Mixed Farming System for Crop Yield Improvement and Adaptation to Climate Change: Evidence from Smallholder Farmers in Ethiopia

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Abstract

Adverse weather appears to compel smallholders in Ethiopia to shift increasingly towards a mixed-farming system. Nearly 90% of the smallholders practiced the shift. However, unless carefully dealt with, the shift could lower crop yield because of the potential disincentive from livestock income. Thus, there is an interesting reason to investigate whether yield declines with livestock size and the increasing adoption of mixed farming. To investigate, we used 'Resilience to Climate Change' data collected in 2021 from 2000 households. Descriptive analysis and econometric models, specifically the Generalized Method of Moments and logit, are employed for the estimations. The findings pointed out: (1) households beyond livestock quartile II, who own 60% of the cropland, produce lower average yields. (2) Major yield factors do not hugely vary between GMM estimations. Mainly high-value crops, the number of equines owned, and renting land out, increased yields, whereas age, dummies of drought frequencies, inter-cropping, and drought-resistant crops decreased yields. The mixed-farming dummy resulted in higher yields only for the

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bottom livestock groups. (3) The transformative investment in thresher increased yields. (4) Agricultural Growth Program increased yield in the land-abundant quartile IV. (5) The estimated logit model shows that higher age, family and landholding sizes, social capital, cooler agro-ecologies, more hot days, the use of modern feed, and fewer drought shocks affected the adoption of mixed farming. The findings offered several policy options. Among others, designing extension services to improve yields in households owning larger livestock sizes requires attention. Moreover, the frequent drought years urge adaptation measures to climate change.

Keywords: Mixed Farming, Yield, Climate change, GMM, Ethiopia
JEL Classification: Q12, Q54

1. Introduction

The increasingly challenging climate conditions appear to be driving smallholder farmers in Ethiopia towards adopting mixed farming as an adaptation strategy. An evidence indicates that 90 percent of smallholders in Ethiopia have embraced the mixed farming system due to its benefits in terms of income generation, food security, availability of manure, access to draught power (e.g., Belay et al., 2022; Mekuria and Mekonnen, 2018), and consumption smoothening (Danso-Abbeam et al., 2021; Tesfaye and Tirivayi, 2020; Thornton and Herrero, 2014). The increasing adoption could also be due to the development of increasing demands for dairy processing (Franzluebbers et al., 2021; Gil et al., 2016). However, from the perspective of its advantage in adaptation to climate change, Berhe et al. (2020) discussed that livestock ownership increases GHG emissions, but other studies advocate that mixed farming increases yield, rehabilitates degraded pastures, and grows forage while mitigating emissions (Shiferaw, 2020; Descheemaeker et al., 2016). This debatable issue calls for further investigation.

In Ethiopia, it is possible that smallholders are increasingly transitioning towards mixed farming as a means to improve their food security and income, while also mitigating the impact of climate change. This trend is observed in other African countries as well (Mekuria and Mekonnen, 2018). However, from the perspective of its advantage in increasing yield and as an adaptation mechanism to climate change (Muchuru and Nhamo, 2019), the mixed-farming system in Ethiopia and globally is not adequately dealt with (Thornton and Herrero, 2014). Previous studies on the mixed-farming system in Ethiopia focused on issues such as farmers' perception of climate change and choice of adaptation strategies (Eshetu et al., 2021; Bedeke et al., 2019), manure and yield advantages in specific crops such as maize (Shiferaw, 2020), and climate-smart agriculture and the yield of individual crops (Wakwoya et al., 2022; Bedeke et al., 2019). Most of those studies carried out on the impact of climate change and adaptation measures use the changes in temperature and rainfall data to investigate the impact of climate change on individual crop yields (e.g., Kassaye et al., 2021; Eshetu et al., 2021). However, the studies neglect the role of households' resource endowment. In order to account for the influence of households' resource endowment on adaptation, it is crucial to aggregate yields at the household level, rather than solely focusing on adaptation measures at the individual crop and plot level, as argued and attempted in this study. In addition to this argument, several previous studies have also suggested the adoption of mixed farming systems as a means of adapting to climate change (Eshetu et al., 2021; Bedeke et al., 2019). However, the increasing number of livestock may not guarantee better yields to ensure food security and adapt to climate change. This could be because, first, the increased income from crop production may simply lead to livestock rearing to consume dairy products (Tesfaye and Tirivayi, 2020; Mellor, 2014). Second, instead of serving as an adaptation option, the free choice of mixed farming could lead to decreasing crop yields because of the potential disincentive effect of livestock income on crop yields. Therefore, it is compelling to examine yield with increased livestock size in the mixed farming system at household levels rather than merely testing the impact of climate variables such as temperature and rainfall on individual crop yield as in previous studies (Wakwoya et al., 2022; Waktola et al., 2014) and rather than boldly recommending the mixed farming system as an adaptation strategy (Eshetu et al., 2021; Bedeke et al., 2019). It is compelling because households in the larger quartile occupy nearly 60 percent of the total land occupied by smallholders.

Theoretical and empirical studies have demonstrated that crop yield is influenced by various household socio-economic, technological, and climatic factors (Zhengfei et al., 2006; de Wit, 1992). Factors such as family labour and effective farm management play a crucial role in optimizing the use of inputs such as seeds, water, and soil nutrients (Zhengfei et al., 2006). The availability of inputs such as water and soil nutrients is influenced by climatic factors such as temperature, precipitation, and agro-ecological diversities (Kassaye et al., 2021; Abate et al., 2015). According to Thornton and Gerber (2011), climate change has a direct impact on crops through extreme weather, drought, and flooding. Descheemaeker et al. (2016) discussed that climate change increases the incidence and severity of pests, weeds, and diseases, which in turn decreases yields. Location also matters in adaptation, which influences yield (Stark et al., 2018; Mendelsohn, 2012), and in a very diverse geography of 18 agro-ecologies in Ethiopia, the role of agro-ecology and location differences could be immense. Also, Teklewold et al. (2019) and Di Falco and Veronesi (2013) stress that the adaptation strategies have positive impact on crop yield and farmers' return when implemented complementarily, not in isolation. The impacts of climate change on yield have been assessed in numerous other studies (Sardar et al., 2021; Ojumu et al., 2020; Clay and Zimmerer, 2020). Ariom et al. (2022) summarized that in African countries, smallholder farmers use adaptation strategies such as drought-resistant varieties, crop diversification, changes in cropping pattern, calendar of planting, conserving soil moisture with appropriate tillage methods, afforestation, and agro-forestry. The adaptation options discussed in IPCC (2007) also include technological, behavioral, investment, and policy-related approaches (Shuai et al., 2018). Muchuru and Nhamo (2019) and Thronton and Gerber (2011) suggested that post-harvest food storage systems, water harvesting (e.g., Wakeyo and Gardebroek, 2017), and road and market infrastructure matter in adaptation.

In mixed farming, the drivers of the increasing adoption of mixed farming by smallholders are interesting too, to get insights for possible interventions. If we assume the adoption of mixed farming practices is climate-smart, the adoption is affected by several direct and indirect factors (Owen, 2020; Thornton and Gerber, 2011), such as technology, environmental, socioeconomic, demographic, and policy design. Mekuria and Mekonnen (2018) found that livestock holding, irrigation, and extension contact significantly influence the adoption of mixed farming, whereas rented-out land, improved seed, and soil fertility status decrease it. In countries with diverse agro-ecologies, such as Brazil, the crop-livestock system is influenced by biophysical, socioeconomic, and institutional factors (Gil et al., 2016). Gil et al. (2016) concluded that education and supply-chain infrastructure play a role in the early adoption of crop-livestock systems, as they are more common in areas closer to research centers and processing facilities for grains and cattle.

Building upon the preceding discussions, it is necessary to raise questions regarding the potential impact of the growing adoption of mixed-crop livestock farming systems on crop yield. Specifically, it is important to investigate whether this adoption could lead to an increase or decrease in crop yield, considering the potential disincentive effect of livestock income. Additionally, it is relevant to explore why certain households continue to focus solely on crop cultivation or livestock keeping, despite the numerous advantages associated with mixed farming. This means that the factors driving the adoption of mixed farming in diverse agro-ecological contexts have to be understood. Thus, this study specifically attempts to (1) look into the crop yield differences by livestock size (quartile), farming system, and agro-ecology; (2) investigate factors of yield differences between households by livestock quartiles; and (3) investigate factors driving households to shift to a crop-livestock system under varying agro-ecology, institutional, climatic, and regional variations.

The rest of the study is organized as follows: In Section 2, conceptual framework of crop yields and climatic linkage is discussed, followed by the discussion of methodology and data in Section 3. In Section 4, the descriptive statistics and estimation results are discussed. Section 5 concludes and reflects on recommendations.

