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Agricultural Intensification in Ethiopia

Patterns, Trends, and Welfare Impacts

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Notices

Abstract

Ethiopia has made substantial efforts in the last three decades to increase agricultural productivity through modern input intensification and stimulate overall economic growth. Despite the high growth rates in recent decade, Ethiopia's overall intensification and yield levels remained below what is considered optimal. This study examines the patterns, trends, and drivers of agricultural intensification and productivity growth during the recent decade (2012 - 2019) using three rounds of representative household data collected from the four main agriculturally important regions of the country. The descriptive results indicate a positive trend in both the adoption rate and intensity of inputs and output, albeit from a low base compared to other contexts and with considerable heterogeneity by access to information, rainfall levels and variability, labor, soil quality, remoteness, among others. The econometric results show significant association between intensification, yield growth, household dietary diversity (a proxy measure for food and nutrition security), and consumer durables. However, the results on the association between current yield levels and per capita consumption expenditures are mixed (i.e., while an increase in cereal yield only improve food consumption expenditures, an increase in cash crops yield mainly improve non-food consumption expenditures). In sum, while the increasing input intensification and the resulting yield gains are associated with improvement in household diets and consumer durables, it falls short to have strong impact on incomes (as measured by total consumption expenditures), indicating that more efforts have to be made to see meaningful impacts on higher order outcomes. Additional welfare improving productivity gains through increased input intensifications may require investments to put in place appropriate fertilizer blends linked with localized soil nutrient requirements, investments to generate locally suited improved seeds and appropriate mechanisms to reach farmers, ways to mitigate production (rainfall) risk, and investments to remodel Ethiopia's extension system to provided much needed technical support to farmers on production methods.

Keywords: Ethiopia, Agricultural transformation, Input intensification, Welfare, Yield

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1. Introduction

A vibrant agricultural sector that deploys modern input intensification and increasing labor productivity that leads to higher agricultural incomes is deemed essential not just for improving the welfare of farming communities whose livelihoods rely on the sector but also for a broad-based sustainable economic growth and transformation (Diao et al., 2018, Dercon et al., 2014; Gollin, 2010). However, increasing population pressures, land fragmentation, and subsequent soil nutrient degradation have made increasing agricultural productivity through modern input intensification challenging (Jayne et al., 2014, Heady et al., 2014(a)). Policy-induced agricultural intensification is thus widely seen as the avenue to mitigate this challenge and Africa is the last continent to take advantage of this step. The last decade or so has however seen renewed interest and commitments to invest in promoting and accelerating modern input use in sub-Saharan Africa (Sheahan et al, 2014).[1] Use of inorganic fertilizers, agrochemicals, improved seed varieties, and mechanization are seen as critical yield-enhancing inputs in Africa and many countries have taken steps to promote these inputs using several policy instruments including subsidies (Ricker-Gilber et al., 2011) and provision of advisory and technical support (Dercon et al., 2009; Berhane et al., 2018).

Ethiopia has made substantial efforts in the last three decades to increase its agricultural productivity through modern input intensification and stimulate overall economic growth. Following changes in the political landscape in the early 1990's and subsequent steps taken to liberalize the economy, Ethiopia envisioned an Agriculture Development Led Industrialization (ADLI) strategy and implemented a series of development plans that mainly focused on transforming its agriculture sector. Early farmer plot-level demonstrations of fertilizer-seed technologies indicated that these technologies would help double cereal yields in non-moisture deficient areas of the country (Spielman et al., 2010). This has motivated policy makers to focus on technology-driven, public extension-led cereal intensification in the following decades. Thus, improving cereal productivity and intensification through improved use of fertilizers, improved

[1] Among the major SSA wide initiatives to boosting agricultural production and productivity include the Comprehensive Africa Agriculture Development Program (CAADP), the Alliance for Green Revolution in Africa (AGRA), The Abuja Fertilize Summit, etc. are some of the recent initiatives in African agriculture.

seeds, and agrochemicals, led by an extensive public extension system has been taken as core pillars of a series of agricultural development strategies implemented in subsequent years. The public extension system was significantly expanded, fielding one of the highest ratios of development agent to farm household in Africa (Davis et al., 2010; Yu and Nin-Pratt, 2014), reaching virtually all farming communities in the country (Berhane et al., 2020). Farmer training centers were set-up in each kebele[2] to help train farmers on similar plots to theirs. Farmer organizations were established partly to serve as input, mainly fertilizer, distribution centers.

Ethiopia has since made significant progress in terms of overall economic growth and agriculture has been the main driver of this growth (Dorosh et al., 2020). For over two decades, Ethiopia's growth strategy has remained agriculture focused as shown by a budget exceeding the CAADP agriculture investment target of 10 percent of the national budget (AGRA, 2018). Within agriculture, crop productivity has received substantial attention as significant investments were made in its extensive extension system and in ensuring access to modern inputs (Berhane et al., 2018). Parallel investments in roads, safety nets, education and health have also contributed to subsequent recovery and turnaround of the sector.

Largely driven by favorable economic conditions, Ethiopia's total value of crop output more than doubled - from 14 million metric tons in 2004/05 to 32 million metric tons in 2015/16. Average crop output grew between 8 to 13 percent a year and cereals accounted for a lion's share of the total crop output growth. In the same period, land under cultivation has expanded by about 27 percent, 90 percent of which was used for cereals (but later declined and leveled off) and average cereal yield has increased by about 5 percent per year. Output growth was attributed to land expansion as well as yield growth (Bachewe et al., 2018).

However, despite the high growth rate trends in recent years, Ethiopia's yield levels and overall intensification remain rather low compared to similar other African or Asian countries – and show signs of slowing down recently (Berhane et al., 2020). Agriculture transformation is associated with sustained increases in land and labor productivity through policy-induced intensification. However, in countries like Ethiopia where land is a major constraint, intensification efforts are further limited by demographic as well as biophysical determinants

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[2] Kebele is the lowest administration unit in Ethiopia.

(Heady et al., 2014(a); Heady et al., 2014(b)). Theoretically, when set in motion, intensification is expected to first increase cultivated land and then cultivated land decreases due to both land constraints and decreases in aggregate prices (Rudel et al., 2008). Initially, intensification provides farmers with higher yields per hectare and growth in overall income, which in turn induces farmers to expand production through increased cultivation of additional land. Increased supply of agricultural produce in aggregate, with relatively inelastic demand, would result in decline of prices driving intensification to focus on knowledge or technology to respond better to additional inputs. In actual terms, the net effect is not clear from the outset and often population pressures hinder policy-induced intensification leading to undesirable outcomes.

Given the lack of detailed and consistently collected data on farm practices, it is not clear what explains intensification or the lack of it and how these drivers impact the farming community. This study examines the patterns, trends, and drivers of agricultural intensification during the recent decade using large, representative, and longitudinal data from the four main agriculturally important regions. Specifically, the study addresses the following research questions. What is the household-level evidence of agricultural intensification in Ethiopia? What explain intensification at the farm (i.e., household) level and what needs to be done to keep up with recent trends to achieve transformation? What explains observed trends and patterns of modern input intensification (e.g., inorganic fertilizers, improved seeds, agrochemicals, use of farm machinery and mechanization) in the context of Ethiopia? Does gender of the household head matter for intensification? To what extent does modern input intensification explain observed trends in land productivity (or yield)? How does production risk (measured by rainfall levels and variability) affect intensification and yield? To what extent does recent trends in yield increases translate into household welfare? Does intensification (not picked by yield) matter for welfare improvements?

The rest of the chapter is organized as follows. Section 2 describes the data and estimation strategy. Section 3 presents the descriptive results on the trends and patterns in input and out intensification with a focus on selected modern inputs mainly inorganic fertilizers, improved seeds, agrochemicals, and use of agriculture machinery. Section 4 discuss the main results on the relationship between agricultural intensification, yield growth, and household welfare. Section 5 concludes with the key findings and their policy implications.

2. Data and methods

2.1. Data

The study used three rounds of the Ethiopian Agricultural Commercialization Clusters (ACC) survey conducted by the International Food Policy Research Institute (IFPRI) for the Ethiopian Agricultural Transformation Agency (ATA). The three surveys interviewed a total of 13,302 rural households, of which 1,899 are panel households interviewed in all three rounds (Table 1). The sample households were selected following a three-stage sampling procedure. First, the woredas (districts) in the four agriculturally important regions of Ethiopia were stratified into Agricultural Commodity Clusters (ACC) defined by the ATA and five sample woredas (districts) were randomly selected from each ACC. Second, two kebeles were randomly selected from each district to be part of the surveys. Finally, 15 farm households were randomly selected from each sample kebeles based on the household lists maintained by local administrations. In addition, about 15-20% of the sample was selected from outside the ACCs, using the same three-stage sampling.

The questionnaire has remained similar across the survey rounds, and it covered a wide range of topics including household demographics, housing and assets, land ownership and use, crop inputs and labor use, crop production, storage and utilization, livestock ownership, sources of non-farm incomes, saving and credit, food and non-food consumption expenditures, and experience-based food (in)security measures.

Table 1. Sample size, by survey round

	Survey rounds		
Sample	2012	2016	2019
Number of households	3000	4991	5311
Number of woreda	99	153	154
Number of kebele	200	334	355
Number of panel households	1899	1899	1899

Source: Analysis of data from the ATA-ACC Survey.

The analysis in this study makes use of both the full sample (for the descriptive statistics) and the panel households (for the econometrics analysis) at various levels of disaggregation (i.e., plot, crop, and household). Table 2 presents the descriptive statistics of sample households in the data used for the econometrics analysis by survey rounds. The vast majority of sample households are male headed (90 percent), and the average age of household heads range from 45 to 50. While the average household head attended secondary education, most spouse has no formal education. Interestingly, there is a sizable increase in mobile ownership from 30 percent in 2012 to 70 percent in 2019. In contrast, there is no change on the share of household that own radio (presumably due to the fact that farm households can use their mobile to tune into radio broadcastings/stations). Not much change is observed on the distance between household dwelling and farms, all weather roads, and rivers over the three-survey period.

Table 2. Descriptive statistics of household and plot characteristics

	Survey rounds		
	2012	2016	2019
Oxen ownership	1.3	1.4	1.8
Log (household size age 16-59)	0.1	0.1	0.0
CV of inter-annual meher rainfall	0.1	0.1	0.1
Per capita farm size	0.3	0.3	0.3
Gender of household head (1=male)	0.9	0.9	0.9
Age of household head	45.6	48.4	50.0
Household head education level	2.3	2.2	2.1
Spouse education level	0.9	0.9	0.9
Improved extension (DA) access	0.7	0.6	0.6
Proportion of plot with organic fertilizer	0.2	0.2	0.2
Cellphone ownership	0.3	0.6	0.7
Radio ownership	0.4	0.4	0.4
Share of marketed surplus	28.8	31.1	32.5
Proportion of poor-quality plot	0.2	0.1	0.1
Distance to parcel	0.3	0.3	0.3
Remoteness tercile	2.0	1.9	1.9
Distance to all weather road	3.9	4.0	3.9
Distance to rivers	8.3	8.4	8.4
Number obs.	1807	1751	1719

Source: Analysis of data from the ATA-ACC Survey.

In addition, in the production risk analyses, we use rainfall data constructed by the Climate Hazard Center (CHC) at the University of California at Santa Barbara and the United States Geological Survey. This database is known as the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) and is constructed from satellite imagery calibrated with data from weather stations covering 40 years of rainfall data with a resolution of about 5.5 × 5.5 km. The CHIRPS data are generated with funding from the United States Agency for International

Development (USAID), the National Aeronautics and Space Administration (NASA), and the National Oceanographic and Atmospheric Administration (NOAA) (CHC, 2021).

