample for cross-sectional data collection. Methods for econometric data analysis and descriptive statistics were used. Therefore, the study focused on how farmers' decisions to adopt or not to adopt hydroponic fodder were influenced by their adoption, as well as how adoption of hydroponic fodder impacts household income.

Key factors influencing the adoption process in the study's area were identified by the study. This understanding is also helpful in reconsidering the impacts to the adoption of hydroponic fodder. The main variables were divided into three categories: institutional, socioeconomic, and demographic. Because different pastoralist households live in various agro-ecologies, socio-cultural contexts, and with varying pastoral resources, these factors are not the same. Adopting hydroponic fodder improves the lives of those who adopt them and helps pastoral households increase their yields. The findings demonstrated that a number of parameters, which warrant careful attention, were highly correlated with the impacts of adopting hydroponic fodder.

Sex significantly positive impact on hydroponic fodder was adopted. Policy makers should prioritize empowering female-headed households to be change agents and participants in the adoption of modern agricultural technologies, such as hydroponic fodder, by taking into account an integrated and comprehensive approach to the country's development, where in their involvement is relevant to all national development endeavors. Compared to illiterate pastoralist households, educated pastoralists have greater access to information, are better able to understand and evaluate it, and are more aware of new technologies. This increased knowledge helps new technologies to be adopted. Additionally, the district education bureau should pay close attention to expanding education access and raising the number of educated pastoralists in order to ensure household income through the adoption of hydroponic fodder. Thus, in order to boost the adoption of hydroponic fodder and raise hydroponic fodder yields, education services must be reinforced.

Herd size is also an important determinant of adoption of hydroponic fodder. This suggests that pastoralists need to be provided technical support especially medication services of animals since the area is exposed to high prevalence of tsetse fly diseases and improving productivity of livestock for income generation. Therefore, research centers, pastoral development offices and pastoral development workers need to play more roles on the livestock production, management, and diseases control through improving resistance of livestock and their nutritional supply.

The study's findings also showed that cooperative membership was favorably and significantly affecting the adoption of hydroponic fodder. Therefore, to support farmer-to-farmer knowledge sharing in the study area, pastoralists' cooperatives need to be strengthened. Additionally, a lot of work needs to be done to capacitate their financial and human resources by offering incentives so that they can serve as the center for agricultural technology transformation. According to the study's findings, pastoralists would make better decisions about the probability of adopting hydroponic fodder if they had better pastoral development agent contacts. Therefore, a suitable and effective PDA contacts can encourage pastoralists to employ hydroponic fodder, which is increase the effectiveness of agricultural extension services. Therefore, the researcher recommends that the development agents identify farmers' circumstances and an issue that promotes smallholders' adoption of hydroponic fodder in order to increase the frequency of extension contacts. The contacts of extension visits with pastoralists about agricultural technologies, namely hydroponic fodder, is greatly influenced by the district's agricultural and rural development office as well as other stakeholders.

The impact of adoption of hydroponic fodder on income of pastoralist households analyzed based on sample of matched treated and control groups. A propensity score matching approach was used to compare adopter households with non-adopters in terms of hydroponic fodder yields (natural log of hydroponic fodder yield) which are measured in quintal. From the kernel matching estimator with bandwidth propensity score closest to (0.01), the estimated of ATT found that adoption of hydroponic fodder had positive impact on treated pastoralists in farm their yields. That means as the pastoralists adopt and practice the impacts of hydroponic fodder was indicating positive outcome of hydroponic fodder adoption on the adopter's hydroponic fodder income obtained. The treated sample households were found to have improved yields difference than the untreated (control group) sample households. The adoption decision of households for hydroponic fodder has generated about 15.5% increases in yields of treated over control groups. Therefore, the adoption of hydroponic fodder was found to have a positive impact on the adopters on hydroponic fodder yield. Hence, encouraging pastoralists towards hydroponic fodder adoption is necessary.

**Acknowledgements**

The authors thank the Cordaid Ethiopia, the lead implementor of RESET Plus Innovation Program in Ethiopia for their generous financial support of the action research.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**Funding**

This publication was funded by the EU-RESET Plus Innovation Fund. The RESET Plus Innovation Program is funded by European Union and implemented by the Cordaid Ethiopia in collaboration with Fair and Sustainable Ethiopia.

**Availability of Data and Materials**

The data that support the findings of this study are available from the corresponding author upon reasonable request and with the permission of CORDAID Ethiopia. The corresponding Author: belaysisay@gmail.com should be contacted upon the request of the data.