2. Conceptual Framework

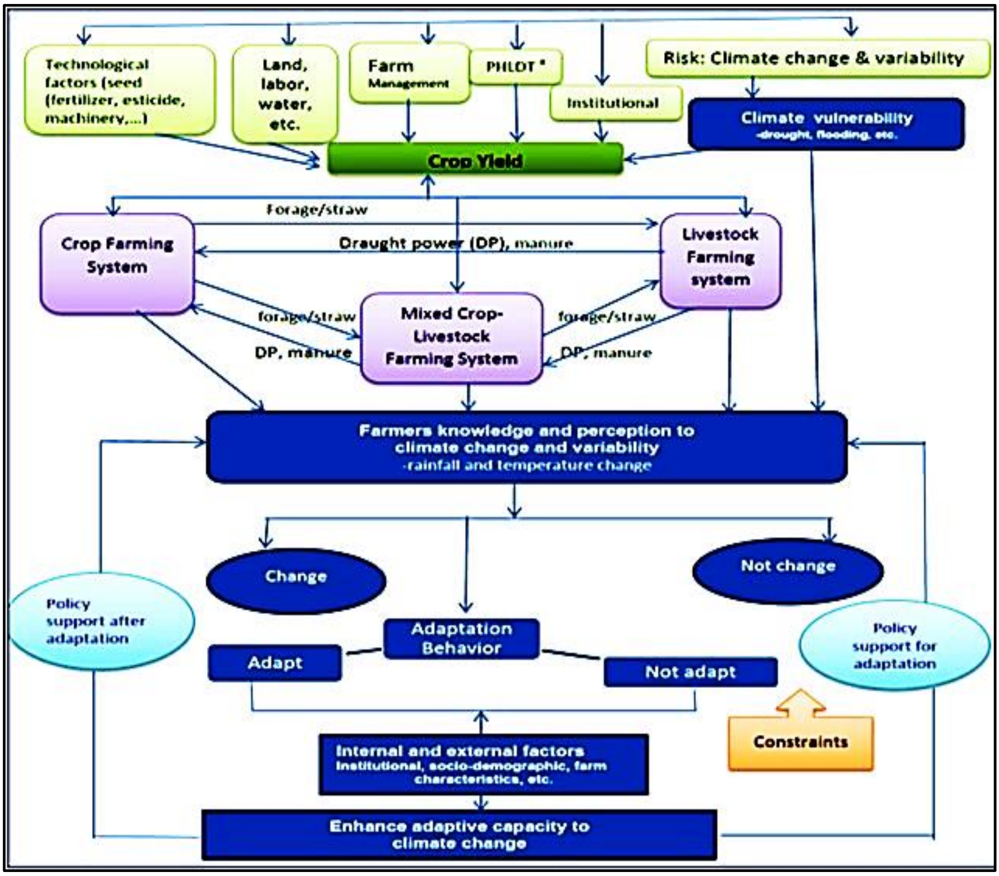
Population pressure and climatic, economic, social, and institutional changes are transforming into mixed farming systems rather than being restricted to either crop-only or livestock-only production as studies, show (e.g. Gil et al., 2016; Thornton and Herrero, 2014). These studies underline that the move to a mixed farming system involves a move to a more intensively managed crop-livestock system. For example, when farmers move from a fully pastoral to an agro-pastoral system, it infers the settlement of pastoral households and the use of cropping technologies. The household decision to move to an agro-pastoral farming system is enhanced by discussions, farmers' training, declining land size, longer distance to water points for humans and livestock, shorter distance to market, and more income from off-farm sources (e.g., Bebe et al., 2012). Similarly, the move from a crop-only to a crop-livestock system occurs as a mechanism for reducing the risk of crop failure (Sertse et al., 2021; Tesfaye and Tirivayi, 2020) and the ease of access to water for livestock. Of course, the risk-coping strategy of the crop-livestock system in Africa is widely recognized as an adaptation mechanism to climate change.

The theoretical link between yield, farming system, and the perception and knowledge of farmers about climate change is illustrated in Figure 1. The figure shows that yield depends on internal and external factors such as technology, resource endowments, farm management, institutional factors, and weather risk (climate change) factors, among others. The technologies influencing crop yield include improved seed, fertilizer, pesticides, herbicides, manure or compost, and machinery such as tractors and harvesters. The institutional factors of yield include policies, access to extension services and information, market and financial conditions, and socio-cultural conditions. The post-harvest loss-decreasing technologies, farm management, risk factors, and portfolio between crop production and livestock rearing challenges are also relevant. Note that the influential theoretical approach to productivity of de Wit (1992) suggests that yield depends on the level of the most constraining input factors, such as water and nutrients, for example, and they cannot be neglected in the link. In the link, yields could also be suboptimal following the resource constraints of the households that diversified into mixed crop-livestock system.

Figure 1: Conceptual Framework

Source: Adopted from Belay et al. (2022) and Stark et al. (2018).

Note: PHLDT stands for Postharvest loss decreasing technologies.



In the conceptual framework, Belay et al. (2022) employed the theory of planned behavior to conceptualize rural farmers' perceptions and behaviors of rural farmers regarding current climate change and variability. Following the framework, the link between the livestock-only (pastoral), the crop-only, and the mixed farming systems is facilitated by the advantage and exchange of draught power and manure, as illustrated in Figure 1. In the same context, the perception and knowledge of farmers about climate change and variability determines their adaptation behavior and choices of adaptation strategies, which can be influenced by policy. The farming system and the adaptation behavior, therefore, affect crop yields. Thus, from the theoretical linkage between yield and farming system presented in Figure1, increasing livestock size could affect yields through input technologies, climate change and variability, institutions, and the significance of these factors could vary with livestock size.

3. Methodology

3.1. Approach to Empirical Estimation

In this study, there is an opportunity to utilize plot-level household's data to examine yield variations within both crop-only and mixed farming systems across livestock quartiles. The analysis of household data by livestock quartiles involves both descriptive and econometric estimations. It is important to note that the conventional measure of 'per hectare output' does not adequately capture the factors driving yield at the household level, prompting the need for alternative approaches. Measuring yield in this way has the limitation of neglecting the area share of the crops, as it has implications of households' resource endowment and yields. To overcome this limitation, standardizing the 'yield by crop-yield index' is ideal, and we discuss in this section the crop-yield index.

In the computation of the crop yield index, for all crop categories in cereals, pulses and oilseeds, and fruits and vegetables, the crop yield index is calculated as a weighted sum of the yields of the crops. The weight attached to each crop is the proportion of land area allocated to the crop out of the total land of the household allocated to the crops. Then, the weight of the crop area is multiplied by the crop yield to obtain the crop yield index (refer to Equation 1).

$$YI_i = \sum_{i=1}^{n} y_{ij} * \frac{a_{ij}}{A_{ij}} \quad \textbf{(1)}$$

where Y_i is the overall crop yield of household i, and $i = 1, 2, \ldots, n$; y_{ij} is the per hectare yield of crop j, and $j = 1, 2, \ldots, M$ in household i; a_{ij} is the area of crop j of household i; and, A_{ij} is the total cropping area of household i. The computation of the crop yield index for households' as utilized in Abdisa et al., (2024), is subsequently followed by the estimation of factors for the weighted yield index across both the aggregated and individual livestock quartiles.

Econometric regression employing the method of moments is utilized to estimate and identify the factors that contribute to the yield, aggregated at the household level. The method allows a general moment condition $E\{\boldsymbol{z_i} u_i(\beta)\} = 0$, where $\boldsymbol{z_i}$ is the vector of instruments and $\boldsymbol{u_i(\beta)}$ is an additive regression error term. In modeling the yield index, the GMM is stated as:

$$YI_i = \sum_n^i \boldsymbol{\beta_i X_i} + u_i. \qquad \textbf{(2)}$$

where, $\boldsymbol{X_i}$ is a vector of observable variables; β_i is a vector of unknown coefficients; and u_i is an additive error term with the property $E\{\boldsymbol{z_i} u_i(\beta)\} = 0$, which allows that some variables are endogenous. The key advantage of the model lies in its ability to calculate a heteroskedasticity-robust weight matrix prior to the primary estimation. It also addresses the endogeneity concerns by employing instrumental variables and effectively captures the non-linearities in yields to overcome any potential limitations. The estimation process tests the impact of variables on yield, which are selected based on both theoretical and empirical justifications.