2.2. Estimation strategy

Agriculture remains a key source of household income in rural Ethiopia. Transforming Ethiopia's agriculture sector is therefore important both for its own sake as a sector as well as in transforming the lives of millions of households whose incomes solely rely on agriculture. Agriculture intensification to transforming lives is therefore a critical decision at the government, household, and plot levels. We define agriculture intensification as an increase in the level of inputs applied with the goal of increasing productivity and income. We follow Singh et al. (1986) to conceptualize intensification as a constrained household utility maximization problem where production and consumption are non-separable in which levels of input use or intensification are affected, in addition to input and output prices, by various socioeconomic and household characteristics (Sadoulet and de Janvry, 1995). Thus, yield can be expressed as a reduced form production function as follows:

$$YIELD_{it} = \beta_1 INPUT_{it} + \beta_2 X_{it} + u_i + \varepsilon_{it} \qquad (1)$$

where $YIELD_{it}$ refers to crop output per hectare produced by household i in time t, $INPUT_{it}$, represents a set of inputs (fertilizer, improved seed, agrochemicals, and machinery use) applied at different intensities;[3] X_{it} is a vector of household, plot, market level characteristics and shocks; β_1 and β_2 are vectors of parameters to be estimated; and ε_{it} is the error term, assumed white noise in our yield estimation; u_i is the time-invariant heterogeneity and can be decomposed as $u_i = \gamma c_i + \mu_i$ where c_i is the observable time-invariant and μ_i is non-random unobserved time-invariant heterogeneity that vary across households.

The interest here is to estimate the extent to which input intensification explains yield. A key challenge when estimating equation (1) is the potential endogeneity between the decision to apply levels of inputs and yield as both may be simultaneously determined by time-invariant unobserved factors, μ_i, such as individual farmer abilities in the management of input use and

[3] For simplicity, we drop the plot-level subscript but note that crop-level attributes such as soil quality are important & included in our estimation.

agronomic practices. We use the correlated random effects (CRE) model to address the time-invariant unobserved heterogeneity (Mundlack, 1978; Chamberlain, 1984). The CRE model has the extra advantage of enabling the estimation of observed time-invariant variables of interest, c_i (e.g., region), which would be removed in fixed-effects estimation. In the estimation, we implement a more recent variant of the CRE model, known as the hybrid model (Allison 2009), where the within-effects and between-effects are estimated in a random-effects model framework as follows:

$$YIELD_{it} = \beta_1(INPUT_{it} - \overline{INPUT_i}) + \beta_2(X_{it} - \overline{X_i}) + \beta_3\left(\overline{INPUT_i}\right) + \beta_4\overline{X_i} + \gamma c_i + \mu_i + \varepsilon_{it} \quad (2)$$

Estimating Equation (2) using random-effects model gives both the within-effects and between-effects while also removing the "within" aspect of the time-invariant heterogeneity.

We follow the same hybrid CRE model approach to estimate the determinants of fertilizer, improved seed, agrochemicals, and machine use intensification. In the same fashion, the following reduced form input demand equations are estimated using the CRE method:

$$INPUT_{it} = \beta_1 M_{it} + \gamma c_i + \mu_i + \varepsilon_{it} \quad (3)$$

where $INPUT_{it}$ is the same inputs defined earlier, M_{it} represents all household and location level characteristics that vary with time and c_i now includes all plot and location characteristics (e.g., distance to roads and markets).

2. Patterns and trends in intensification and welfare outcomes

2.1. Trends in agricultural intensification

We define intensification both relative to area cultivated (units or value of agricultural inputs per unit of cultivated land) and relative to output (the value of inputs as a ratio of the value of output). The area intensification measures include adoption and use of fertilizer, improved seed, agrochemical, and agricultural machineries. We also examine measures of productivity, including output per unit of land (yield) and output per unit of labor (labor productivity) since this is the intermediate objective of agricultural intensification. This section briefly discusses the descriptive evolution of the patterns and trends of these indicators over the period of the data/analysis considered.

Fertilizer intensification

Inorganic fertilizers (fertilizers from this point on) is one of the key productivity-enhancing inputs widely promoted by the extension system in Ethiopia to increase yields through addressing the productivity losses caused by declining soil fertility. Fertilizer intensification has been considered as a key game changer in Ethiopia's agriculture transformation agenda, and as a result fertilizer imports have more than doubled over the last two decades (Berhane et al., 2020). Data from the Agricultural Sample Survey (AGSS) of the Central Statistics Agency (CSA) indicates that fertilizer applied area has increased by 55 percent between 2007/08 and 2016/17, with overall increase in fertilizer intensification from 0.45 to 0.95 quintal per hectare in the same period (Appendix A: Table A9).

The ACC data, albeit showing relatively lower figures, confirms this overall trend observed in the nationally representative AGSS data (Table 3). Specifically, the ACC data shows a positive trend in the adoption rate and intensity of fertilizer use over the period of analysis. Among crops, cereals account for the most part of fertilizer intensification. This is not surprising given Ethiopia's input intensification has been cereal biased. The share of households using fertilizer on cereals increased by 20 percentage points between 2012 and 2019. Likewise, the share of cereal area fertilized increased by about 6 percentage points and rates of application as measured by amount of any fertilizer use per hectare of land has doubled. Recent evidence however shows that there is still room for improvement, mainly, by increasing overall fertilizer intensity (Berhane et al., 2020), matching the right fertilizer blend or formulation to soil nutrient requirements as well as introducing proper application rates (Abay et al., 2021). We also note that there is no sizable difference on adoption and application rates of fertilizer between male and female headed households across crops and crop groups (Appendix A: Table A1), although this trend changes in favor of female headed households once other factors are controlled for in a regression framework (we return to this discussion in Section 4).

Table 3. Trends in fertilizer adoption and application rates

Crop group	Adoption (% of households)			Adoption (% of area)			Intensity (kg per hectare cultivated)		
	2012	2016	2019	2012	2016	2019	2012	2016	2019
Cereals	52.0	63.2	71.6	16.9	19.9	22.8	71.4	112.7	158.1
Barley	52.5	60.2	63.6	39.0	41.3	43.2	62.9	102.6	121.2
Maize	42.1	57.1	66.0	29.9	42.7	46.8	71.7	122.3	161.4
Sorghum	11.6	17.3	28.6	8.5	12.8	20.8	9.4	14.5	34.4
Teff	70.2	79.8	84.0	41.9	46.0	47.4	82.3	125.1	173.5
Wheat	76.0	83.5	87.9	49.8	51.8	52.0	120.5	166.7	222.1
Pulses	12.1	16.1	21.0	9.6	11.2	14.3	14.9	21.7	31.2
Oilseeds	15.1	13.2	26.1	9.7	10.1	19.1	8.5	11.2	20.9
Vegetables	23.7	32.3	53.0	18.7	25.6	44.7	61.0	108.9	205.0
Root crops	9.6	10.9	21.4	6.7	7.7	16.0	17.0	23.6	45.8
Fruits	0.0	0.3	1.6	0.0	0.3	1.3	0.0	0.6	2.2

Source: Analysis of data from the ATA-ACC Survey.

Improved seed intensification

Like fertilizers, improved seed intensification has also been at the center of Ethiopia's drive to increase cereal productivity over at least the last two decades (Spielman et al., 2013). As such, improved seed has been at the forefront of Ethiopia's public investments on agricultural research and extension services. A key challenge has been the exclusive mandating of improved seed production and multiplication to public sector enterprises, with limited roles played by the private sector (Alemu et al., 2007; Spielman et al., 2010; Alemu et al., 2019). As a result, the sector has been characterized by mismatches between supply of and demand for varieties and related anomalies. Despite this situation, Ethiopia has seen important improvements in this sector as well, with nationally cultivated area covered with improved seeds jumping from 4.7 percent in 2007/08 to 13 percent in 2016/17 (Appendix A: Table A9). The number of improved varieties released to farmers has increased rapidly, with official figures indicating up to five-fold growth between 2004 and 2014 (Bachewe et al., 2018). However, variety release rates vary by crop: there were about 50 varieties of wheat and 20 varieties each for maize, barely, and teff over the same period (Bachewe et al., 2018).

The ACC data shows similar trends on improved seed adoption rates, albeit to a rather limited extent (Table 4). For example, between 2012 and 2019, the share of households that adopted a newly purchased seed has increased by 17 percentage points for maize and 3 percentage points for vegetables. Teff has also seen some improvements. The remaining crops have seen declines on improved seed adoption rates over the period considered.

In the same period, the share of area covered by newly purchased seed varieties has also increased by 11.4 percentage points for maize and by 6.2 percentage points for vegetables. The share of area covered by root crops has also increased slightly, while for the remaining crops it has either remained the same or declined slightly. Similarly, overall seed intensification has also remained very limited, with cereals (an increase by 1.6 kg per hectare) (Table 4). Clearly, maize and vegetables are the only crops with relatively high level of improved seed coverage, presumably the hybrid nature of maize seeds and the difficulty in collecting and storing vegetable seeds necessitate farm households to buy them on yearly basis. We also note that there is not substantial difference in improved seed adoption and intensity of use between male- and female-headed households (Appendix A: Table A2).

Table 4. Trends in improved seed adoption and intensity of use

Crop group	Adoption (%)			Adoption (share of area)			Intensity (kg per hectare, total area)		
	2012	2016	2019	2012	2016	2019	2012	2016	2019
Cereals	21.6	24.6	24.3	8.2	9.6	9.5	15.3	16.8	17.0
Barley	19.3	17.0	16.7	15.6	13.6	12.3	32.0	30.6	30.5
Maize	41.8	50.0	58.2	29.4	37.6	40.7	14.8	14.4	17.4
Sorghum	8.0	9.2	6.6	6.8	7.8	5.2	2.3	3.5	2.6
Teff	12.7	17.1	13.8	9.3	12.4	9.5	6.8	7.8	6.5
Wheat	20.0	23.5	18.9	15.9	17.1	13.4	30.6	34.7	31.0
Pulses	22.3	19.3	15.1	16.5	14.3	10.8	20.6	20.3	18.2
Oilseeds	21.8	20.2	16.0	17.3	17.0	13.4	7.2	5.3	6.9
Vegetables	37.4	34.3	40.1	28.7	27.1	34.9	72.1	48.0	46.7
Root crops	19.5	13.0	18.1	14.7	9.5	15.2	94.0	59.6	74.8
Fruits	2.7	0.2	2.0	1.8	0.2	1.6	6.1	1.1	6.0

Source: Analysis of data from the ATA-ACC Survey.

That said, while the limited share of households using freshly purchased seed somehow can indicate a lower seed replacement rate, it may not necessarily reflect the true picture of improved seed adoption or intensity. Reuse of improved seeds is common among farm households in Ethiopia, and farmers may fail to consider a reused improved seed as improved. A recent study based on DNA fingerprinting indicates that reuse rates of improved maize and wheat varieties are significantly higher than those reported in household surveys (Yirga et al., 2016).

Fertilizer and improved seed intensification

While the individual use of modern agricultural inputs is beneficial to some extent, it is the combined use that can lead to larger yield gains due to the strong complementarities between these inputs (e.g., Abay et al., 2018). More specifically, while fertilizers are commonly used with traditional varieties, improved seeds are often recommended along with fertilizers (Ogada and Nyangena, 2019).

Table 5 shows the trends in agricultural intensification measured by joint use of fertilizers and (newly purchased) improved seeds in a given plot. Overall, the results show that limited share of households have jointly used improved seeds and fertilizers in at least one of their plots, again with no meaningful difference between female and male headed households (Appendix A: Table A3).

Table 5. Trends in joint adoption of fertilizer and improved seed

Crop group	Adoption (% of households)			Adoption (% of area)		
	2012	2016	2019	2012	2016	2019
Cereals	14.5	19.4	20.3	5.4	7.3	7.8
Barley	11.0	11.4	12.1	8.9	9.4	8.8
Maize	30.6	41.8	50.5	21.2	31.0	35.1
Sorghum	0.8	1.8	1.4	0.6	1.4	1.1
Teff	8.5	13.3	11.2	6.2	9.3	7.5
Wheat	15.5	21.1	17.4	12.0	15.2	12.0
Pulses	4.0	5.3	5.0	3.2	4.1	3.6
Oilseeds	2.6	2.5	4.9	2.1	2.1	3.9
Vegetables	9.0	16.5	27.6	6.9	12.9	24.5
Root crops	4.8	5.5	7.8	3.6	4.1	6.4
Fruits	0.0	0.1	0.2	0.0	0.1	0.2

Source: Analysis of data from the ATA-ACC Survey.

The results are even much lower when we consider the share of area planted with improved seed and fertilized. This is driven by the small share of planted area covered by improved seeds. Again, the only exception is maize, partly because a recycled maize seed does not maintain its yield over time as well as other crops (e.g., wheat) and farmers need to use fertilizer to fully tap the yield potential of hybrid maize seed.