**Ethical approval and consent to participate**

Ethical approval was obtained from the Wolaita Sodo University Human Research Ethics Committee WSU/HREC/543/2023. Informed written consent was obtained from the participants

**Declaration**

The study follows the declaration of Helsinki (https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects/**).**

## Reference


Agius, Alan, Grazia Pastorelli, and Everaldo Attard. 2019. "Cows Fed Hydroponic Fodder and Conventional Diet: Effects on Milk Quality." *Archives Animal Breeding* 62 (2): 517–25. https://doi.org/10.5194/aab-62-517-2019.

Ahamed, Md Shamim, Muhammad Sultan, Redmond R. Shamshiri, Md Mostafizar Rahman, Muhammad Aleem, and Siva K. Balasundram. 2023a. "Present Status and Challenges of Fodder Production in Controlled Environments: A Review." *Smart Agricultural Technology* 3 (February): 100080. https://doi.org/10.1016/j.atech.2022.100080.

———. 2023b. "Present Status and Challenges of Fodder Production in Controlled Environments: A Review." *Smart Agricultural Technology* 3 (June 2022): 100080. https://doi.org/10.1016/j.atech.2022.100080.

Alberto, Riccardo D, Matteo Zavalloni, and Meri Raggi. 2018. "AES Impact Evaluation With Integrated Farm Data : Combining Statistical Matching and Propensity Score Matching," 1–24. https://doi.org/10.3390/su10114320.

Ali, Hussien, Mesfin Menza, Fitsum Hagos, and Amare Haileslassie. 2022. "Impact of Climate-Smart Agriculture Adoption on Food Security and Multidimensional Poverty of Rural Farm Households in the Central Rift Valley of Ethiopia." *Agriculture and Food Security* 11 (1): 1–16. https://doi.org/10.1186/s40066-022-00401-5.

Amare, Abayineh, and Belay Simane. 2018. "Does Adaptation to Climate Change and Variability Provide Household Food Security? Evidence from Muger Sub-Basin of the Upper Blue-Nile, Ethiopia." *Ecological Processes* 7 (1). https://doi.org/10.1186/s13717-018-0124-x.

Arif, Muhammad, Qahtan A.W. Khalaf, Abd Ur Rehman, Sayed M. Hussain, Najlaa H. Almohmadi, Najah M. Al-Baqami, Mohamed E. Abd El-Hack, Mahmoud Kamal, Mohamed Tharwat, and Ayman A. Swelum. 2023. "Effects of Feeding Maize Hydroponic Fodder on Growth Performance, Nitrogen Balance, Nutrient Digestibility, Hematology, and Blood Metabolites of Water Buffalo Calves." *Open Veterinary Journal* 13 (12): 1607–13. https://doi.org/10.5455/OVJ.2023.v13.i12.10.

Asrat, Dagninet, Adugnaw Anteneh, Mohammed Adem, and Zewdu Berhanie. 2022. "Impact of Awash Irrigation on the Welfare of Smallholder Farmers in Eastern Ethiopia." *Cogent Economics and Finance* 10 (1). https://doi.org/10.1080/23322039.2021.2024722.

Austin, Peter C. 2011. "An Introduction to Propensity Score Methods for Reducing the Effects of Confounding in Observational Studies." *Multivariate Behavioral Research* 46 (3): 399–424. https://doi.org/10.1080/00273171.2011.568786.

Berhanu Gebremedhin, Ephrem Tesema, Azage Tegegne. 2016. "Value Chain Opportunities for Women and Young People in Livestock Production in Ethiopia : Lessons Learned Young People in Livestock Production In," 1–36.

Caliendo, Marco, and Sabine Kopeinig. 2008. "Some Practical Guidance for the Implementation of Propensity Score Matching." *Journal of Economic Surveys* 22 (1): 31–72. https://doi.org/10.1111/j.1467-6419.2007.00527.x.

Gebru, Kebede Manjur, Crelis Rammelt, and Maggi Leung. 2022. "Paradoxes of Inclusion: Adverse Effects of Inclusive Interventions in Northern Ethiopia." *European Journal of Development Research* 34 (5): 2324–45. https://doi.org/10.1057/s41287-022-00518-0.

Gunasekaran, S., C. Bandeswaran, and C. Valli. 2019. "Low-Cost Hydroponic Fodder Production Technology for Sustainable Livestock Farming during Fodder Scarcity." *Current Science* 116 (4): 526–28.