The methods of analysis, therefore, include descriptive and quantitative estimations using econometrics. To see the yield differences, the use of descriptive analysis by quartiles of livestock is used, followed by the econometric estimations of the Generalized Method of Moments (Verbeek, 2008) by livestock quartiles, to find out the factors driving the yield differences. Many of the previous studies such as Belay et. al. (2017), have relied on localized small sample-size data, which restricts the capacity to examine yield differences across various agro-ecologies, regions, and other sources of diversity.

The preliminary analysis of the data shows that more than 81 percent of the households increasingly shifted to the crop-livestock system seeking its various advantages. Belay et al. (2022) discussed that farmers' response to adaptation decisions may be driven by internal and external factors and these factors could be a constraint for farmers to participate in the adaptation process. Thus, the hypothesized factors driving the adoption decision include household characteristics, socioeconomic, technological, agro-ecological, and regional variables. The factors influencing the decision to adapt adaptation mechanisms, including technologies and practices, in both crop-livestock systems and crop-only or livestock-only (primarily pastoral) systems are examined using probit model estimation, following the approach of Belay et al. (2017). Belay et al. (2017) employed probit model to identify the driving factors. Similarly, Mekuria and Mekonnen (2018) estimated the tobit model to test whether water scarcity, livestock holding, agro-ecology, and other socioeconomic factors influence crop–livestock diversification, in the Ethiopian agriculture. But different from what they estimated, in this study, the aim is to test the factors driving adoption rather than diversification.

Both probit and logit models are viable options for this type of estimation. However, the criterion for selecting between the two is that in large sample-size data, the estimation of logit model tends to perform better than the probit model (Cakmakyapan and Goktas, 2013). Verbeek (2008) underlines that in large-size data, logit has several advantages compared to probit. The cumulative distribution function of the logit model is:

$$\Pr(Y = 1/X)e^{-x'\beta} \qquad \textbf{(3)}$$

where Y is the dichotomous dependent variable that represents the choice of mixed farming or not; $\Pr(Y = 1/X)$is the probability of choosing mixed farming given the vector of explanatory variables X; β is vector of coefficient of explanatory variables; and e is the base of natural logarithm. Following this, equation (3) leads to the estimation of the most simplified form of the probability of choosing mixed farming an individual variable keeping the influence of all other variables constant:

$$\Pr(Y = 1/X) = \frac{e^{\beta_o + \sum_i^k \beta_i x_i}}{1 + e^{\beta_o + \sum_i^k \beta_i x_i}} \qquad \textbf{(4)}$$

Note that Equation (4) is equivalent to estimating the marginal effect of each exogenous variable (Cameron and Trivedi, 2009: 479).

3.2. Data

The data utilized for this study is derived the nationally representative plot-level survey on Resilience to Climate Change, conducted in 2021. The data encompasses a wide range of agro-ecologies and administrative regions across Ethiopia. The study's sample size consists of 2000 households, and a multistage stratified sampling approach was employed for the sampling strategy. Woredas (administrative divisions) were randomly selected from six regions, namely Amhara, Oromia, SNNPR, Somali, Gambela, and Dire Dawa Administrations. Subsequently, farmers' associations were selected from each woreda, and a random selection of sample households was conducted for the purpose of interview.

4. Results

4.1. Descriptive Analysis

The findings regarding the impact of livestock size, agro-ecology, and farming systems on crop yield index are presented in Table 1.

4.1.1. Livestock quartile vis-à-vis yield index

The livestock quartiles computed, based on the number of livestock owned by households, have cut points of 0-3, 4-7, 8-14, and 15 and above heads of livestock from quartiles I to IV. The number of households in each of these livestock quartiles is 546, 509, 483, and 462, respectively. In per capita terms, livestock ownership is increasing smoothly across all categories livestock quartiles.

The total land occupied by all households in each quartile and the mean landholding of the sample households in each livestock quartiles are both increasing successively. This implies that proportionately larger cropland is occupied by owners of large livestock sizes. For example, 35 percent of the total land in the study area is occupied by livestock quartile IV, and 60 percent is occupied by livestock quartiles III and IV. The per capita landholding of the sample households in each livestock quartile tells the same story of high per capita landholding. Specifically, the per capita landholding of households in quartile IV is more than double that of the households in quartile I.

The mean yields computed for the aggregate households decline successively from livestock quartile I to IV. The average decline rate of the aggregated yield is 23 percent, with a maximum of 25 percent between QII and QIII and a minimum of 19.5 percent between QI and QII. The decline in yield affects 81 percent of the land occupied by the sample households. However, when we control for outlier yields, the story changes and the decline is from QI to QII and from QIII to QIV, at a 17.2 percent average decline rate.

Table 1: Number of households, average livestock size, per capita livestock ownership, and land occupied (in ha), by livestock quartile

Livestock quartiles	Quartile-I	Quartile-II	Quartile-III	Quartile-IV	Total
Range of heads of livestock in each quartile	0-3	4-7	8-14	15-105	0-105
Number of households in each quartile	546	509	437	462	1954
Total number of livestock by livestock category					
Cattle	466	1,265	1,949	3,745	7,425
Shoats (sheep & goat)	150	578	1198	3537	5,463
Equines	96	232	426	597	1,351
Chicken	114	686	1,570	4,135	6,505
Total number of Livestock	826	2,761	5,143	12,014	20,744
Average per capita ownership					
Cattle	0.33	0.53	0.76	1.41	0.82
Shoats (sheep & goat)	0.32	0.42	0.63	1.49	0.90
Equines	0.17	0.21	0.24	0.29	0.25
Chicken	0.30	0.47	0.75	1.74	1.03
Average per capita livestock	0.28	0.41	0.60	1.23	0.75
Landholding and average yield					
Total land (ha) occupied	593.40 (30.10)	663.50 (28.70)	802.70 (34.80)	1084.40 (44.20)	3144.00 (72.50)
Average land size (ha)*	1.12 (1.29)	1.33 (1.27)	1.67 (1.58)	2.37 (2.10)	1.66 (1.63)
Average crop yield (all households)	42.00 (405.20)	33.80 (275.30)	25.40 (53.10)	19.20 (40.20)	30.50 (252.80)
Average crop yield (all households) with outliers controlled	24.6 (89.9)	21.6 (47.8)	25.4 (53.1)	19.6 (40.2)	22.8 (61.2)
Average crop yield (crop-only producing households)	29.5 (118.9)	19.6 (47.7)	18.3 (22.3)	16.9 (22.2)	26.5 (103.0)
Average crop yield (mixed crop-livestock households)	19.7 (44.3)	21.9 (47.9)	25.6 (54.4)	19.4 (41.0)	22.0 (47.6)

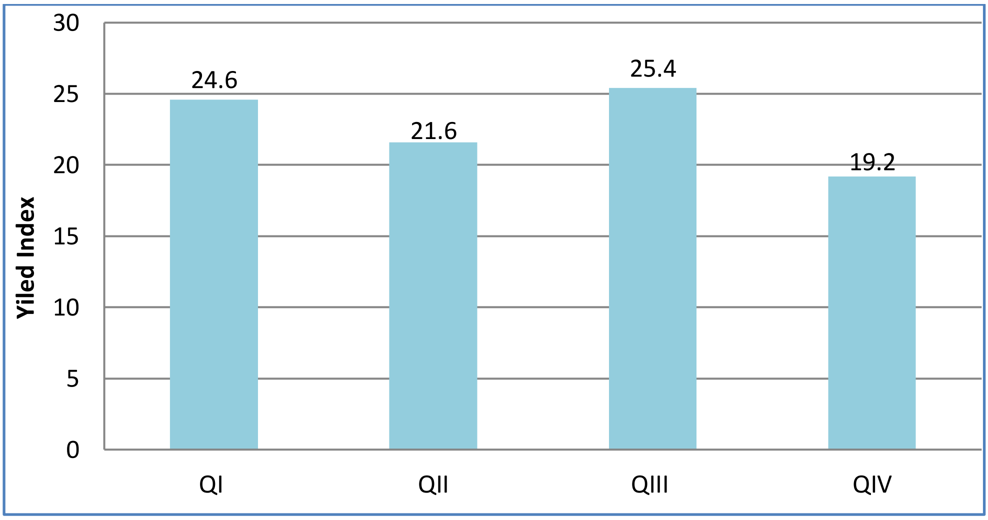
Source: Authors' computation. Notes: In brackets are standard errors; * the average excludes zero ha.

Similarly, in the regions of Amhara, Oromia, Gambella, and Dire Dawa, the mean yield declines after quartile II or III. In all regions except SNNPR, the computed yields of quartile IV decline compared to those of quartiles II and III. This might indicate the role of the disincentive of owning larger livestock size or possibly the yield-decreasing factors such as farm management, technology, and economic and non-economic factors that constrain the yield of households in quartile IV. Contrary to this declining trend, in the SNNP region, the largest proportion of households compared to all other regions (more than 71%) use high-value crops and yield is successively increasing from quartile II to IV.