Agrochemicals and machinery use

The use of agrochemical and agricultural machinery shows steady growths over the last decide, albeit from a low base compared to similar other contexts (Tamru et al., 2017; Berhane et al., 2021). CSA's AGSS data shows, for example, nationally pesticide applied area has increased by more than 50 percent from 21 percent in 2007/08 to 32 percent in 2016/17 (Appendix A: Table A9). Table 6 provides trends in the cost of agrochemicals and machinery used (per hectare) based on our ACC data. In general, average use of agrochemicals and machinery has increased between 2012 and 2019. The average increase is higher for agrochemicals (76 birr per hectare) than machinery use (6.3 birr per hectare).

Table 6. Trends in agrochemicals and machinery use

Crop group	Agrochemical (birr/ha)			Machinery use (birr/ha)		
	2012	2016	2019	2012	2016	2019
Cereals	26.4	57.7	112.8	2.8	6.4	9.7
Barley	21.6	41.7	77.9	1.2	1.5	3.9
Maize	6.1	24.8	68.9	1.2	2.0	5.6
Sorghum	16.7	37.5	62.1	9.7	12.7	18.7
Teff	39.1	72.3	131.7	1.3	2.3	4.1
Wheat	49.1	109.6	188.9	2.6	19.8	24.3
Pulses	21.5	49.9	98.8	1.3	0.4	1.9
Oilseeds	5.2	31.0	55.4	26.6	37.1	39.1
Vegetables	21.1	69.0	203.0	0.1	4.0	5.8
Root crops	7.9	7.9	39.3	0.2	0.5	2.7
Fruits	0.0	3.7	5.3	0.7	0.3	0.8

Source: Analysis of data from the ATA-ACC Survey.

In relative terms, on average, the intensity of agrochemical use is greatest on vegetables (203 birr per hectare) followed by wheat (188.9 birr per hectare), and teff (131.7 birr per hectare), perhaps due to susceptibility of both crops to pests and diseases. And, the average cost of machinery use is highest for oilseeds (39.1 birr per hectare), followed by wheat (24.3 birr per hectare) and sorghum (18.7 birr per hectare). Mechanized oilseed farms are common in the lowland sesame producing areas, and mechanized wheat farms are common in Arsi and Bale areas of Oromia region. We find that female-headed households spend relatively more on agrochemicals and machinery than their male-headed counterparts. Higher use of agrochemicals and machinery could be due to labor constraints faced by female-headed households (please see Appendix A:

Table A4 and Table A5 for disaggregated results by crop and gender of the head of the household).

Has input intensification been profitable?

For farmers to adopt and continue using agricultural inputs, given production risk, the returns to these inputs and hence profitability is critical. In other words, additional revenues from production using these inputs need to cover the cost of all inputs deployed and the premium for production risk involved. Calculating profits in the context of farm households is not straightforward as, among others, family labor and other household implicit production costs are not easy to capture in household surveys. Comparing partial average input costs (excluding family labor and other implicit costs incurred by the household) to average values of outputs (or simply partial gross revenues) would however enable us to gauge the extent to which revenues can cover production costs – partial profitability.

Table 7 presents share of average total cost of inputs (excluding labor and other implicit costs) to average total values of outputs produced by the average household in our sample, by survey round (in birr). Inputs costs considered in this calculation include fertilizers, improved seeds, agrochemicals, and machinery use.

Table 7. Share of value of inputs (excluding labor) to values of output, by survey round (in Birr)

Crop group	Input to output value ratio (%)		
	2012	2016	2019
Cereals	11.5	21.6	13.8
Barley	14.6	19.4	14.8
Maize	11.1	26.0	14.0
Sorghum	6.0	18.2	8.9
Teff	11.5	21.1	13.9
Wheat	14.5	24.1	15.8
Pulses	10.1	15.8	13.7
Oilseeds	7.9	15.9	11.0
Vegetables	8.7	15.0	12.6
Root crops	8.9	10.8	13.2
Fruits	5.9	8.1	6.9

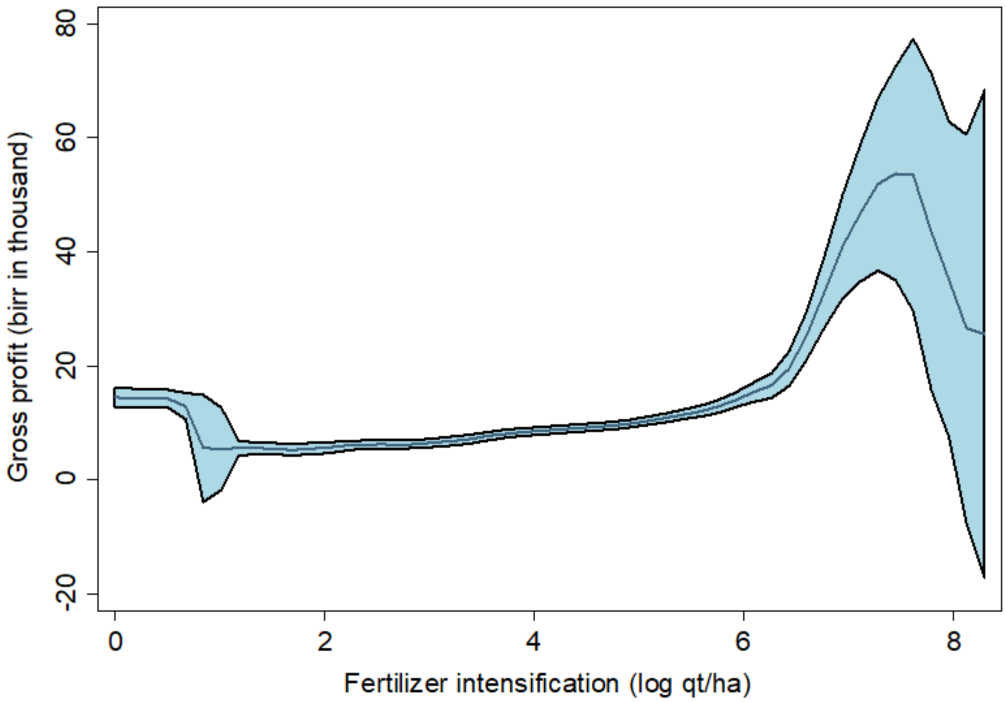
Source: Analysis of data from the ATA-ACC Survey.

In general, excluding costs of labor and other implicit costs, average input costs have accounted for about 6.0 – 14.6 percent of average value of outputs in 2012 and 7.0 – 15.8 percent in 2019. Clearly, on average, input costs are only a small fraction of value of outputs. In relative terms, share of input costs to output value ratio is highest for wheat and lowest for sorghum and fruit. Oilseeds and pulses fall in the middle of the two crop groups.

Overall, the share of average value of inputs to average value of outputs for all crops has increased from 9.9 percent in 2012 to 12.5 percent in 2019 and that the average cost of inputs relative to average value of outputs has generally increased between 2012 and 2019, on average. This may mirror the recent foreign exchange driven price increases of imported inputs in Ethiopia, mainly of fertilizers, agrochemicals, and machineries. Recent changes in output prices, mainly wheat prices, may also reflect similar fluctuations in the import market. The relative input cost to output value ratios presented in Table 7 help understand the overall picture of (partial) profitability of inputs used. However, these results do not tell us, other factors remaining the same, a level of intensification at which an input contributes to meaningful increases in profits. We use a local polynomial smoothing – a simple non-parametric regression useful to analyze these relationships. Figure 1 depicts the local polynomial smoothing graph for fertilizer intensification (log of quintal per hectare) and (partial) profitability (birr per hectare)[4]. We focus on fertilizer intensification to answer this question as fertilizers are the most widely applied agricultural inputs in Ethiopia.

The key message from this relationship is that while any level of fertilizer application is associated with positive profits, a jump in profitability is achieved only after an intensification level of 78 kg per hectare (at log of 6 quintal per hectare in Figure 1). Note however that the confidence interval gets wider the further away from the threshold, suggesting few farmers in our data achieve this level of intensification and thus this result is cautiously interpreted.

[4] Profit is calculated as the average value of outputs minus average cost of inputs (fertilizer, improved seeds, agrochemicals, and machinery use), excluding family and hired labor, and other implicit costs associated with using other household inputs.



Note: The shaded are shows 95% CI.
Source: Analysis of data from the ATA-ACC Survey.

Figure 1. Gross profit (without labor and other implicit costs) by fertilizer intensification

Land and labor productivity

An important premise behind the drive for purchased input intensification such as fertilizers and improved seeds is that such inputs can eventually improve the productivity of land and labor – two important sources of household income. National data for land productivity (or yield) shows cereal yield stood at 26.8 quintal per hectare in 2018/19 (Berhane 2020). Among cereals, maize registered the highest (39.9 quintal per hectare) and teff the lowest (17.6 quintal per hectare). Fruits (69.6 quintal per hectare) and vegetables (36.9 quintal per hectare) are among the other crop groups that registered higher average yields nationally. Data for labor productivity is hard to get, and comparable national labor productivity figures are not easily available.

Table 8 presents trends in land and labor productivity for each crop group based on the ACC data. Overall, based on quintal or birr per hectare, yield shows increasing trends between 2012 and 2019. Although the ACC data shows similar growth trends as the national AGSS data, average figures based on the ACC are way lower than the national averages. For example, based on ACC, average cereal yields stood at 19.5 quintal per hectare in 2019 (as opposed to 26.8 quintal per hectare based on the AGSS data). Similar lower than AGSS-based average figures are also reported by other recent datasets, e.g., the ESS and AGSS averages are generally on the high bound (for comparative analysis see Bachewe et al., 2018).

Table 8. Trends in crop and labor productivity

Crop group	Yield (quintals per hectare)			Yield (birr per hectare, in thousand)			Labor productivity (value of output/person days per crop season; in thousands birr)	
	2012	2016	2019	2012	2016	2019	2012	2019
Cereals	15.3	18.0	19.5	8.4	8.6	11.2	0.1	0.1
Barley	13.3	15.6	18.0	7.2	7.2	10.0	0.1	0.1
Maize	22.0	28.3	30.3	8.9	8.1	10.1	0.1	0.1
Sorghum	14.0	14.0	15.4	6.9	5.0	7.7	0.1	0.1
Teff	9.2	9.6	11.6	7.9	8.9	11.7	0.1	0.2
Wheat	16.9	17.8	20.9	10.9	9.8	13.7	0.2	0.2
Pulses	11.0	13.5	12.3	10.5	11.7	10.6	0.1	0.2
Oilseeds	5.0	6.5	8.4	6.7	7.9	11.3	0.1	0.2
Vegetables	39.4	49.3	66.3	29.2	41.9	41.7	0.1	0.2
Root crops	65.5	101.4	96.4	26.6	38.5	40.5	0.1	0.1
Fruits	109.4	123.2	101.1	41.6	46.1	37.9	0.4	0.3

Source: Analysis of data from the ATA-ACC Survey.

That said, average yields for individual crops as maize (30.3 quintal per hectare), wheat (20.9 quintal per hectare), fruits (101.1 quintal per hectare) are however not far off from the AGSS figures. Overall, between 2012 and 2019, all crops have seen yield growth ranging between 10 percent (for sorghum) to 69 percent (for oilseeds). Among crops, for the same period, the highest yield growth was recorded for oilseeds (69 percent), vegetables (68 percent), root crops (47 percent), barely (36 percent) and maize (38 percent) (Table 8). Fruits on the contrary have seen declines in yield growth over the same period. There was also a positive labor productivity (measured by volume of output per person days per crop season) and the growth rate is almost similar for all crops. Growth rate for root crops is slightly higher followed by wheat.

2.2. Trends in welfare indicators

We used three welfare indicators to answer one of our key questions: Does yield growth and input intensification bring about welfare changes to the household level? The welfare indicators include household dietary diversity score (HDDS), real household consumption expenditure (food and non-food)[5], and household durable assets. Table 9 present the descriptive evolution of the two welfare indicators over the period of the analysis considered (the durable asset indicators is based on a principal component analysis and the summary statistics in itself does not have an intuitive interpretation). While there is only marginal improvement in household dietary diversity score, the trends in household real total (food and non-food) consumption expenditure show substantial improvement (Table 9).