Harerimana, Theophile, Eric Hatungimana, Claire d.Andre Hirwa, and Remy Titien Niyireba. 2023. "Effect of Hydroponic Wheat Fodder Supplementation on Dry Matter Intake and Growth Performances of Piglets." *Scientific African* 19. https://doi.org/10.1016/j.sciaf.2022.e01507.

Heckman, James J. 1976. "The Common Structure of Statistical Models of Truncation, Sample Selection and Limited Dependent Variables and a Simple Estimator for Such Models." *Annals of Economic and Social Measurement* 5 (4): 475–92. http://ideas.repec.org/h/nbr/nberch/10491.html.

Horton, Douglas, André Devaux, Thomas Bernet, Sarah Mayanja, Miguel Ordinola, and Graham Thiele. 2023. "Inclusive Innovation in Agricultural Value Chains: Lessons from Use of a Systems Approach in Diverse Settings." *Innovation and Development* 13 (3): 517–39. https://doi.org/10.1080/2157930X.2022.2070587.

Issahaku, Gazali, and Awudu Abdulai. 2020. "Adoption of Climate-Smart Practices and Its Impact on Farm Performance and Risk Exposure among Smallholder Farmers in Ghana." *Australian Journal of Agricultural and Resource Economics* 64 (2): 396–420. https://doi.org/10.1111/1467-8489.12357.

Jambo, Yilma, Abera Alemu, and Workalemahu Tasew. 2021a. "Impact of Small-Scale Irrigation on Household Food

Security: Evidence from Ethiopia." *Agriculture and Food Security* 10 (1): 1–16. https://doi.org/10.1186/s40066-021-00294-w.
———. 2021b. "Impact of Small-Scale Irrigation on Household Food Security: Evidence from Ethiopia." *Agriculture and Food Security* 10 (1): 1–16. https://doi.org/10.1186/s40066-021-00294-w.
Kassegn, Andualem, and Ebrahim Endris. 2021. "Review on Livelihood Diversification and Food Security Situations in Ethiopia." *Cogent Food and Agriculture* 7 (1). https://doi.org/10.1080/23311932.2021.1882135.
Kassie, Koyachew Enkuahone, and Bamlaku Alamirew Alemu. 2021. "Does Irrigation Improve Household's Food Security? The Case of Koga Irrigation Development Project in Northern Ethiopia." *Food Security* 13 (2): 291–307. https://doi.org/10.1007/s12571-020-01129-5.
Kothari, CR. 2004. *Research Methodology: Methods and Techniques: New Age International (P) Ltd Publishers.* Second Rev. New Delhi.
Mekonnen, Adisu, Ayele Tessema, Zerhun Ganewo, and Ashenafi Haile. 2021. "Climate Change Impacts on Household Food Security and Adaptation Strategies in Southern Ethiopia." *Food and Energy Security* 10 (1): 1–14. https://doi.org/10.1002/fes3.266.
Mendoza, Ronald U., and Nina Thelen. 2008. "Innovations to Make Markets More Inclusive for the Poor." *Development Policy Review* 26 (4): 427–58. https://doi.org/10.1111/j.1467-7679.2008.00417.x.
Menghistu, Habtamu Taddele, Amanuel Zenebe Abraha, Girmay Tesfay, and Gebrehiwot Tadesse Mawcha. 2020. "Determinant Factors of Climate Change Adaptation by Pastoral/Agro-Pastoral Communities and Smallholder Farmers in Sub-Saharan Africa: A Systematic Review." *International Journal of Climate Change Strategies and Management* 12 (3): 305–21. https://doi.org/10.1108/IJCCSM-07-2019-0049.
Meskel, Tezera W., Mengistu Ketema, Jema Haji, and Lemma Zemedu. 2020. "Welfare Impact of Moringa Market Participation in Southern Ethiopia." *Sustainable Agriculture Research* 9 (3): 98. https://doi.org/10.5539/sar.v9n3p98.
Moores, Dane, and Andy Hunters. 2018. "Inclusive Market Systems Development Sustainable Growth for Everyone." *World Vision Policy Paper*, no. June. worldvision.com.au.
Mugambi, F. M. 2020. "Factors Affecting the Approbation of Hydroponics Farming as a Means to Mitigate and Adapt to Climate Change amongst Small Scale Farmers: A Case Study of Meru County, Kenya." *Master's Thesis, Norwegian University of Life Sciences, Ås* 1 (6): 1–25.
Naik, Kumar, Parashurama Chandravanshi, Basavaraj Naik, Pradeep S, Sannathimmappa C, and Sunil C. 2020. "Study on Hydroponic Maize Fodder Effect on Milk Production." *Journal of Pharmacognosy and Phytochemistry* 9 (6): 664–69.
Omollo, Erick Ouma, Oliver Vivian Wasonga, Mohammed Yazan Elhadi, and William Ngoyawu Mnene. 2018. "Determinants of Pastoral and Agro-Pastoral Households' Participation in Fodder Production in Makueni and Kajiado Counties, Kenya." *Pastoralism* 8 (1). https://doi.org/10.1186/s13570-018-0113-9.
Pouw, Nicky, Daniëlle de Winter, Katie Minderhoud, and Ellen Lammers. 2020. "Inclusive Business for Sustainable Food Systems."
Schoneveld, George C. 2020. "Sustainable Business Models for Inclusive Growth: Towards a Conceptual Foundation of Inclusive Business." *Journal of Cleaner Production* 277: 124062. https://doi.org/10.1016/j.jclepro.2020.124062.
Shit, Nonigopal. 2019. "Hydroponic Fodder Production: An Alternative Technology for Sustainable Livestock Production in India." *Exploratory Animal and Medical Research* 9 (2): 108–19.
Singha, Chandan. 2019. "Impact of the Adoption of Vegetative Soil Conservation Measures on Farm Profit, Revenue and Variable Cost in Darjeeling District, India." *Environment and Development Economics* 24 (5): 529–53. https://doi.org/10.1017/S1355770X19000226.
TC, Suma, Vivek R Kamat, Sangeetha TR, and Malla Reddy. 2020. "Review on Hydroponics Green Fodder Production: Enhancement of Nutrient and Water Use Efficiency." *International Journal of Chemical Studies* 8 (2): 2096–2102. https://doi.org/10.22271/chemi.2020.v8.i2af.9060.
Teklewold, Hailemariam, Alemu Mekonnen, Gunnar Kohlin, and Salvatore DI Falco. 2017. "Does Adoption of Multiple Climate-Smart Practices Improve Farmers' Climate Resilience? Empirical Evidence from the Nile Basin of Ethiopia." *Climate Change Economics* 8 (1). https://doi.org/10.1142/S2010007817500014.
Tesfaye, Wondimagegn, Garrick Blalock, and Nyasha Tirivayi. 2020. "Climate-Smart Innovations and Rural Poverty in Ethiopia: Exploring Impacts and Pathways." *American Journal of Agricultural Economics*. https://doi.org/10.1111/ajae.12161.