The lower average yield in the last quartile indicates that the larger landholdings occupied by the fourth quartile households, which account for nearly 35 percent of the cropland, are not efficiently utilized. When considering the average yield in the last two quartiles, the proportion of land occupied by these households increases to 60 percent of the total land occupied by all the households, highlighting the extent of inefficient land used.

The control of outliers of the highest reported yield in the computation, however, changes the figures, but the yield of the last quartile is yet the lowest of all yields by livestock quartile (Figure 2). In this case, yield declined from quartile III to IV by 24 percent.

Figure 2: Average crop yield by livestock quartiles



Source: Author computation. Note that the outliers are sugarcane yields.

4.1.2. Crop yield by farming system

The farming system in the survey has six classifications. However, only the ‘crop only’ and the’ mixed farming’ systems of these classifications have adequate sample sizes for comparison of yields. In the classifications, however, only the absolute number of livestock owned is considered. Some households use their livestock as a capital good rather than owning livestock for dairy products, and this approach gives room for adequate samples in the classification. In this approach, beyond the 155 households that own no livestock, 133 own one or two oxen, bulls or young bulls, one or two horses, or one or two donkeys. The number of these households considered in this study as crop-only producers increased from 189 to 375. This means that almost half of the 375 households own some livestock used not for dairy products, like in the case of mixed farming households, but rather as a capital good for draught power and means of transport.

The yield index computed for the two farming systems indicates that crop-only households have a superior average yield of 26.5 quintals per hectare over mixed farming households, which have an average crop yield of nearly 22.0 quintals per hectare. The average yield difference between the two household groups is statistically significant at the one percent level of significance. So, the average yield of crop-only producers is greater than that of mixed farming households. This means that the average yield of mixed farming households is lower than the former by 17 percent. Also, the average yield of the third and fourth quartiles in the crop-only and mixed farming systems is 18.3 and 16.9 and 25.8 and 19.4, respectively. The difference between the average yield of quartiles III and IV in mixed farming is 24.8 percent, which is higher than that of the crop-only farming system (7.7%) and statistically significant at a five percent level of significance. Thus, similar to the cases of the average yield computed for all households (and regions), the average crop yield of mixed farming households also declines in the last quartile, and the difference is significant at five percent.

By gender, the average yield of male and female-headed households of crop-only households and mixed crop-livestock farming households is 25.6 and 29.0 and 22.0 and 21.7, respectively. However, the yield difference by gender is not statistically significant, even at a 10 percent level, in both cases. Thus, on average, differences in the farming system cause little difference in yield by gender computed for all households.

4.1.3. Yield by agro-ecology

The yield index computed by agro-ecology and livestock quartile is indicated in Table 2. . The scientific classification of the agro-ecologies depends on the elevation of locations in meters above sea level (masl from now on), with desert, hot, moderate, cool, and frost elevating differently in masl, successively from desert to frost. The mid-altitude areas of woyina dega dominate the land coverage, accounting for more than half of the total area (nearly 52.3%) of the sample households.

Table 2: Average crop yield by agro-ecology and livestock quartile

Agro-ecology /altitude in masl	Aggregated		QI		QII		QIII		QIV	
	N	**Yield**	**N**	**Yield**	**N**	**Yield**	**N**	**Yield**	**N**	**Yield**
Frost (> 3200)	21	13.9(16.3)	5	7.7(9.2)	4	8.0(4.0)	5	9.9(3.9)	7	22.4(24.1)
Cool (3200-2300)	538	26.4(65.0)	101	32.4(113.4)	125	28.3(64.1)	159	29.6(50.2)	153	17.4(19.2)
Moderate (2300-15	1046	22.2(67.2)	302	23.2(94.2)	290	20.1(43.7)	242	23.9(59.0)	212	21.8(55.7)
Hot (1500-500)	271	20.9(35.1)	83	23.5(43.7)	68	16.9(29.2)	58	25.7(41.3)	62	17.2(17.0)
Desert (< 500)	70	13.3(25.1)	24	17.1(39.7)	9	17.7(20.1)	15	8.9(7.9)	22	10.2(9.7)

Source: authors’ computation. NB. In the brackets are standard errors; N signifies frequency

The survey data shows that each farming system has the highest representation in the mid-altitude, similar to the case of other developing countries (Thornton and Herrero, 2011). In the mid-altitude, 47.6 percent, 66.7 percent, 53.4 percent, and 100 percent of the crop-only, livestock-only, mixed farming, and agro-pastoral farming systems are practiced, respectively. Of the total plots, 52.9 percent are located in the moderate agro-ecology, followed by 27 percent in the high-altitude cool areas, showing a dominant crop growing in Ethiopia in the mid-altitude than in the extreme weather. However, the highest average yield is observed in moderately cool agro-ecology. The moderately cool condition has adequate moisture to increase yield relative to other agro-ecological conditions. The yield difference between the cool and moderate highlands by livestock quartile is statistically significant only in the third quartile at the 10 percent level. In the other quartiles, the yield difference is statistically insignificant.

This table also shows that the average yields in the mid-altitude (moderate) and hot agro-ecologies are almost comparable in all quartiles. The mean-tests show that the difference in yield between the mid-altitude (moderate) and lowlands (hot) quartiles is statistically insignificant. Thus, in agro-ecology, if farmers invest to increase moisture in moist agro-ecology, there is potential to increase yield, and this could also work for lowland hot agro-ecology.

In the case of the highest elevation areas of frost agro-ecology, the experience is that crop yield increased in livestock quartile IV, unlike many other cases. In a relatively small number of observations of only seven households, it could be difficult to conclude this, but surprisingly, even though the number of livestock falls within quartile IV, the numbers of livestock are relatively lower, and they are found at the bottom of quartile IV with 15 to 27 livestock when the data is scrutinized. The lower number of livestock in the quartile seems to have a relatively lower disincentive role, unlike households that own larger livestock sizes up to 105. Note that the number of livestock in moderately cold, mid-altitude, lowland, and desert agro-ecologies ranges from 15-68, 15-103, 15-105, and 15-66, respectively, which is by far greater than that of the highest elevation or frost agro-ecology, that is, 15-27 heads of livestock. Another interesting point is that the average yield of the frost and that of the cold seem to be mirror images of each other and that of hot and desert has also the same pattern, which requires further study.

4.2. Factors of Crop Yield by Livestock Quartiles

The estimation results of the generalized method of moments (GMM) are presented in Table 3. In the estimated result, age, area proportion of high-value crops in the cropping area, the dummies of years of drought frequencies in the last five years, the use of thresher, rented-out cropland, intercropping, and drought-resistant crops, not participating in any of the flagship programs, increasing the number of livestock as an adaptation strategy, migration of at least a member of the household, shift from livestock to crop, and regional and agro-ecological dummies have significantly explained the households' crop yields in at least three of the five estimations. Of course, some of the estimations are weakly significant, and in others, they carry mixed (positive and negative) signs. Many other variables explained yield less than once or twice. However, variables such as household size (proxy to family labour), use of fertilizer and seed dummies, whether the households currently use irrigation or not, owning a tractor or not, shifting from livestock to crop, and also being in Dire Dawa (except weakly in the aggregated estimation) have no significant influence on households average yield on any of the estimations, and those variables are not reported in Table 3.

Among these variables which explain yield, age and the area proportion of high-value crops strongly explained it. The other variables that consistently and strongly explained yield are climatic variables. Those include dummies of climate change noticed as hotter days, four years drought frequency in the last five years. Moreover, practicing intercropping and drought resistant crops, using thresher, increasing the number of livestock as an adaptation strategy to climate change, not participating in flagship programs, and being in Gambela region consistently and significantly explained the yields in at least three of the estimations. Among these yield influencing variables, the signs of the coefficients in the frequency of drought dummy show mixed coefficients. This means that in the aggregated and livestock quartiles I, II, and III, they carry consistently negative and strongly significant signs, whereas in the livestock quartile IV, they carry positive sign though weakly significant. Furthermore, of these variables, age, frequency of the number of years of drought in the last five years, dummies of practicing intercropping, and drought resistant crops decreased households' average yield, whereas the rest of the variables increased it. The advantages of intercropping could also be greater in individual crop yield than in the case where household yield is aggregated. The individual crop yield advantage of intercropping is found in Bedeke et al. (2019), but the disadvantages are discussed in Waktola et al. (2014).