Table 9. Outcome indicators, by survey round

	Survey rounds		
Subsample	2012	2016	2019
Household dietary diversity score (HDDS)	5.8	6.2	6.0
Household real total (food and non-food) consumption expenditure (birr)	48.6	95.4	126.3

Source: Analysis of data from the ATA-ACC Survey.

3. Agricultural intensification, productivity, and welfare

After decades of misguided agriculture policies in the 1980s, Ethiopia launched a major policy reform in the early 1990s that gave significant attention to the agriculture sector to lead the rest of the economy (Dorosh et al., 2020). A major departure in this reform included the setting up of a large extension system covering all grain producing areas of the country. It focused on the supply of modern agricultural inputs that were deemed major constraints of growth in productivity and agricultural incomes (Berhane et al., 2020). Lessons were drawn from early experimentations such as those by the Sasakawa Global 2000 and other pilots that demonstrated a major departure in productivity improvements through fertilizer and improved seed intensification on farmers' plots (Plucknett, 2004).

In a bid to increase productivity and hence agricultural household incomes and achieve food security, Ethiopia has pursued for over two decades a policy of fertilizer-seed technology push focusing mainly on cereal intensification (Spielman et al., 2010). In the decade between 2004 and 2014, fertilizer imports have more than doubled and area applied with fertilizers nearly doubled, and the number of farmers using fertilizers jumped from 4.7 million in 2004/05 to 10.1

[5] All values have been deflated using the General Consumer Price Index to reflect prices of 2019

million in 2015/16 (Berhane, 2020). Fertilizer use per hectare of arable land was 2.8 times higher in 2014-2016 than in 1991-1992. Adoption and intensification of improved seeds has also increased substantially and use of better farm tools and mechanization improved over the same decade albeit all from a low base (Berhane et al., 2020; Abate et al., 2015, Tamru et al., 2017). Decades of investments on input intensification combined with other favorable macroeconomic outcomes have led to sustained yield increases, spurring growth in Ethiopia's overall economy, making it one of the fastest growing economies in the 2004 – 2014 (Bachewe et al., 2018, Dorosh, 2020).

Despite all these positive input intensification trends, our descriptive results in section 3 have pointed out that broader use and application rates inputs remain low across crops and households. To what extent are these improvements associated with productivity increases? Does yield growth and input intensification bring about welfare changes at the household level? Does the level of intensification and yield vary by production risks (level and variability of rainfall)? These are the three important questions we seek to address in this section. We focus on four important inputs in Ethiopia's agriculture input landscape, namely inorganic fertilizers, improved seeds, agrochemicals, and mechanization and three measures of welfare (i.e., household dietary diversity, consumption expenditure, and durable assets).

3.1. Determinants of input intensification

Although input intensification passes through an adoption hurdle, our interest here is understanding what explains intensification once the adoption hurdle is passed. We thus run a reduced form input intensification equation and estimate it using correlated random effects (CRE) model, a variant of a fixed effects model that enables to address time-invariant sources of heterogeneity but has the extra advantage of not dropping time-invariant variables of interest. Table 10 presents correlates of intensification in these inputs. From the outset, we note that despite the methodological rigor put in place, we do not claim causality on some of our policy variables and are interpreted cautiously.

A number of findings stand out. We begin with those that entail policy implications for most of the inputs considered. First, as expected, improvements in access to extension services and ownership of modern information sources as mobile phones and radio are statistically significant determinants of intensification of most of these inputs.

Second, rainfall variability as measured by coefficient of variation of inter-annual *meher* rainfall variability, quality of soils and remoteness of plots (except for machine use that has the expected opposite effect) work in the opposite direction of input intensification, mainly fertilizer and improved seed. Third, availability of able-bodied labor in the household remains a critical determinant of intensification for all four inputs. Household labor remains an indispensable input as some intensification activities e.g., row-planting have proved labor-demanding in the absence of mechanical tools to facilitate it.

Table 10. Determinants of input intensification (CRE estimates)

	Log inorganic fertilizer (Qt/ha)	Use of purchased seed (1=yes)	Log agrochemicals (birr/ha)	Log machine use (birr/ha)
Ratio of organic fertilizer applied area	-0.446***			
	(0.096)			
Log fertilizer use (Qt/ha)		0.071***		
		(0.005)		
Log labour use, age 15-59, per ha	0.056*	-0.004	0.143***	0.072***
	(0.033)	(0.010)	(0.041)	(0.025)
Log of farm size (ha)	-0.346***	0.038*	0.267***	0.207***
	(0.084)	(0.022)	(0.099)	(0.058)
Gender of household head(1=male)	0.362***	0.013	0.108	-0.044
	(0.101)	(0.024)	(0.115)	(0.067)
Age of head(years)	0.005	-0.001	-0.002	-0.002
	(0.004)	(0.001)	(0.005)	(0.003)
Education of head	-0.009	0.003	0.010	0.007
	(0.009)	(0.003)	(0.011)	(0.007)
CV of inter-annual *meher* rainfall (10 years mm)	-3.569**	0.035	-4.287**	-3.886***
	(1.430)	(0.431)	(1.819)	(1.106)
Distance to parcel, hours	-0.267***	-0.051**	0.184*	0.472***
	(0.091)	(0.024)	(0.107)	(0.064)
Distance to cooperatives	-0.000	-0.000	0.001	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
DA access improved(yes)	0.169***	-0.003	0.083	-0.004
	(0.049)	(0.014)	(0.061)	(0.037)
Own cellphone	0.380***	0.045***	0.528***	0.125***
	(0.057)	(0.016)	(0.069)	(0.041)
Owns radio	0.237***	-0.023	0.183***	0.071*
	(0.055)	(0.015)	(0.066)	(0.039)
Distance to any weather road	-0.062***	-0.002	-0.011	-0.007
	(0.008)	(0.002)	(0.009)	(0.005)
Distance to small city	-0.018**	-0.002	0.010	0.011**
	(0.008)	(0.002)	(0.009)	(0.005)
Plots poor quality (of total ha planted)	-0.143**	0.027	-0.109	-0.149***
	(0.072)	(0.021)	(0.090)	(0.054)
Region	yes	yes	yes	yes
Round	yes	yes	yes	yes
Observation by panel	4,592	4,592	4,592	4,592
Observation by round	1,588	1,588	1,588	1,588

Note: Estimation based on three-round balanced panel data. ***p<0.01, **p<0.05 *p<0.1.
Source: Analysis of data from the ATA-ACC Survey.

Fourth, as expected, there is statistically strong association between use of purchased seeds and fertilizers. The direction of causation is not however easy to determine. On the other hand, we note that organic and inorganic fertilizers are direct substitutes contrary to the normal practice in developed farming systems, suggesting that combined intensification of these two important complimentary inputs is not yet achieved.

Important among household characteristics for fertilizer intensification include the gender of the head of the household. Compared to female-headed households, male-headed households are more likely to apply fertilizers. Gender difference in other input intensification (other than fertilizers) remains the same even after controlling for access to extension services, distance to cooperatives and markets. No statistically significant difference is observed between male-headed and female-headed households in the intensification of the improved seeds, agrochemicals, and use of machineries.

3.2. Intensification and yield growth

Ethiopia's agriculture growth in the last two decades has been characterized by sustained public investments in the agriculture sector in the form delivery of key inputs as fertilizers, improved seeds, and agrochemicals (Berhane et al., 2020). In line with this, for over two decades, Ethiopia has seen significant yield growth rates often surpassing the CAADP target of 6 percent (Berhane et al., 2020). The ACC data also indicates that between 2012 and 2019, overall yield grew by 21 percent (Table 8), the largest growth rate being recorded for oilseeds (by 45 percent) followed by vegetables (31 percent) and cereals (23 percent). These growth rates are comparable to those documented in other studies using other household surveys and nationally representative official statistics (Bachewe et al., 2018; Berhane et al., 2020). However, there exist substantial heterogeneity across farm households, and the evidence as to why such heterogeneities exists including in similar biophysical contexts is far from clear (Suri, 2011, Abay et al., 2018; Gollin and Udry, 2021). A natural question is what explains yield growth at the household level? To what extent does input intensification explain yield growth in our data? What other sources of heterogeneities are important in explaining yield growth at the household level? Using panel data at hand, this section tries to examine the factors that explain yield growth in the Ethiopian context.

We measure yield at the household level as real value of output per unit of land used for production and includes cereals, pulses, oilseeds, vegetables, root crops and fruits.[6] Our estimation follows a standard reduced form production function where yield is defined as a

[6] We have also conducted plot level yield analysis and the results are presented in Appendix B.

function of the traditional inputs of labor, capital inputs, and other sources of input allocation at the household and plot levels. Logarithmic transformations are used to scale down skewness towards large values as well as facilitate interpretation of results as percentage changes. Table 11 provides results from the CRE model discussed earlier, along with estimates based on household fixed effects model as reference. We note that the CRE model is superior to the standard FE model and thus results from the CRE model are interpreted here.

As expected, fertilizer and agrochemical intensification are statistically significant determinants of growth in yield. Contrary to our theoretical expectation, use of purchased seed is statistically significant with a negative sign. Other production inputs such as household labor, oxen ownership, and use of organic fertilizers also exhibit statistically strong association with yield growth. Rainfall variability (measured by rainfall variance) also came out as important shock negatively influencing yield growth. This is consistent with the strong evidence showing weather shocks among key hurdles of Ethiopia's rainfed agriculture.

Radio ownership (an important source of extension information in Ethiopia), commercialization (share of output sold) and age (measuring experience) of the head of the household are also found to be statistically strongly associated with yield growth. On the other hand, education of the head and the spouse of the head is not a statistically significant determinant of yield growth. This is not surprising given the low level of education in these contexts. Access to extension services is also statistically insignificant, consistent with findings by Berhane et al. (2018) that showed that other than through its effects in the supply of agricultural inputs, Ethiopia's agriculture extension system did not have direct impacts on yield growth. Gender of the head of household is also important determinant of yield in that as compared to female-headed, male-headed households are less likely to see increases in yield growth. Although this latter finding seems contrary to what is considered common knowledge in these rural contexts, it may well be true given all other gender-based sources of productivity differences are controlled for (Ragasa et al., 2013).

Table 11. CRE estimates of determinants of land productivity (log, birr/ha)

	Fixed effect model	CRE model
Log fertilizer application, (Qt/ha)	0.040***	0.045***
	(0.011)	(0.011)
Use of purchased seed (1=yes)	-0.017	-0.065**
	(0.036)	(0.028)
Log agrochemical use, (birr/ha)	0.024***	0.025***
	(0.009)	(0.009)
Oxen use, number/ha	0.035***	0.034***
	(0.005)	(0.005)
Log labor use, ages 15 -59, per ha	0.033	0.038**
	(0.021)	(0.019)
Log of farm size (ha)	-0.480***	-0.462***
	(0.065)	(0.041)
CV of inter-annual *meher* rainfall (10 years mm)	-1.470*	-1.491*
	(0.848)	(0.840)
Gender of household head (1=male)		-0.086*
		(0.045)
Age of head (years)	0.005**	0.005**
	(0.002)	(0.002)
Education of head	0.008	0.008
	(0.005)	(0.005)
Education of spouse	-0.006	-0.007
	(0.008)	(0.008)
Extension services	0.022	0.015
	(0.031)	(0.026)
Applied organic fertilizer	0.128**	0.185***
	(0.063)	(0.052)
Cellphone ownership	0.009	0.052*
	(0.039)	(0.030)
Radio ownership (yes)	0.108***	0.111***
	(0.038)	(0.028)
Share of output sold (%)	0.014***	0.014***
	(0.001)	(0.001)
Poor quality plots	-0.156***	-0.141***
	(0.045)	(0.039)
Distance to parcel, hrs	-0.109*	-0.136***
	(0.066)	(0.045)
Remoteness – distance to town		-0.010
		(0.018)
Distance to any road		-0.004
		(0.003)
Region	yes	yes
Round	yes	yes
Observations, by panel	4,679	4,679
Observations, by round	1,589	1,589

Note: Estimation based on three-round balanced panel data. ***p<0.01, **p<0.05 *p<0.1.
Source: Analysis of data from the ATA-ACC Survey.