Thornton, Philip K., Anthony Whitbread, Tobias Baedeker, Jill Cairns, Lieven Claessens, Walter Baethgen, Christian Bunn, et al. 2018. “A Framework for Priority-Setting in Climate Smart Agriculture Research.” *Agricultural Systems* 167 (September): 161–75. https://doi.org/10.1016/j.agsy.2018.09.009.

Tofu, Daniel Assefa, Chalchisa Fana, Tegegn Dilbato, Niguse Bekele Dirbaba, and Gutu Tesso. 2023. “Pastoralists’ and Agro-Pastoralists’ Livelihood Resilience to Climate Change-Induced Risks in the Borana Zone, South Ethiopia: Using Resilience Index Measurement Approach.” *Pastoralism* 13 (1). https://doi.org/10.1186/s13570-022-00263-3.

Upreti, Sujaya, Ram P. Ghimire, and Niraj Banskota. 2022. “Comparison of Different Cereal Grains for Hydroponic Fodder Production in Locally Constructed Polyhouse at Khumaltar, Lalitpur, Nepal.” *Journal of Agriculture and Natural Resources* 5 (1): 27–33. https://doi.org/10.3126/janr.v5i1.50378.

Veterinary, Tamil Nadu. 2012. “Production of Low Cost Hydroponic Maize Fodder to Mitigate Fodder Shortage for Livestock during Drought Conditions,” 9–11.

WFP. 2020. “Ethiopia Annual Country Report 2020 Country Strategic Plan 2020-2025, Wolrd Food Programme , Addis Ababa, Ethiopia.”

Worku, Mitiku Adisu, Gudina Legese Feyisa, and Kassahun Ture Beketie. 2022. “Climate Trend Analysis for a Semi-Arid Borana Zone in Southern Ethiopia during 1981–2018.” *Environmental Systems Research* 11 (1). https://doi.org/10.1186/s40068-022-00247-7.