Table 3: Factors Affecting the Household Yield-index

Dependent variable: ln of yield- index	**Aggregated households**	**Livestock Q-I**	**Livestock Q-II**	**Livestock Q-III**	**Livestock Q-IV**
	Robust coefficients (in brackets are their standard errors)				
Ln of the age of household	-0.26***	-0.35*	-0.15	-0.43**	-0.11
head	(0.11)	(0.22)	(0.16)	(0.22)	(0.18)
Gender dummy, (male =1)	0.12	0.19	0.31**	-0.08	0.24*
	(0.11)	(0.15)	(0.15)	(0.25)	(0.15)
Education dummy, grade 8-	0.13*	0.36*	-0.02	0.02	0.06
12=1, 0 otherwise	(0.08)	(0.25)	(0.15)	(0.15)	(0.12)
Are you a widow? (yes=1), 0	0.30**		0.56***	0.09	
otherwise	(0.16)		(0.20)	(0.36)	
Number of equines owned	0.09**	0.01	0.01	0.09	0.13***
	(0.04)	(0.16)	(0.07)	(0.06)	(0.03)
Proportion of high value crops	1.44***	1.29***	0.66**	1.43***	0.96**
(in terms of area)	(0.19)	(0.37)	(0.29)	(0.39)	(0.45)
Dummy, did you earn off-	-0.42	0.81	0.34	0.11	1.17***
farm/ nonfarm income? yes =1	(0.75)	(1.09)	(0.39)	(0.37)	(0.43)
Do you use info for	0.06	-0.27	0.45***	-0.22	0.25**
agricultural forecasting?	(0.11)	(0.26)	(0.16)	(0.18)	(0.12)
Dummy. Yes =1					
No. of drought frequency in	-0.36***	-0.79***	-0.12	-0.13	0.62**
the last 5 years dummy, once	(0.13)	(0.26)	(0.22)	(0.26)	(0.24)
No. of drought freq. in the last	-0.56***	-1.25***	-0.35	-0.67***	0.75*
5 years dummy, 1 if twice	(0.16)	(0.35)	(0.38)	(0.27)	(0.39)
No. of drought freq. in the last	-1.00***	-1.66***	-0.97**	-0.25	0.90**
5 years dummy, 1 if thrice...	(0.22)	(0.44)	(0.41)	(0.49)	(0.42)
No. of drought frequency in	-0.94**	-1.78***	-0.91*		
the last 5 years dummy, 1 if 4	(0.31)	(0.48)	(0.62)		
times and 0 otherwise					
Did you sell livestock? Yes =		0.29	0.08	-0.09	-0.46*
1, 0 otherwise.		(0.31)	(0.48)	(0.29)	(0.24)
Have you rented out cropland?	0.30**	0.64**	0.39*	0.01	-0.93***
dummy, yes =1, 0 otherwise	(0.15)	(0.27)	(0.22)	(0.01)	(0.32)
Number of relatives that you	0.02**	-0.02	0.01	0.01	0.01*
rely on for critical time	(0.01)	(0.04)	(0.02)	(0.01)	(0.02)
Faced crop loss in the last five				-0.87**	-0.21
years? Dummy, yes =1				(0.38)	(0.19)
Climate change noticed as	0.14*	0.22*	0.35***	0.05	-0.10
hotter days? Dummy, yes =1	(0.08)	(0.15)	(0.11)	(0.13)	(0.11)

Dependent variable: ln of yield- index	**Aggregated households**	**Livestock Q-I**	**Livestock Q-II**	**Livestock Q-III**	**Livestock Q-IV**
	Robust coefficients (in brackets are their standard errors)				
Dummy, diversify crop?	-0.01	-0.34*	-0.17*	-0.08	-0.01
yes=1	(0.09)	(0.18)	(0.12)	(0.14)	(0.13)
Dummy, intercropped? Yes	-0.15**	-0.01	0.08	-0.21*	-0.29***
=1	(0.08)	(0.15)	(0.11)	(0.12)	(0.10)
Dummy, minimum tillage?	-0.28***	-0.06	-0.56***	0.14	0.06
Yes =1	(0.11)	(0.21)	(0.12)	(0.15)	(0.17)
Dummy, drought resistant	-0.22***	-0.30*	-0.16*	-0.21*	-0.13
crop? Yes =1	(0.08)	(0.18)	(0.11)	(0.13)	(0.12)
Dummy, used thresher?	0.54***	1.38***	0.28	0.75**	0.37**
yes=1	(0.13	(0.50)	(0.20)	(0.32)	(0.16)
Dummy, increase number of	0.23**	0.36*	-0.18	0.25*	0.36*
livestock? yes=1	(0.10)	(0.21)	(0.16)	(0.17)	(0.21)
Dummy, mixed crop-	0.48**	1.06**	0.08	0.01	0.27
livestock? yes=1	(0.23	(0.45)	(0.28)	(0.41	(0.28)
Dummy, shift crop to	-0.74***	0.03	-0.70***	-0.67**	-0.23
livestock? Yes = 1	(0.22)	(0.25)	(0.26)	(0.34)	(0.33)
Dummy migrated? Yes =1	0.31*	0.77**	0.02	-0.04	0.41***
	(0.16)	(0.30)	(0.32)	(0.34)	(0.21)
Quantity of manure used in kg	0.00	-0.07	0.02	0.03***	0.04
	(0.02)	(0.19)	(0.06)	(0.01)	(0.03)
PSNP_dummy, 1 if	-0.07	1.70**	-0.52*	1.21**	0.42
beneficiary	(0.74)	(0.74)	(0.28)	(0.56)	(0.46)
AGP_dummy, 1 if beneficiary	-0.38	-0.07	0.25	0.12	1.06**
	(0.41)	(0.71)	(0.28)	(0.36)	(0.44)
Non-program_dummy, 1 if	0.17	1.45***	0.56**	0.95***	0.74***
non-beneficiary	(0.67)	(0.54)	(0.23)	(0.35)	(0.28)
Amhara region dummy	0.87*	1.09***	-0.82***	1.89**	1.32**
	(0.47)	(0.45)	(0.24)	(0.96)	(0.65)
Oromia region, dummy	0.70*	0.39	-0.48*	1.54*	0.96*
	(0.41)	(0.57)	(0.27)	(0.92)	(0.60)
Somali region, dummy			-1.33***		
			(0.50)		
SNNP region, dummy	0.33	-0.55	-0.88***	1.33*	1.87***
	(0.27)	(0.62)	0.28	(0.88)	(0.62)
Gambela region, dummy	1.09			2.67**	2.77***
	(0.79)			(1.07)	(0.78)
Dire Dawa region, dummy	0.62*	-1.03		1.68	0.52

Dependent variable: ln of yield- index	**Aggregated households**	**Livestock Q-I**	**Livestock Q-II**	**Livestock Q-III**	**Livestock Q-IV**
	Robust coefficients (in brackets are their standard errors)				
	(0.41)	(0.90)		(1.79)	(0.79)
Agro-ecology frost	-0.11	-1.55*	1.31***	-0.39	0.86*
(highest altitude), dummy	(0.35)	(0.92)	(0.48)	(0.85)	(0.59)
Agro-ecology cold, dummy	0.12	-1.44**	0.75**	1.00***	1.09***
	(0.22)	(0.62)	(0.32)	(0.35)	(0.39)
Agro-ecology moderate (mid-	0.28	-1.06*	-0.74*	0.94***	0.71**
altitude), dummy	(0.22)	(0.59)	(0.32)	(0.32)	(0.35)
Agro-ecology hot	0.29*	-0.84*	0.46***	1.00***	0.96***
(low altitude), dummy	(0.20)	(0.64)	(0.31)	(0.33)	(0.36)
Dummy, livestock quartiles I	-0.35				
	(0.29)				
Dummy, livestock quartiles II	0.77**				
	(0.38)				
Dummy, livestock quartiles III	0.20				
	(0.41)				
Constant term	1.90**	2.32**	2.40***	0.47	0.12
	(0.93)	(0.92)	(0.72)	(1.34)	(0.98)
Number of observation (N)	1948	516	497	479	456
GMM Weight matrix	Robust	Robust	Robust	Robust	Robust
	Chi^2 (11)	Chi^2 (16)	Chi^2 (23)	Chi^2 (17)	Chi^2 (16)
Hansen's J chi2 (.)	14.79***	9.04***	25.20***	11.50***	14.90***
	(p=0.1923)	(p= 0.916)	(p=0.3414)	(p=0.8285)	(p=0.5357)

Note: ***p < 0.01, **p < 0.05 and *p < 0.1. Note that variables with no significance coefficient at all are dropped.