Other factors that are negatively associated with yield growth include poor quality of soils, poor access to markets, and remoteness as measured by distance to parcel and road infrastructures. In other words, sample households with poor quality plots and reside far away from their plot, markets, and all-weather roads produce less output per unit of land than their counterpart (Table 11). The plot level analysis shows comparable results (Appendix B).

3.3. Yield growth, input intensification, and welfare

The previous sections have focused on what explains intensification and yield growth. This section focuses on whether yield growth and input intensification bring about welfare changes to the household.[7] We calculate yield for all crops as well as separately for cereals and cash crops. We use the CRE model discussed earlier to estimate effect of yield growth and input intensification on some selected household level welfare outcomes, mainly household diet diversity score (HDDS), consumer durables, and adult equivalent food, non-food, and total consumption expenditures. While the CRE model allows us to account for potential time-invariant unobserved characteristics, heterogeneities that may arise due to time-varying unobserved characteristics remain unaddressed. To account for these, we use the control function (CF) method where we instrument our key independent variable of interest, e.g., yield and include the residuals in the second stage welfare estimation. To implement this, we carefully selected a set of exogenous instruments (correlated with our independent variables but not directly correlated with our welfare outcomes other than through the independent variable of interest). For example, for our yield estimation, we use distance to cooperatives (as measure of access to inputs), coefficients of variance of rainfall and distance to rivers (proxying for access to irrigation and moisture shock critical in Ethiopia's crop agriculture), distance to any road (proxying for overall market access).

Variants of these instruments are used in our estimation of welfare and input intensification. Table 12 summarizes the results based on the CRE model combined with the control function method (detailed results for each of the outcome variables estimated can be obtained upon request).

Two important findings are drawn from this analysis. First, controlling for a host of household and location characteristics, total yield growth is strongly associated with household-level diet diversity score (HDDS), household durable assets, and adult equivalent non-food expenditures.

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[7] Yield is calculated as total value of production per hectares of land cultivated.

However, yield growth is not statistically significantly associated with adult equivalent food and total expenditures. On the other hand, while cereal yield is weakly (at 10 percent significance level) associated with adult equivalent food expenditures, cash crop yield growth is statistically strongly associated with adult equivalent non-food and total expenditures, suggesting that improvements in cereal yields are likely to improve food consumption, while cash crops are likely to be allocated to non-food investments. Yield growth in both cereals and cash crops is also strongly associated with increases in HDDS. This is plausible given HDDS is likely to be improved either through production diversification (via cereal production diversification), or through access to diversified food markets (via cash crop income increases). Cereal yield growth is also strongly associated with increases in household durables, implying in smallholder contexts early income increases are likely to improve household durables before substantive increases are made on consumer goods.

Table 12. Effect of yield and input intensification on household welfare using correlated random effects (CRE) and control function

	Household level welfare indicators				
			Daily consumption expenditure per adult equivalent, log		
Intensification measures	HDDS	Consumer durables	Food	Non-Food	Total
Yield, log (Birr/ha)	0.300**	0.794***	-0.082	0.146*	-0.036
	(0.156)	(0.213)	(0.106)	(0.091)	(0.103)
Cereal, log (Birr/ha)	0.088***	0.038***	0.023*	-0.006	0.01
	(0.028)	(0.022)	(0.012)	(0.013)	(0.011)
Cash crops, log (Birr/ha)	0.038**	0.007	0.008	0.014***	0.010**
	(0.015)	(0.016)	(0.005)	(0.005)	(0.005)
Seed intensification, log (Birr/ha)	-0.059	0.421**	0.243***	0.225***	0.257***
	(0.194)	(0.218)	(0.093)	(0.073)	(0.084)
Fertilizer intensification, log (Birr/ha)	0.558***	0.636***	0.111	0.075	0.064
	(0.211)	(0.169)	(0.109)	(0.071)	(0.100)
Other controls	yes	yes	yes	yes	yes
Region	yes	yes	yes	yes	yes
Round	yes	yes	yes	yes	yes

Note: Estimation based on three-round balanced panel data. Estimates control for household head (education, age and sex), household (spouse education, household size, dependency ratio, cellphone, radio, oxen,), kebele level (farm size, production diversity and share of market sold). Each row in the table indicates a separate regression with HH level welfare indicators. ***p<0.01, **p<0.05 *p<0.1.
Source: Analysis of data from the ATA-ACC Survey.

Second, intensification measures, mainly fertilizer and seed have positive and significant relationship with most of the welfare indicators. Seed intensification measured by value of seed per hectare has a strong and positive relationship with consumption expenditure. Although fertilizer intensification has positive effect, it is not statistically associated with consumption expenditure per adult equivalent. However, it is found to be statistically significant with strong effect on household diet diversity score (HDDS) and consumer durables.

4. Production risk and intensifications

Risk is a way of life in agriculture but more so in the context of smallholder rainfed agriculture where production is simply subject to the vagaries of nature. While use of modern inputs and intensification is critical to agricultural productivity increases, it exposes farmers to additional costs due to the inherent risk in production, one of which is associated with weather. In the absence of well-functioning insurance markets, farmers are forced to bear the additional cost of modern input use when production fails. The perceived risk associated with the use of modern inputs thus adds to the overall risk involved in production, often leading to sub-optimal production decisions referred to as the vicious circle of low-risk, low-productivity poverty trap (Hurley, 2010; Dercon, 1998). This problem lies at the heart of the low adoption-low intensification challenge to improve agriculture productivity in sub-Sahara Africa. In this paper, we try to understand the extent to which weather risk can explain the challenges of agriculture intensification in Ethiopia.

We specifically use monthly rainfall data extracted from the CHIRPS dataset introduced in Section 2. This data is matched with the 180 kebeles included in the three-round panel data collected by the ATA-ACC Survey (the average kebele is about 37 km^2, while each pixel is around 30 km^2). We measured our key variable of rainfall level and variability using annual *meher* rainfall (June to September) – the main rainfall season in Ethiopia accounting for about 95 percent (and exclude the *belg* season that represents the remaining small share) of agricultural output. Specifically, we construct a 10 year-rainfall data for each enumeration area in the survey and calculate the coefficient of variation of average *meher* rainfall for 10 years, each corresponding to the ACC survey years.

To assess the effect of weather/rainfall risk on agriculture intensification in Ethiopia, we used the CRE model described in Section 2. Our dependent variable includes production input use (mainly fertilizer, seed, agrochemicals and use of machinery). Table 13 presents results of the effect of rainfall levels and variability on household level of input intensification. We first estimate a restricted model of input intensification as a function of inter-annual *meher* rainfall variability (given in the first column of each of our outcome variables) and then introduce additional household level and location characteristics discussed in Section 2 in the second column.

Table 13. Effect of rainfall variability on agricultural input intensification (CRE estimates)

	Log inorganic fertilizer (Qt/ha)		Use of purchased seed (1=yes)		Log agrochemicals (birr/ha)		Log machine use (birr/ha)	
Panel A: Inter-annual rainfall								
CV of inter-annual *meher* rainfall(10 years)	-5.024***	-4.166***	-0.824*	-0.313	-4.271**	-3.883***	-4.148***	-3.972***
	(1.454)	(1.460)	(0.439)	(0.439)	(1.804)	(1.859)	(1.081)	(1.130)
Average *meher* rainfall (10 years mm)	0.002	0.001	-0.001***	-0.001***	0.008***	0.008***	0.002**	0.002*
	(0.001)	(0.001)	(0.003)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)
Square of avg. *meher* rainfall(10 years mm)	-0.000***	-0.000***	0.000	0.000*	-0.000***	-0.000***	-0.000***	-0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
All other variables controlled	No	Yes	No	Yes	No	Yes	No	Yes
Region	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Observation by panel	4770	4592	4770	4,592	4770	4592	4770	4592
Observation by round	1590	1588	1590	1588	1590	1588	1590	1588
Panel B: Intra-annual rainfall								
CV of intra-annual *meher* rainfall (10 years)	-3.398***	-2.573**	-0.462	-0.296	-2.876**	-2.938**	-1.374*	-0.707
	(1.047)	(1.064)	(0.316)	(0.320)	(1.297)	(1.353)	(0.780)	(0.825)
Average *meher* rainfall (10 years mm)	0.001	0.001	-0.001***	-0.001***	0.007***	0.007***	0.002**	0.002*
	(0.001)	(0.001)	(0.000)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)
Square of avg. *meher* rainfall(10 years mm)	-0.000**	-0.000**	0.000	0.000	-0.000***	-0.000***	-0.000***	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
All other variables controlled	No	Yes	No	Yes	No	Yes	No	Yes
Region	yes	yes	yes	yes	yes	yes	yes	yes
Year dummy	yes	yes	yes	yes	yes	yes	yes	yes
Observation by panel	4770	4592	4770	4592	4770	4592	4770	4592
Observation by round	1590	1588	1590	1588	1590	1588	1590	1588

Note: Estimation based on three-round balanced panel data. ***p<0.01, **p<0.05 *p<0.1.
Source: Analysis of data from the ATA-ACC Survey.

We note that the point estimates in the first and second column of each outcome remains stable. The result indicates that weather risk as indicated by the rainfall variability is negatively and significantly associated with input intensification, suggesting weather risk stands out to be strong in explaining agriculture intensification in this dataset. These effects are large and consistent across the restricted and the unrestricted model specifications, except for use of purchased seeds. Furthermore, as a robustness check, we redo the estimation using the intra-annual rainfall as an alternative measure of rainfall variability. We find the same and consistent result where rainfall risk is negatively and significantly associated with agricultural intensification.

Table 14. Effect of rainfall variability on land productivity (log, birr/ha)

Correlates	Dependent variable: land productivity (log, birr/ha)			
	Fixed effect model		CRE model	
Panel A: Inter-annual rainfall				
CV of inter-annual *meher* rainfall (10 years)	-2.240**	-0.723	-2.222***	-0.937
	(0.910)	(0.876)	(0.909)	(0.861)
Average *meher* rainfall (10 years mm)	0.000	-0.003	0.002***	0.001**
	(0.002)	(0.002)	(0.001)	(0.001)
Square of avg. *meher* rainfall (10 years mm)	0.000	0.000**	0.000	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
All other variables controlled	No	Yes	No	Yes
Region	No	No	yes	yes
Year dummy	yes	yes	yes	yes
Observation by panel	4738	4679	4738	4679
Observation by round	1590	1589	1590	1589
Panel A: Intra-annual rainfall				
CV of intra-annual *meher* rainfall (10 years)	-1.926***	-0.587	-1.932***	-0.807
	(0.654)	(0.651)	(0.653)	(0.623)
Average *meher* rainfall (10 years mm)	0.000	-0.003	0.002***	0.001**
	(0.002)	(0.002)	(0.001)	(0.001)
Square of avg. m*eher* rainfall (10 years mm)	0.000	0.000**	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
All other variables controlled	No	Yes	No	Yes
Region	No	No	yes	yes
Year dummy	yes	yes	yes	yes
Observation by panel	4738	4679	4738	4679
Observation by round	1590	1589	1590	1589

Note: Estimation based on three-round balanced panel data. ***p<0.01, **p<0.05 *p<0.1.
Source: Analysis of data from the ATA-ACC Survey.

Table 14 shows the effect of inter- and intra-seasonal variability of rainfall on yield (after accounting for rainfall levels). The dependent variable is measured by logarithm of yield (value of production per hectare). All the other control variables are similar to the ones used in Table 11. To clearly see the effect of rainfall risk, we do the estimate in a stepwise fashion using fixed effect and CRE approach. For both approaches, we first use a parsimonious specification where we only include rainfall variable measured by coefficient of variation and average rainfall levels. Second, in the unrestricted model specification, we control for several important household and location variables. The results show that rainfall level is statistically strongly associated with yield. However, when controlling for other covariates, we see that the statistical significance of the coefficient of rainfall variability disappears while that of rainfall levels stay statistically strong, suggesting that once input use decisions are made, it is the level of rainfall rather than the variability of it that matters for productivity. This is consistent with the finding (from Table 13) that rainfall variability remains an important determinant of input intensification.

5. Conclusions and policy implications

Ethiopia is one of SSA countries that made substantial efforts in the last three decades to increase agricultural productivity through modern input intensification and stimulate overall economic growth. For over three decades, Ethiopia's growth strategy has remained agriculture focused as shown by a budget exceeding the CAADP agriculture investment target of 10 percent of the national budget. Important progresses have been registered since in terms of overall economic growth and agriculture has been the main driver of growth. Within agriculture, crop productivity has received substantial attention and significant investments were made on the extension system in a bid to ensuring access to modern/improved inputs.

Despite the high growth rate trends in recent years, Ethiopia's yield levels and overall intensification remained rather low, e.g., compared to those seen in Asia's Green Revolution. This study examines the patterns, trends, and drivers of agricultural intensification during the recent decade. Specifically, the study addresses the following research questions. What is the household-level evidence of agricultural intensification in Ethiopia? What explain intensification at the farm (i.e., household) level and what needs to be done to keep up with recent trends to achieve transformation? What explains observed trends and patterns of modern input intensification (e.g., inorganic fertilizers, improved seeds, agrochemicals, use of farm machinery and mechanization) in the context of Ethiopia? Does gender of the household head matter for intensification? To what extent does modern input intensification explain observed trends in land productivity (or yield)? To what extent does recent trends in yield increases translate into household welfare? Does intensification (not picked by yield) matter for welfare improvements? How does production risk (measured by rainfall levels and variability) affect intensification and yield?

The study used three rounds of the Ethiopian Agricultural Commercialization Clusters (ACC) survey conducted by the International Food Policy Research Institute (IFPRI) for the Ethiopian Agricultural Transformation Agency (ATA). The three surveys covered 13,302 sample households, of which 1,899 are panel households interviewed in all three rounds. The analysis in this study has used both the full sample (for the descriptive statistics) and the panel households (for the econometrics analysis) at various levels of disaggregation (i.e., plot, crop, and household). In the econometric estimation, we use the hybrid model, a recent variant of the CRE model to address the time-invariant unobserved heterogeneity and a control function mainly in estimating the effect of yield and input intensification on welfare outcomes to mitigate time-varying unobserved heterogeneity.

Fertilizer intensification. Fertilizer has been one of the key productivity-enhancing inputs widely promoted by the extension system in Ethiopia. Consistent with findings from other nationally representative surveys, the ACC data shows a positive trend in the adoption rate and intensity of fertilizer use between 2012 and 2019. Among crops, cereals account for the most part of fertilizer intensification. The share of households using fertilizer on cereals increased by 20 percentage points between 2012 and 2019. Likewise, the share of cereal area fertilized increased by about 6 percentage points and intensification has doubled. No difference in fertilizer adoption and intensity is observed between male and female headed households.

Improved seed, agrochemicals, and machine use intensification. We find similar, but rather from a low base, trends for improved seed adoption and intensification. The share of households that adopted improved seeds have increased by 17 percentage points for maize and 3 percentage points for vegetables. The rest of the crops have had small increments. The share of area covered by improved seeds increased by 11.4 percentage points for maize and 6.2 percentage points for vegetables. We also see slight increases in share of root crops (3.4 percentage points) and fruits declined by 1.1 percentage points over the same period. Increases in intensity remained negligible for most crops with an increase by 1.7 kg per hectare for maize. However, another study based on DNA fingerprinting data indicate that these rates might be underestimated because of the difficulty to account for reuse of seeds in subsequent years after first adoption. The joint use of fertilizers and improved seeds is also limited, suggesting intensification among these households is low compared to other contexts (Berhane et al., 2020). Agrochemicals are relatively well used in these contexts, with an average increase of 76 birr per hectare between 2012 and 2019. Vegetables (203 birr per hectare) followed by wheat (188.9 birr per hectare) and teff (131.7 birr per hectare) enjoyed the largest increases. Wheat and vegetables are known for their sensitivity to pest and disease and have relatively well-organized production systems in parts of Ethiopia. Machine use is very low in Ethiopian agriculture – limited to the sesame producing lowlands and wheat growing Arsi, Bale and Gojam areas.

Has intensification, wherever it happened, been profitable? Considering the cost of the four inputs (fertilizer, improved seeds, agrochemicals, and machinery use; excluding costs of labor and other implicit costs) for which data is available, we find that average input costs have accounted for about 6 –16 percent of average value of outputs in 2012 and 2019. Share of input costs to output value is higher for cereals than for fruits, root crops or vegetables.

What level of intensification is needed to maximize profitability? We use local polynomial smoothing regression to compare, for example, fertilizer intensification against profitability. We find that while any level of fertilizer application is associated with positive profits, a jump in profitability is achieved only after an intensification level of 78 kg per hectare. This suggests that there is big room for further profitable intensification for crops below that threshold, mainly fruits, root crops, pulses, and sorghum. We also note that cereals (except sorghum) and vegetables have already achieved the threshold level of intensification and hence already at a relatively higher profitability levels, given the other constraints.

Overall, growth in land productivity (yield) between 2012 and 2019 ranged between 10 percent (sorghum) and 69 percent (oilseeds). Among crops, oilseeds (69 percent), vegetables (68 percent), root crops (47 percent), barely (36 percent) and maize (38 percent) have seen higher yield growth rates between 2012 and 2019. Fruits on the contrary have seen declines in yield growth over the same period. There was also a positive labor productivity (measured by volume of output per person days per crop season) and the growth rate is almost similar for all crops.

The descriptive results so far indicated a positive trend in input intensification and with considerable heterogeneity across crops and households, which we explored further in the econometrics analysis with the following guiding questions. What explains the heterogeneities in input intensification? To what extent are input intensifications associated with productivity increases? Does yield growth and input intensification bring about welfare changes to farm households?

What explains heterogeneities in input intensification? Among important positive determinants of all input intensification include improvements in access to extension services, availability of labor in the household, and ownership of modern information sources as mobile phones and radio. Rainfall variability, poor quality of soils, and remoteness of plots are negative and significantly associated with fertilizer and improved seed intensification. In addition, controlling for all other inputs that limit access to inputs, female-headed households are more likely to intensify fertilizers but not improved seeds, agrochemicals or machinery use.

To what extent is input intensifications associated with productivity (yield) increases? We find that fertilizer and agrochemical intensification are statistically significant determinants of yield growth while improved (purchased) seed is statistically significant but with a negative sign. Other production inputs as household labor, oxen ownership, and use of organic fertilizers also exhibit statistically strong association with yield growth. In addition, radio ownership, commercialization, and age (measuring experience) of the head of the household are also statistically strongly associated with yield growth. Access to extension services on the other hand is statistically insignificantly associated with yield growth. This is consistent with findings by Berhane et al. (2018) which shows that the extension system did not have direct impacts on yield growth other than indirectly through its input use effects. Gender of the head of household is also important determinant of yield. Compared to female-headed, male-headed households are less likely to see increases in yield. Although this finding seems contrary to what is considered common knowledge in these contexts, it may well be true given all other gender-based sources of productivity differences are controlled for (Ragasa et al., 2013).

How does production risk (measured by rainfall level and variability) affect intensification? We also specifically conduct analysis on the association between production risk and intensification to assess whether rainfall levels and variability lead to sub-optimal decision on the adoption/use of improved inputs. The results indicate that weather (production) risk as measured by rainfall variability negatively affects intensification. In other words, sample households in locations with relatively higher inter- or intra-seasonal rainfall variability, modern input use or its intensification is reduced.

Does yield growth and input intensification improve household welfare? Three welfare indicators are considered to answer this question: household dietary diversity, household durable assets, and expenditure per adult equivalent. Two findings are noteworthy. First, yield growth has positive and statistically significant effect only on household diet diversity index (HDDS) and on durable assets (consumer durables). Although there is no statistical evidence established between yield growth and adult equivalent total consumption expenditures, we found statistically significant effect on household non-food consumption expenditure. On the other hand, there is evidence that cereal yield growth has positive and significant effect on food consumption and household dietary diversity, suggesting growth in cereal yield has been important improving household welfare. Yields of cash crops are also found to be important for non-food consumption expenditures and dietary diversity but not to food consumption. Second, intensification measures, mainly fertilizer and seed have positive and significant relationship with most of the welfare indicators. Total seed intensification measured by value of seed per hectare has a strong and positive relationship with consumption expenditure. Although fertilizer intensification has positive effect, it is not statistically associated with consumption expenditure per adult equivalent. However, it is found to be statistically significant with strong effect on household diet diversity score (HDDS) and consumer durables.

In sum, it can be concluded that intensified use of inputs and subsequent improvements in total yield have improved household level diet diversity, an important proxy for food security, non-food expenditures, and consumer durables, but do not seem to have statistically meaningful impacts on food consumption expenditures. However, the disaggregation by cereal and cash crop yield uncovers rather interesting results. As expected, improvements in cereal yield has immediate important implications for food consumption, improvements in dietary diversity (partly because of the diversification in production), and improvements in household durables. On the other hand, those that have seen improvements in cash crop yields, have seen improvements in non-food (e.g., housing improvements) as well as dietary diversity. These may suggest that Ethiopia's agricultural intensification has had important implications to bring about qualitative improvements in improving availability of diverse foods, improvements in food and non-food consumption, as well as household durables.

Finally, the following policy implications may be drawn from this study. We note that a lot has been done to improve Ethiopia's input intensification landscape. Our analyses suggest that progress has been made in terms of familiarizing fertilizers such that fertilizer adoption is not a core challenge of policymakers anymore. Household datasets, including ours, repeatedly show that most farmers in Ethiopia adopt and experiment with fertilizers available to date in blanket recommendations. Thus, achieving profitable intensification remains a challenge. A deeper look into this problem therefore suggests that lack of availability of the right blend of fertilizers suitable to specific soil nutrient requirements, along with lack of customized technical support (something lacking in Ethiopia's extension system) in applying the right soil nutrient-fertilizer mixes are among those limiting transformative fertilizer intensifications.

Lack of access to appropriate improved seeds is also another hurdle to increasing productivity through proper input mix intensification. Again, our findings suggest that lack of availability of improved seeds is limiting seed replacements rates and sustained intensification. Improving the structural constraints of generating locally suitable improved seeds and putting in place the right supply chains to reach out farm households on timely manner can take the sector a long way.

It should also be noted that rainfall risk, or the lack of reliable moisture is another important hurdle in the intensification of Ethiopia's predominantly rainfed agriculture. Investments in smallholder/small scale irrigation structures remains a core priority for the years to come.

Our study has also shown that all those efforts in input intensification (along with several other factors) have led to productivity (yield) increases but yet from a low base compared to similar other contexts. It maybe that additional transformative productivity gains would come not only from improvements in the supply of the right inputs but also from putting in place the right research-extension systems to provide farmers with much needed technical support. Additional investments to remodeling Ethiopia's extension system to fit these purposes remains among top priorities of Ethiopia's policymakers and its development partners.

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Appendix A. Intensification trends and patterns by crop (crop group), gender, farm size, and remoteness

Table A1. Trends in fertilizer adoption and application rates, by gender of the household head

	Cereal	Barley	Maize	Sorghum	Teff	Wheat	Pulses	Oilseeds	Vegetables	Roots crops	Fruits
Adoption (% of hh)											
Male headed											
2012	51.9	52.1	42.4	11.6	70.3	76.1	11.3	14.9	22.9	9.7	0.0
2016	63.1	60.9	57.1	16.6	79.4	83.8	15.6	12.8	32.1	10.7	0.3
2019	71.6	64.0	66.5	27.9	83.9	87.7	20.9	26.0	54.7	22.1	1.5
Female headed											
2012	52.5	55.2	38.6	11.5	69.8	75.0	20.9	17.5	31.3	9.1	0.0
2016	63.8	53.8	56.8	26.6	84.7	81.1	23.1	19.2	34.7	13.1	0.0
2019	71.3	59.0	60.0	38.5	85.5	89.3	23.8	28.2	37.9	13.8	3.9
Adoption (% of area)											
Male headed											
2012	16.4	39.2	29.6	8.4	41.6	49.7	9.1	9.7	17.9	6.8	0.0
2016	19.5	41.2	42.4	12.4	45.6	51.6	10.7	9.7	25.7	7.5	0.3
2019	22.3	43.2	46.6	20.1	46.9	51.8	14.2	18.8	45.9	16.3	1.2
Female headed											
2012	21.9	36.9	33.2	9.4	44.8	50.4	15.5	9.0	26.9	5.4	0.0
2016	24.0	41.7	46.1	18.0	51.7	53.8	17.9	16.5	24.7	9.3	0.0
2019	28.3	43.5	49.8	29.2	54.5	54.2	16.8	23.1	34.5	12.3	2.6
Intensity(kg/ha)											
Male headed											
2012	71.9	62.2	74.0	9.0	82.4	123.6	13.8	8.5	58.1	17.2	0.0
2016	112.5	103.5	122.4	13.7	124.4	166.6	20.9	11.1	105.5	22.7	0.6
2019	157.2	121.7	162.2	33.0	172.9	218.6	31.2	21.3	212.5	45.8	2.2
Female headed											
2012	65.8	69.2	47.1	14.3	81.2	95.7	26.4	7.2	90.9	15.1	0.0
2016	115.5	94.5	120.8	24.4	134.2	167.0	31.2	13.4	150.6	33.5	0.0
2019	169.3	115.4	150.7	52.9	181.5	259.3	32.2	15.9	136.9	46.6	2.1

Source: Analysis of data from the ATA-ACC Survey.