In the aggregated estimation, 18 of the 44 variables strongly explained households' average yield (Table 3). In this estimation, consistent with our expectation, a higher age by one year of household head on average decreases yield by 0.25 percent (Table 3). Similarly, a move to one, two, three, and four years of drought frequencies from no drought frequency consistently decreases yield by 0.36, 0.56, 1.00, and 0.94 percent, respectively. In addition, the use of intercropping, minimum tillage, and drought-resistant crops significantly decreased yield by 0.15, 0.28, and 0.22 percent, respectively, all significant at least at a five percent level. The fact that minimum tillage frequently produces no gain in yield is consistent with Cock et al. (2022). In the case of the variable 'shifting from and to livestock' as an adaptation strategy to climate change, lower yield could be the factor for the lower shift to livestock (123 households, or only 6%), compared to the shift from livestock to crop (211 households, or nearly 11%), contrary to the finding of Descheemaeke et al. (2016). The shift from livestock to crop also significantly decreased yield in the aggregate estimation at a one percent level.

On the other hand, in the aggregated estimation, several variables increase yield, including number of equines owned, the proportion of high-value crops, the dummies of being a widow, social capital, the use of threshers, the mixed farming system, the increase in the number of livestock as an adaptation strategy (relatively higher increase in Quartile I and III), being in livestock Quartile II, and whether anyone in the household migrated, significantly increasing yield at least at the 5% level of significance. Those yield-increasing variables on average increased yield by 0.46 percent (at least by 0.02% due to social capital and at most doubling yield due to the proportion of high-value crops with 1.44%) for the aggregated households. It is not surprising to see the highest yield increase for being in Gambela, the most fertile region, relative to being in the often drought-hit Somali region. On the top of the variables, dummies of secondary education, climate change noticed as hotter days, and being in Amhara, Oromia, and Dire Dawa regions and moderately hot agro-ecology, all increase households yield, but weakly significantly at 10%.

Importantly, the variables of interest of the livestock quartiles I, II, and III entered in the aggregated estimation as dummy variables; only livestock quartile II strongly and significantly increased yield. The significant coefficient of quartile II shows better yield in the relatively lower livestock quartile than in the higher quartiles III and IV, consistent with the descriptive analysis.

Related to the households' average yield in quartile IV, the number of equines owned, the proportion of high value crops, dummies of earning off-farm income are variables of household characteristics. Similarly, the use of information for agricultural forecast, once to three times drought frequency in the last five years are climate related variables that explained yield in Quartile IV. Moreover, participating in Agricultural Growth Program (AGP from now onwards), not participating in the flagship programs, the use of thresher, out-migration explained yield in Quartile IV. Also, the regional variables of being in Amhara, SNNP, and Gambela regions, as well as being in relatively cooler highlands (dega), moderate highlands, and hot lowlands, all strongly and significantly increase yield in quartile IV. Other variables such as dummies of renting out cropland and intercropping strongly and significantly decrease yield at least at 5 percent level of significance. The renting out of cropland does not seem to be consistent with the argument that livestock income is disincentive unless the size and proportion of the land rented out are possibly small. In this livestock quartile, surprisingly, the frequency of drought years of once, twice, and three times increases yield, whereas in the other quartiles, they decrease yield, though weakly significant in the case of twice drought frequency (Table 3). This yield-increasing effect might be related to the fact that the number of drought frequency-reporting households is the lowest in quartile IV compared to that of other quartiles. For example, the number of households that reported draught frequency once, twice, three times, and four times is 43, 15, 9, and 1, respectively, in quartile IV, whereas they are 58, 34, 9, and 1 in quartile III. The cases of quartile IV are lower than those in quartile III, and this lower number of households reporting each drought frequency might contribute to the change in the sign of the coefficient. Last is the strong and significant influence of participating on AGP in increasing yield in quartile IV, unlike in the other quartiles. This could be consistent with the inception of AGP that land and abundant resources are beneficiaries of the project, which supports the significance of the quartile IV estimate. Note that in livestock quartile IV, nearly 24.3 percent of households are beneficiaries of AGP.

On the other hand, the dummies of information used for agricultural forecasting and PSNP significantly influence yield in other quartiles but not in quartile IV, contrary to the case of the number of equines owned, off-farm income, and intercropping, where they are significantly influencing yield in quartile IV but not in other quartiles. Other explanatory variables are significantly affecting yield in all the quartiles, including quartile IV. Those explanatory variables include dummies of the use of a thresher, increased number of livestock (but significant only at 10%), out-migration, not participating in any flagship program, relatively cold, moderate, and hot agro-ecologies, owning a thresher (except quartile II), regional dummies, and renting out cropland (Table 3).

Overall, most of the variables significantly influencing the yield by livestock quartiles are common to many of the quartile estimations. Moreover, for the aggregated households and the livestock quartiles I, the variable 'mixed farming' consistently and significantly increases yield. This means that mixed farming increases yield in the relatively lower livestock quartile, whereas its income-disincentive role could be formidable in the upper livestock quartile, which is evident from the yield-decreasing effect of increasing livestock size mainly in the descriptive analysis. The influence of gender (quartiles II and IV), being widowed (quartile II), education (aggregated and quartile I), facing crop loss due to drought (quartile II), diversifying crops (livestock quartiles I and II, but weakly significant), and quantity of manure used (quartile III) are significant only in a few quartiles rather than a consistent role in many of the quartiles.

4.3. Effects of Climate Change Variables and Crop Yield

The need for adaptation to climate change is critical in developing countries like Ethiopia. Let alone neglecting them, even a high level of adaptation in the agricultural sector does not prevent the negative effect of climate change on yield (for example, Shuai et al., 2018; Mendelsohn, 2012). Among the adaptation measures found to not significantly influence yields is irrigation. However, the dummies of irrigation use carry positive coefficients in all estimations by quartiles, though they are insignificant. In addition, as a means of adaptation to climate change, households engage in non-farm activities, but the variable has a positive influence on yield only in the estimation of quartile IV. Its yield-increasing role in quartile IV could be surprising because households slash their farm management time to work off-farm, but still, it contributes to increasing yield. Also, households that noticed hotter days due to climate change have positive and significant coefficients in the aggregate estimations, quartile I, and II estimations though weakly significant in the latter two. This shows that in the African context, where there is evidence that land surface temperatures are rising faster than on any other continent and that climate variability is increasing (Akinnagbe and Irohibe, 2014), the increasing yield on more hot days varies across countries (Mendelsohn, 2012). The dummy variable of whether households use the information for the agricultural forecast is strongly and significantly increasing yield in quartiles II and IV. Nearly 16 percent of households use the information for agricultural forecasting, and their proportion increases over the livestock quartiles, which might have contributed to significantly increasing yield in quartiles II and IV. The dummies of drought frequency in the last five years of once, twice, three, and four times all decrease yield consistent with expectations except in quartile IV, but significantly increase yield in quartile IV. The descriptive analysis of the frequencies shows that in quartile IV, the proportion of households that reported the frequency of drought once to five times is only 14.7 percent, whereas it is 30.6, 26.7, and 22.0 percent in quartiles I, II, and III, respectively, and the lower proportion in quartile IV might be one of the factors for the change in sign. In the descriptive statistics, 60 percent of the sample households are those living in mid-altitude agro-ecology, followed by those living in the cold highlands (20%) and in the hot lowlands (15%). The data shows that, at least with strong significance in quartile II and weak significance in the aggregate and quartile I estimations, more hot days consistently increase yield.

The crop diversification dummy has negative coefficients throughout the estimation. It decreases yield in quartiles I and II, but weakly significantly. In Ethiopian agriculture, low-income farmers are risk-averse, and they tend to diversify their crops, which makes yields sub optimal, as the evidence shows. The fact that the variable is at least weakly significant in the lower livestock quartiles and has no effect in the upper quartiles is consistent with expectations. The other variables of resilience to climate change, such as intercropping, minimum tillage, and the use of drought-resistant crop dummies, decrease yield rather than increase it (Table 3). The role of those variables is mixed, as the evidence in the literature shows. On the other hand, as resilience to climate change increases, the dummies of the use of tractor and thresher increase yield consistent with expectations, but the former has insignificant coefficients unlike the latter, that has a strongly significant coefficient. The insignificance of tractor use, despite its positive coefficient throughout the estimations, could be because the proportion of tractor users is low, that is, only five percent of the farmers use it. The users of modern threshers have the advantage of decreasing harvest losses during threshing, and on average, seven percent of households use them. However, the dummies of improved seed and chemical fertilizer have no significant influence on yield, possibly because the application rate of these inputs is extremely low in contrast to the number of crops grown. The descriptive statistics show nearly 55 and 73 percent of the sample households use improved seed and chemical fertilizer, respectively, but this is mainly to limited cereal crops such as wheat and teff than to all the crops produced used for the estimation of the yield index.