Table A2. Trends in improved seed adoption and intensity of use, by gender of the household head

	Cereal	Barley	Maize	Sorghum	Teff	Wheat	Pulses	Oilseeds	Vegetables	Roots crops	Fruits
Adoption(% of hh)											
Male headed											
2012	21.5	19.5	42.1	7.6	12.4	19.9	21.7	21.7	36.9	20.1	2.9
2016	24.4	16.8	49.8	8.8	16.9	23.3	19.1	19.1	33.9	13.1	0.2
2019	24.1	16.9	58.3	6.4	13.4	18.3	14.8	16.1	40.4	17.7	2.2
Female headed											
2012	23.1	18.1	38.6	12.5	17.0	20.8	28.4	22.5	41.8	12.9	0.0
2016	27.8	19.0	52.5	14.7	19.1	26.1	21.6	36.5	40.0	11.9	0.0
2019	26.2	13.7	55.9	9.0	18.5	25.3	18.8	15.4	37.9	22.8	0.0
Adoption (% of area)											
Male headed											
2012	7.9	15.7	29.0	6.3	9.0	15.9	16.0	17.0	27.9	15.4	1.9
2016	9.3	13.3	37.2	7.4	12.3	16.9	14.1	15.8	26.5	9.3	0.2
2019	9.2	12.3	40.3	5.0	9.1	13.0	10.7	13.5	35.1	14.8	1.7
Female headed											
2012	11.5	14.8	32.9	11.4	13.0	15.8	21.3	22.5	37.5	8.5	0.0
2016	13.3	15.7	42.5	13.1	14.6	19.3	16.8	34.6	34.0	11.1	0.0
2019	13.7	12.2	46.4	7.7	14.2	17.3	11.5	12.8	33.6	20.6	0.0
Intensity(kg/ha)											
Male headed											
2012	15.0	32.1	14.9	2.3	6.1	30.5	20.4	7.0	72.1	98.3	6.7
2016	16.2	29.2	14.1	3.3	7.6	34.3	20.2	5.0	46.6	60.5	1.2
2019	16.6	30.9	17.2	2.6	6.3	29.8	17.9	6.9	42.4	71.9	6.5
Female headed											
2012	18.9	30.9	14.3	2.5	15.2	31.3	23.0	10.6	72.5	51.1	0.0
2016	23.8	43.5	18.3	6.2	10.9	39.1	22.3	10.2	65.4	49.3	0.0
2019	21.3	26.2	18.9	2.1	9.6	44.0	22.0	6.9	85.7	110.7	0.0

Source: Analysis of data from the ATA-ACC Survey.

Table A3. Trends in joint/combined adoption of fertilizer and improved seed, by gender of the household head

	Cereal	Barley	Maize	Sorghum	Teff	Wheat	Pulses	Oilseeds	Vegetables	Roots crops	Fruits
Adoption (% of hh)											
Male headed											
2012	14.6	11.0	31.1	0.7	8.4	15.4	3.5	2.8	8.0	4.7	0.0
2016	19.1	11.1	41.7	1.6	13.1	20.8	5.1	2.3	16.3	5.5	0.1
2019	20.3	12.6	50.9	1.5	10.9	16.7	4.9	5.1	28.0	7.7	0.2
Female headed											
2012	14.4	11.4	25.0	2.1	10.1	16.0	9.0	0.0	19.4	6.1	0.0
2016	22.0	13.9	42.4	4.6	16.3	23.9	7.5	5.8	18.7	4.5	0.0
2019	20.8	7.2	44.5	0.0	15.7	24.0	6.9	2.6	24.1	8.1	0.0
Adoption (% of area)											
Male headed											
2012	5.2	8.9	21.2	0.5	6.1	12.0	3.0	2.2	6.0	3.6	0.0
2016	7.1	9.2	30.8	1.3	9.1	15.0	3.9	1.8	12.7	4.1	0.1
2019	7.6	9.1	35.0	1.2	7.2	11.6	3.5	4.0	24.7	6.3	0.2
Female headed											
2012	7.2	8.6	21.0	2.1	7.8	12.1	6.2	0.0	16.4	3.6	0.0
2016	9.8	11.6	33.2	3.4	12.1	17.4	6.4	5.8	14.9	4.1	0.0
2019	10.2	6.5	36.1	0.0	12.1	16.3	4.5	2.6	22.4	7.6	0.0

Source: Analysis of data from the ATA-ACC Survey.

Table A4. Trends in agrochemicals use (value of agrochemicals per hectare of planted area: birr/ha), by gender of household head

Crop group	Male headed			Female headed		
	2012	2016	2019	2012	2016	2019
Cereals	26.4	57.5	113.1	26.3	60.5	108.3
Barley	20.2	41.5	77.6	34.0	43.3	81.9
Maize	5.7	25.1	69.7	10.6	20.0	58.8
Sorghum	17.6	38.5	62.5	7.4	24.6	56.3
Teff	39.0	71.6	132.4	40.3	81.5	122.8
Wheat	50.3	108.8	188.6	38.9	118.2	191.9
Pulses	31.7	33.7	88.1	20.5	51.2	99.5
Oilseeds	18.0	24.9	27.7	4.4	31.4	57.3
Vegetables	51.1	29.8	90.9	18.2	72.2	215.4
Root crops	8.6	15.0	47.2	7.8	7.2	38.7
Fruits	0.0	17.9	0.0	0.0	2.5	5.8

Source: Analysis of data from the ATA-ACC Survey.

Table A5. Trends in machinery use (value of machinery per hectare of planted area: birr/ha), by gender of household head

Crop group	Male headed			Female headed		
	2012	2016	2019	2012	2016	2019
Cereals	2.9	6.1	9.5	1.8	10.5	12.3
Barley	1.3	1.4	3.1	0.2	2.5	11.9
Maize	1.3	1.9	5.5	0.0	3.8	6.9
Sorghum	9.8	12.2	19.1	8.1	19.5	13.9
Teff	1.2	2.1	3.6	2.2	4.9	10.6
Wheat	2.9	19.1	24.5	0.9	26.8	21.7
Pulses	1.4	0.4	1.9	0.1	0.0	2.7
Oilseeds	25.9	34.0	38.1	35.8	84.0	53.7
Vegetables	0.1	4.3	6.4	0.2	0.0	0.0
Root crops	0.2	0.3	2.7	0.0	3.0	3.1
Fruits	0.7	0.3	0.9	0.0	0.0	0.0

Source: Analysis of data from the ATA-ACC Survey.

Table A6. Trends in share of value of inputs (excluding labor) to value of production

Crop group	Male headed			Female headed		
	2012	2016	2019	2012	2016	2019
Cereals	11.0	21.4	13.6	15.9	24.7	16.1
Barley	13.5	18.8	14.8	23.5	24.4	15.2
Maize	11.2	26.3	14.0	9.7	23.1	14.8
Sorghum	5.8	17.4	8.9	8.0	30.4	8.6
Teff	11.4	20.7	13.8	13.1	27.4	16.2
Wheat	12.9	23.9	15.3	26.9	25.3	21.0
Pulses	10.2	15.7	13.6	8.8	17.1	16.2
Oilseeds	8.0	15.5	11.0	6.8	22.9	9.7
Vegetables	8.6	14.8	12.5	10.1	17.3	13.0
Root crops	9.0	10.8	12.9	8.4	11.0	17.5
Fruits	6.2	7.8	7.0	2.9	11.9	5.2

Source: Analysis of data from the ATA-ACC Survey.

Table A7. Trends in crop productivity (yield)

Crop group	Male-headed			Female-headed		
	2012	2016	2019	2012	2016	2019
Panel A: yield (quintals per hectare)						
Cereals	15.4	18.1	19.5	14.2	17.5	19.8
Barley	13.2	15.6	17.9	14.0	16.0	19.4
Maize	22.3	28.4	30.2	18.7	27.9	30.7
Sorghum	14.2	14.1	15.5	11.7	12.6	14.4
Teff	9.2	9.6	11.6	8.9	10.1	11.4
Wheat	16.9	18.0	21.0	16.7	15.7	20.5
Pulses	11.1	13.7	12.4	9.7	11.4	10.5
Oilseeds	5.0	6.6	8.5	4.4	5.2	6.3
Vegetables	38.6	48.0	68.1	46.9	64.3	50.2
Root crops	66.4	103.1	96.1	57.2	83.5	100.5
Fruits	106.7	126.3	98.5	135.3	80.8	132.3
Panel B: yield (birr per hectare, in thousand)						
Cereals	8.4	8.6	11.2	8.2	8.0	11.6
Barley	7.2	7.2	10.0	7.8	6.9	10.7
Maize	9.0	8.2	10.0	8.0	7.4	11.0
Sorghum	7.0	5.0	7.7	5.9	4.4	7.7
Teff	7.9	8.8	11.7	7.8	9.2	12.0
Wheat	10.9	9.9	13.8	11.1	8.6	13.4
Pulses	9.8	10.3	10.0	10.5	11.8	10.6
Oilseeds	6.4	6.3	10.1	6.7	8.0	11.4
Vegetables	26.6	48.0	28.8	29.5	41.4	43.2
Root crops	27.0	29.8	43.8	26.6	39.3	40.2
Fruits	61.3	26.1	57.9	39.6	47.6	36.3

Source: Analysis of data from the ATA-ACC Survey.

Table A8. Trends in labor productivity (value of output/person days per crop season; in thousands birr), by gender of household head

Crop group	Male headed		Female headed	
	2012	2019	2012	2019
Cereals	0.1	0.1	0.1	0.1
Barley	0.1	0.1	0.1	0.1
Maize	0.1	0.1	0.1	0.1
Sorghum	0.1	0.1	0.1	0.2
Teff	0.1	0.2	0.1	0.1
Wheat	0.2	0.2	0.2	0.2
Pulses	0.1	0.2	0.1	0.2
Oilseeds	0.1	0.2	0.1	0.2
Vegetables	0.1	0.2	0.1	0.3
Root crops	0.1	0.1	0.1	0.1
Fruits	0.4	0.3	0.7	0.3

Source: Analysis of data from the ATA-ACC Survey.

Table A9. Agricultural input use, based CSA's AgSS data

	2007/08	2016/17
Fertilizer Applied area (%)	39	60.4
Fertilizer application (qt per ha)	0.45	0.95
Improved Seed Area (%)	4.7	13
Pesticide Applied Area (%)	21	32
Extension Covered Area (%)	15	37

Source: CSA's AgSS survey.

Table A10. Trends in Household Dietary Diversity Score (HDDS) by gender, remoteness, and farm size categories

Subsample	Survey rounds		
	2012	2016	2019
Gender			
Female headed	5.6	5.8	5.8
Male headed	5.8	6.2	6.1
Remoteness			
Tercile 1	5.9	6.2	6.0
Tercile 2	5.6	6.3	6.2
Tercile 3	5.9	6.0	6.0
Farm size category			
<0.5ha	5.4	5.9	5.8
0.5ha - 1ha	5.5	6.0	5.8
1ha - 2ha	5.8	6.1	6.0
2ha - 3ha	6.0	6.4	6.3
≥3ha	6.5	6.6	6.5
Total	5.8	6.2	6.0

Source: Analysis of data from the ATA-ACC Survey.

Table A11. Trends in total daily consumption expenditure by gender, remoteness, and farm size categories

Subsample	Survey rounds		
	2012	2016	2019
Gender			
Female headed	46.8	83.3	96.7
Male headed	48.8	96.7	129.6
Remoteness			
Tercile 1	48.8	91.9	131.2
Tercile 2	45.3	104.9	127.6
Tercile 3	51.8	88.3	120.0
Farm size category			
<0.5ha	43.7	74.5	100.7
0.5ha - 1ha	43.4	84.9	111.0
1ha - 2ha	44.2	92.0	126.2
2ha - 3ha	50.5	103.5	141.6
≥3ha	70.6	127.4	161.7
Total	48.6	95.4	126.3

Source: Analysis of data from the ATA-ACC Survey.

Table A12. Trends in durable assets (principal component analysis) by gender, remoteness, and farm size categories

Subsample	Survey rounds		
	2012	2016	2019
Gender			
Female headed	-0.1	-0.2	-0.1
Male headed	0.0	0.1	0.1
Remoteness			
Tercile 1	-0.0	0.0	0.1
Tercile 2	0.1	0.2	0.1
Tercile 3	0.0	-0.1	-0.1
Farm size category			
<0.5ha	-0.3	-0.4	-0.4
0.5ha - 1ha	-0.2	-0.2	-0.3
1ha - 2ha	-0.1	-0.1	-0.1
2ha - 3ha	0.2	0.3	0.4
≥3ha	0.7	0.8	0.9
Total	0.0	0.0	0.0

Source: Analysis of data from the ATA-ACC Survey.

Table A13. Gross profit per hectare, by farm size category and year

Farm size category	2012	2016	2019	Total
>= 3	14,893.3	11,830.0	21,099.0	16,143.8
2.0 - 3.0	10,963.2	9,053.2	12,354.2	10,771.6
1.0 - 2.0	8,381.3	8,741.6	10,613.9	9,244.8
0.5 - 1	6,879.9	7,343.2	9,472.5	7,875.3
< 0.5	6,433.7	5,701.1	6,918.3	6,337.3
Total	9,438.5	8,383.7	11,615.2	9,801.0

Source: Analysis of data from the ATA-ACC Survey.

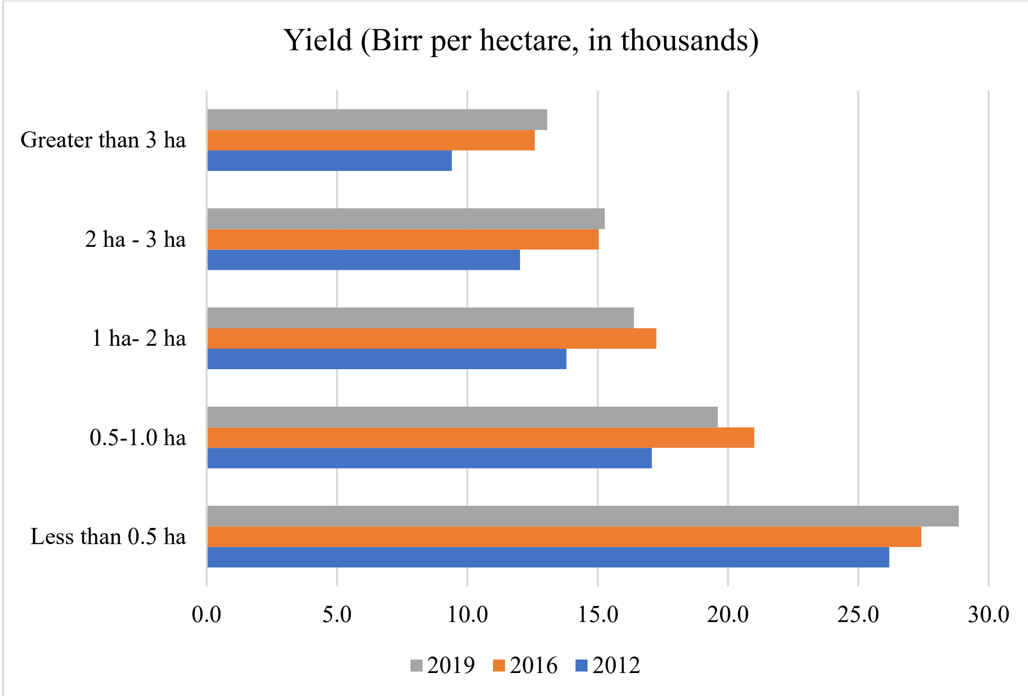
Appendix B: Results based on plot level analysis

Table B1 Tends of yield by farm size category and crop types (plot level analysis)

Panel A: yield (quintals per hectare)		**Less than 0.5 ha**	**0.5-1.0 ha**	**1 ha-2 ha**	**2 ha-3 ha**	**Greater than 3 ha**
Cereal	2012	19.2	15.2	15.1	14.7	14.0
	2016	22.6	19.2	18.1	17.1	15.4
	2019	30.3	20.3	17.8	17.4	17.8
Barley	2012	16.0	13.1	13.2	12.1	12.8
	2016	16.2	15.8	16.0	15.2	14.6
	2019	22.4	20.2	16.0	15.9	18.4
Maize	2012	28.4	21.7	21.0	20.8	20.0
	2016	36.0	29.8	28.5	25.7	23.8
	2019	47.1	32.5	27.8	25.2	25.0
Sorghum	2012	16.5	15.0	14.6	12.7	11.7
	2016	16.3	15.4	14.7	13.0	12.0
	2019	24.8	15.9	14.1	14.9	13.2
Teff	2012	10.5	9.9	9.2	8.7	7.8
	2016	10.9	10.3	9.7	9.3	8.5
	2019	17.6	12.0	10.8	10.6	10.1
Wheat	2012	17.6	15.9	16.8	18.3	16.6
	2016	18.9	17.8	17.3	18.8	17.3
	2019	32.2	20.1	18.8	19.6	22.8
Pulses	2012	17.1	10.1	10.9	10.0	9.6
	2016	21.2	14.8	13.8	11.6	10.3
	2019	17.8	13.2	11.6	9.9	12.0
Oilseeds	2012	5.7	5.5	5.8	4.4	4.5
	2016	10.3	7.6	7.4	6.4	5.4
	2019	13.7	13.7	9.0	7.3	6.1
Vegetables	2012	64.8	40.4	39.6	32.0	26.3
	2016	36.6	61.5	51.9	48.6	36.1
	2019	79.8	69.7	62.9	51.6	71.1
Root crops	2012	93.8	57.7	55.2	67.3	53.2
	2016	131.4	108.3	93.5	95.5	66.5
	2019	135.6	91.5	87.5	98.7	73.8
Fruits	2012	163.0	116.4	111.4	90.4	46.5
	2016	129.6	132.2	126.1	119.2	104.8
	2019	136.5	116.8	96.9	72.4	89.0

Panel B: yield (birr per hectare, in thousand)		**Less than 0.5 ha**	**0.5-1.0 ha**	**1 ha-2 ha**	**2 ha-3 ha**	**Greater than 3 ha**
Cereal	2012	10.3	8.6	8.6	7.9	7.0
	2016	10.9	9.3	8.8	8.1	6.7
	2019	16.3	12.2	10.6	9.8	9.2
Barley	2012	8.7	7.3	7.4	6.4	6.5
	2016	7.6	7.4	7.3	7.1	6.3
	2019	12.6	11.5	9.0	8.7	9.5
Maize	2012	12.2	9.0	8.6	8.7	6.9
	2016	11.5	8.8	8.4	7.1	5.6
	2019	15.1	11.0	9.4	8.0	8.4
Sorghum	2012	8.1	8.1	7.5	5.8	5.0
	2016	6.4	5.9	5.5	4.3	3.7
	2019	13.5	8.3	7.6	7.1	5.2
Teff	2012	9.1	8.6	8.2	7.3	6.5
	2016	10.6	9.7	9.0	8.4	7.2
	2019	18.4	12.6	11.2	10.3	9.3
Wheat	2012	11.8	10.4	11.0	11.6	10.4
	2016	10.4	10.2	9.5	10.4	9.2
	2019	20.8	13.6	12.6	12.8	13.9
Pulses	2012	15.2	10.5	10.4	9.6	8.6
	2016	15.4	12.6	12.3	10.3	9.0
	2019	13.8	11.9	10.5	8.1	9.4
Oilseeds	2012	6.5	6.3	7.7	5.9	6.6
	2016	11.1	9.9	9.7	7.9	6.1
	2019	15.9	17.4	11.9	10.5	8.8
Vegetables	2012	31.8	30.0	32.8	28.9	19.9
	2016	31.0	40.6	48.8	43.1	35.5
	2019	46.0	44.4	38.9	33.9	47.8
Root crops	2012	40.5	24.2	21.8	24.7	20.4
	2016	54.1	40.6	35.0	34.4	24.0
	2019	61.0	38.9	34.0	43.2	30.2
Fruits	2012	59.6	59.3	38.8	22.0	11.1
	2016	51.6	50.6	46.8	42.9	37.9
	2019	57.2	41.7	36.6	28.2	30.2

Source: Analysis of data from the ATA-ACC Survey.



Source: Analysis of data from the ATA-ACC Survey.

Figure 1: Yield by farm size categories

Table B2. Determinants of land productivity at plot level

Variables	Dependent variable: Land productivity at plot level (log, birr/ha) 2012	2016	2019
Log fertilizer application(kg/ha)	0.084***	0.063***	0.064***
	(0.008)	(0.006)	(0.005)
Use of purchased seed (1=yes)	-0.072*	-0.093***	-0.000
	(0.033)	(0.026)	(0.023)
Log agrochemical use(birr/ha)	0.029***	0.025***	0.035***
	(0.008)	(0.006)	(0.004)
Log labor use, age 15-59, per ha	0.096***	0.065**	0.078***
	(0.026)	(0.022)	(0.014)
CV of inter-annual *meher* rainfall (10 years mm)	3.483***	-0.688	0.972**
	(1.020)	(0.576)	(0.350)
Per capita farm size	-0.188**	-0.295***	-0.202***
	(0.060)	(0.055)	(0.044)
Gender of household head(1=male)	-0.050	0.022	-0.095**
	(0.054)	(0.042)	(0.034)
Age of head (Years)	0.002	-0.000	0.002
	(0.001)	(0.001)	(0.001)
Education of head	0.008*	0.002	0.002
	(0.004)	(0.003)	(0.004)
Education of spouse	0.000	0.005	0.003
	(0.005)	(0.005)	(0.005)
Distance to cooperatives, minutes	-0.001	-0.000	-0.000
	(0.000)	(0.000)	(0.000)
Organic input used(1=yes)		0.095***	0.042*
		(0.025)	(0.020)
Share of output sold (%)	0.006***	0.008***	0.006***
	(0.001)	(0.001)	(0.000)
Asset index tercile	0.007	0.003	0.063***
	(0.027)	(0.023)	(0.018)
Cellphone ownership(1=yes)	0.047	0.005	-0.030
	(0.036)	(0.028)	(0.027)
Radio ownership (1=yes)	0.052	0.014	0.020
	(0.036)	(0.026)	(0.022)
Poor quality plots	0.094*	-0.111***	-0.133***
	(0.037)	(0.030)	(0.026)
Steeped plots		-0.032	-0.126***
		(0.028)	(0.021)
Distance to parcel, hrs	-0.116***	-0.080**	-0.099***
	(0.027)	(0.026)	(0.021)
Remoteness - distance to town	-0.046	-0.012	-0.012
	(0.031)	(0.026)	(0.019)
Distance to any road	-0.007	-0.005	0.001
	(0.006)	(0.005)	(0.003)
Dist. to the nearest financial institution, minutes		0.000	-0.000
		(0.000)	(0.000)
Region Controlled	Yes	Yes	Yes
Crops Controlled	Yes	Yes	Yes
Observations	11,535	15,929	19,062
R-squared	0.259	0.355	0.285

Source: Analysis of data from the ATA-ACC Survey.

*** $p<0.001$, ** $p<0.01$, * $p<0.05$, + $p<0.1$

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