Other four variables of resilience to climate change include increasing the number of livestock dummies and mixed crop-livestock dummies, as well as shifting from livestock to crop and crop to livestock dummies. Of those variables, the first increases yield in the quartiles I, III, and IV, but weakly significantly. The second variable increases yield in the aggregate and quartiles. On the other hand, the shift from crop to livestock consistently decreases yield, but the shift from livestock to crop has no significant effect on yield in any of the estimations. As a resilience factor, the dummy of outmigration and quantity of manure used both increase yields in some of the quartiles and the aggregated estimations, but remittance has no role in increasing yield. Households receiving remittances could use the incoming resource to purchase or pay for yield-increasing input and services as an advantage, but there is no strong evidence to support this claim. Contrarily, outmigration of at least one member of a household contributes to increasing yield in some of the estimations by transferring finance to smallholder households for the purchase of inputs. In the descriptive statistics, less than one percent of the sample households migrate, and they are fairly distributed across the livestock quartiles.

In the end, the tests of the GMM estimations are worth discussing. In all five GMM estimations, the over-identifying restriction test (Hansen's J chi2 (2)) shows that the null that the instruments used are fulfilling the orthogonality condition of no correlation to the error term fails to be rejected even at 10% statistical significance. Therefore, the estimated model is robust. On top of this, the weight matrix, which is robust in all five estimations, has heteroskedasticity and robust standard errors.

4.4. Factors Driving the Adoption of Mixed Farming System

A logit model is estimated to identify the factors influencing the adoption of the crop-livestock farming system. The use of logit is because the data is large, and in large-size data, logit has several advantages compared to probit (Verbeek, 2008). The preliminary analysis of the data shows that more than 81 percent of households have increasingly shifted to the crop-livestock system, seeking its various advantages. Belay et al. (2022) discussed that farmers' responses to adaptation decisions may be driven by internal and external factors, and these factors could be a constraint for farmers to participate in the adaptation process. Thus, the hypothesized factors driving the adoption decision include household characteristics, socio-economic, technological, agro-ecological, and regional variables. The estimated results summarized in Table 4 indicate that 12 variables strongly explain the adoption of mixed farming, while only six of them weakly explain the adoption. This conclusion is based on a robust estimation of the model from the Wald test.

Table 4: Factors driving the adoption of mixed farming system (RCC): Logit Model

Dependent variable: crop-livestock mixed farming dummy (1 if mixed farming, 0 otherwise)	Coefficient	Stand Error
Gender dummy, 0= Female, 1= male	0.127	0.163
Education dummy, Grade 8-12 is 1	0.136	0.182
Household size (proxy to family labour)	0.156***	0.033
Non-farm income dummy, 1 if yes	-0.190	0.132
Climate change noticed? 1 if yes	0.229	0.201
Information on rainfall & temp, 1 if yes	0.196	0.167
Rented-out crop land, 1 if yes	0.652**	0.314
Climate change, hot days? 1 if yes	-0.383**	0.181
Mobile ownership, 1 if yes	0.267**	0.121
Use modern (improved) feed? 1 if yes	1.035***	0.276
AGP Dummy, 1 if beneficiary,	-0.299	0.200
PSNP dummy, 1 if participants	-0.186	0.190
Non-program Dummy, 1 if not a member to programs	-0.212	0.211
Total land size of crop production	0.198***	0.075
Drought shock in the last 5 years? 1 if yes	-0.328*	0.174
Ease of access to land, water & feed for livestock? 1 if yes	0.453***	0.132
Any remittance? dummy, 1 if yes	0.224	0.199
# of relatives that you rely on for a critical time	0.052*	0.094
Divorce dummy, 1 if yes	-0.460	0.332
Number of crops produced	0.163***	0.051
Amhara region, dummy	0.480**	0.189
SNNPR region, dummy	0.101	0.197
Somale region, dummy	-1.083***	0.348
Gambela region, dummy	-0.621*	0.363
Dire Dawa Admi. region, dummy	3.061***	1.025
Frost lands, dummy	0.644	0.364
Cold highlands, dummy	0.664***	0.233
Desert lands, dummy	-0.538	0.372
Mid-highlands (moderate), dummy	0.109	0.204
Constant term	-0.546	0.372
Wald chi2(29) = 204.63 (P=0.0000) N = 1990	**Pseudo R2 = 13.2%**	
Log pseudo likelihood = -849.924		

Note: ***p < 0.01, **p < 0.05 and *p < 0.1.

Among the factors that strongly explained the adoption of mixed farming, household size (family labour), ownership of mobile telephone, use of modern feed, total landholding, whether leased out land, ease of access to land, water, and feed, level of crop diversification, being found in Dire Dawa relative to Oromia, and being in the relatively cold highland increase the probability of adopting mixed farming, whereas more hot days due to climate change and being in Amhara and Somali regions relative to being in Oromia decrease the probability of adopting mixed farming. More crop-diversifying households tend to diversify into livestock too, compared to fewer crop-diversifying households. The variables that weakly explained the dependent variables are the number of drought shocks in the last five years, and being in Gambela relative to being in Oromia decreases the probability of adopting, whereas social capital increases the probability of adopting mixed farming.

4.5. Discussion

One of the fears in estimating aggregated crop-yield models is that the aggregation masks the role of explanatory variables. In such a case, it is advisable to run the estimations by quartiles of livestock ownership. In this study, we have estimated the yield factors in aggregation and by quartiles. From the estimation, a number of climatic and adaptation variables influencing yield are captured. Among others, the frequency of drought shocks, variables of climate-smart agriculture, long-run adaptive investments, and technologies significantly influence yield, and this is supported by the descriptive analysis of yield. The estimation also helped to identify the adaptation mechanisms, though in this kind of yield estimation, the role of intercropping and minimum tillage, which increased yield in individual crops (for example, Bedeke et al., 2019), is found to contrarily decrease yield in the household yield index, consistent with Waktola et al. (2014). Nevertheless, the econometric estimation is consistent with the descriptive statistics of the yield-index variations by livestock quartiles.

In the crop yield index, controlling the proportion of high-value crops was critical. This is because even though their proportion in crop diversification is low, the weight of the high-value crop is high, and this could increase the yield index, even when the household is less efficient. Therefore, it is not surprising to find the significant influence of the variable on yield, similar to the case of AGP II, similar crop-yield index was computed for the sample households for a baseline study in 63 AGP II woredas (Wakeyo et al., 2017). In Wakeyo et al. (2017), the average weighted yield of selected cereals and pulses for aggregated households was 16.2, whereas that of fruits and vegetables was 18.6, which shows that fruits and vegetables (high-value crops) have higher contributions to the weighted yield index used in the estimation.

The fact that moisture stress and drought decrease yield at the time of climate change is supported both in theory and empirical evidence (Mendelsohn, 2012; de Wit, 1992). Mendelsohn (2012) remarked that with no insurance, climate variability limits households from using expensive inputs, such as improved seeds and fertilizer. Similarly, de Wit (1992) underlined that yield is low to the extent that one of the inputs, such as water or rainfall, is under stress, which largely happens to crop production at the time of drought. As the estimation result shows, increasing drought frequencies in the last five years, which exacerbate moisture stress, have strongly, significantly, and consistently decreased yield because of the constraining effect of rainfall shortages. Other studies found that with drought frequency due to climate change, yield shrinks, and this varies with locations (Shuai et al., 2018; Mendelsohn, 2012). Consistent with those findings, the findings in this study show that yield varies by regions and agro-ecologies.

In the estimations, the number of equines owned by households increases the quantity of manure that can be used for increasing soil fertility (Belay et al., 2022), beyond the advantage in drought power and transportation. With an adequate number of equines, farmers can use manure. Farmers can transport their harvest in time from the field to threshing centers and storage, and this decreases post-harvest loss. Similarly, the use of a thresher has consistently and significantly increased yield in almost all estimations, consistent with the finding in Abraham (2015). Threshers increase yield by minimizing crop losses during harvesting and threshing; it increases time efficiency to overcome crop overstaying on fields to escape crop susceptibility to damages from rainfall, temperature, wind, and animals, consistent with Thornton and Herrero (2014). In Ethiopia, where threshing is manually done, 20-30 percent post-harvest losses have been common (Hengsdijk and de Boer, 2017).

Studies show that yield is negatively affected by climate change due to its impact on the reduction of soil moisture, faster depletion of soil organic matter, premature drying of grains, increased heat stress, and limited irrigation (Pequeno et al., 2021; Descheemaeker et al., 2016). Climate change studies that focus on individual crops in many cases found that warming decreases yield (Descheemaeker et al., 2016), which is consistent with the finding that the perception that hotter days by farmers increases yield. The perception of hotter days increase yield is consistent with Di Falco and Veronesi (2013). On the other hand, minimum tillage is found to decrease yield consistently in many of the estimates in this study, consistent with the findings of Mihretie et al. (2022) and Rusu et al. (2009), but contrary to the findings of Mupangwa et al. (2007) in Zambia for maize yield. In many of the previous studies, the soil water conservation advantages of the minimum tillage practices were more positive and significant than their yield advantages (Mihretie et al., 2022; Rusu et al., 2009). Other studies underline that minimum tillage increases soil acidity, which in turn decreases yield (Wakwoya et al., 2022), and this shows that minimum tillage has to be complemented with other farming practices and technologies (for example, liming to decrease soil acidity) to enhance yield. In addition to the minimum tillage, the finding shows that intercropping also significantly decreases yield, at least in some of the estimations by quartiles. Intercropping decreases yield, as estimated by Bekele et al. (2016) for maize and soybean, which is consistent with these findings. However, this contradicts the result of Waktola et al. (2014), although it is important to note that these studies focus on individual crop yields obtained from different locations. Farmers' experience in intercropping at various locations could result in a yield advantage, though this could be altered with climate change and input use traditions. The other climate-smart practice is the use of drought-resistant crops, a dummy variable. The finding shows that the dummy significantly decreases yield. It is expected that those crops have the advantage of overcoming moisture stress, but the extent of research in Ethiopia on their viability in diverse locations is limited, except for sorghum.

The result also shows that households that rent out their land score higher in aggregated households and quartiles I and II, and their yield decreases in quartile IV. Households often rent out their land because of labour and other resource constraints (for example, Descheemaeke et al., 2016). The finding that household size, a proxy for family labour (Wakeyo and Gardebroek, 2017), increases yield at least in the aggregated estimation matches with the logic that those who rent out land score higher yield, but this may not always be the case. The finding related to the role of land tenure, climate shocks, and social capital is consistent with the finding of Teklewold et al. (2019).

The finding also shows that the dummy for participation in the flagship program of AGP significantly increases yield in the land-abundant quartile IV. This is consistent with the finding of Weldesilassie et al. (2020) that yield increased in the AGP woredas compared to the non-AGP woredas. The AGP intervention woredas have a number of advantages compared to those of non-AGP woredas, for example, yield-increasing training and demonstration, encouragement of irrigation schemes, and climate-smart agriculture. Those AGP interventions increased crop yields (Weldesilassie et al., 2020).

Agro-ecology dummies are found to influence yield significantly. Altitude differences mark the agro-ecologies classified into five. The influence of agro-ecologies is mixed, but often, contrary to Descheemaeker et al. (2016), hotter agro-ecologies do not always decrease yields. In this connection, the finding shows that hot agro-ecologies increase yield consistently and significantly in quartiles II, III, and IV, and consistent with the summary of Thornton and Herrero (2014), cooler agro-ecologies increase yield in quartiles II, III, and IV too. As the descriptive analysis shows, the average yield in the cool highlands is the highest of all the average yields in other agro-ecologies. The findings also indicate that regional variations in yield may attributed to the level of commitment by administrations in the implementation regional development plans, consistent with the findings of Assefa et al. (2020), Shuai et al. (2018), and Abate et al. (2015).

Importantly, in the aggregated estimations the quartile II dummy increased yield, though weakly significantly, but there is no evidence that livestock quartile III increases yield. This reinforces the finding in the descriptive statistics that household-level yield falls in the upper livestock quartiles.

The yield factors estimation is followed by the factor driving the adoption of mixed farming. Among others, household size (family labour) and the use of modern feed increase the probability of adopting a mixed farming system. In addition, previous livestock ownership matters in the adoption. For example, Mekuria and Mekonnen (2018) indicated that the ownership of livestock positively and significantly influences the adoption of crop-livestock diversification. However, they did not provide any indication as to whether this influence is driven by increased land ownership or increased livestock ownership. Rather than previous livestock ownership, the use of modern feed and the ease of accessing land and water for livestock significantly influence the adoption of crop-livestock systems. Previous studies somehow found similar findings. For example, Descheemaeker et al. (2016) underlined that numerous adaptation measures exist, but smallholders face constraints of small farm sizes, poor access to markets and relevant knowledge, land tenure insecurity, and the common property status of grazing resources, which are relevant to the case of Ethiopia.

The increasing adoption of the crop-livestock system by smallholder farmers could result from either the maximization of return or from the upcoming programs that encourage and add to the livestock sector. Interventions such as AGP and the Sustainable Land Management Program (SLMP) might have also contributed to the increased crop-livestock system among smallholders. In this study, the likely adaptation strategy of households in the future can be better understood. This means that households could tend to continue with cropping or adding livestock rearing as an adaptation strategy to climate change, such as more severe water scarcity and labour shortages, and upcoming opportunities in investments (for example, agro-processing). In both cases, smallholders could likely be more resilient to climate change, be it due to lower crop productivity or due to labour and technological factors.

One can understand the influence of micro-water-use practices on starting livestock. Since the early 2000s, these technologies and practices have been encouraged, and their role is substantial in starting livestock on top of using them for the production of high-value crops (Bekele and Ayele, 2008). An optimal livestock size and combination of species would provide policy insight into the freely increasing livestock size in the mixed crop-livestock system.

5. Conclusion and Recommendations

5.1. Conclusion

In a country facing significant challenges of food insecurity due to droughts and climate change, reducing livestock yield by quartile poses a considerable challenge. This is because relatively more land is in the hands of livestock quartile-III and quartile-IV households. The disincentives for higher yield by livestock quartile have to be addressed rather than paying attention only to the poor who have limited land. The finding mainly shows that though mixed farming contributes to increased yield in the lower quartiles, its yield-decreasing effect in the upper quartiles sparks concern.

Drought shocks decrease the probability of adopting mixed farming, and information on rainfall, temperature, and land abundance improves the move to a mixed farming system. On the contrary, the findings show that difficulty accessing water and land decreases the probability of adopting mixed farming. Relative to SNNPR, most regions tend to stay in crop-only farming systems. This means that households tend to continue with cropping or adding livestock rearing, either as an adaptation strategy to climate change with severe water scarcity and labour shortages or as an upcoming investment (for example, agro-processing).

The finding strongly supports that climatic shocks in the frequency of drought in the last five years in the sample areas play a predominant role in decreasing crop yield. Surprisingly, the rate of the influence of the shocks on yield increases with the frequency of the drought, which is most likely to happen. This requires the attention of policymakers to improve the adaptation mechanisms of smallholder farmers. Currently, investment in irrigation and water management technologies has gotten the attention of the government. This is an encouraging strategy to increase the irrigated land to decrease the risk of climate change or drought shocks. Moreover, in line with the findings, the use of threshers improves yield because of their advantages in decreasing harvest losses.

5.2. Recommendations

The study found that increasing livestock size creates a disincentive to increase crop yield. Given that nearly 60 percent of the cropland is occupied by upper livestock quartile households, it urges attention to accommodate the extension and other support services to the upper livestock quartile households. In other words, there is a need to expand current agricultural interventions by designing appropriate strategies that specifically address the challenges faced by the most affluent farmers.

The finding shows that drought frequency over several years significantly decreases yield. This has an essential implication. In the relatively surface water-abundant Ethiopia, it is essential to understand that irrigation and water technologies and practices need to be encouraged as adaptation strategies. In the estimations, the coefficient of irrigation is positive but insignificant in many of the estimations, possibly because of the limited number of users of irrigation (only 15%), but investment in irrigation has to be further encouraged.

Drought-resistant crops are only second best relative to the crops that farmers would grow under non-drought-normal conditions, and the finding shows this practice decreases yield. Research institutes on crop varieties need to work on these varieties to improve their yield contributions as options in drought years, which is a critical assignment in the Ethiopian context.

The agricultural information helps farmers forecast, and the findings show that this increases yield. This implies the need to enhance information sharing with farmers through digital and non-digital mechanisms to increase yield.

The finding strongly supports transformative investments, such as the implementation of threshers to increase yield. This highlights the need for affordable threshers that either available for purchase or for rental, as the current expensive options pose a barrier. Exploring the reasons behind the low adoption rate of threshers and their profitability could be areas of further research.

The fact that outmigration increases yield shows that labour productivity could be low and has the potential to increase labour productivity, which transforms agriculture. This is consistent with the prediction of the Lewis model. The path to influencing crop yield per hectare is that those outmigrantors could transfer financial resources to household to purchase yield-increasing inputs.

Last but not least, the finding that yield varies with agro-ecologies and administrative regions magnifies the need to avoid a one-fits-all type of recommendations and emphasizes the importance of considering agro-ecologies and regional variations to increase crop yields. Several studies, such as Mendolson (2012) highlight this crucial issue in agricultural transformation.

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