Agricultural Intensification in Ethiopia: Trends and Welfare Impacts

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Abstract

Ethiopia has made substantial efforts in the last three decades to increase agricultural productivity through modern input intensification and stimulate overall economic growth. Important progresses have been registered in terms of overall economic growth and agriculture has been the main driver of growth. Despite the high growth rates in recent decade, Ethiopia's overall intensification and yield levels remained low. This study examines the trends and drivers of agricultural intensification and productivity growth during the recent decade using three rounds of household data collected from the four agriculturally largest regions of the country. The main analysis on the relationship between input intensification, yield, and household welfare employs a recent variant of the correlated random effect model to address the time-invariant unobserved heterogeneity and a control function to mitigate time-varying unobserved heterogeneity. The descriptive results indicate a positive trend in both the adoption rate and intensity of inputs and output, albeit from a low base and with considerable heterogeneity by access to information, rainfall variability, labor, soil quality, remoteness, among others. The econometric results show significant association between intensification, yield growth, and household dietary diversity (a proxy measure for food and nutrition security). However, the current yield level is not significantly associated with household durable assets and per capita consumption expenditures. 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 rainfall risk, and investments to remodel Ethiopia's extension system to provided much needed technical support to farmers on production methods.

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).[2] 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, 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

[2] 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.

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[3] 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 these favorable 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 – 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 (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,

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

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 and prohibitive land tenure structures 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 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 of modern input intensification (e.g., inorganic fertilizers, improved seeds, agrochemicals, use of farm machinery and mechanization) in the context of Ethiopia? To what extent does modern input intensification associate with observed trends in land productivity (or yield)? To what extent does recent trends in yield increases translate into household welfare? Does intensification 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 in input 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 is more or less the same 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 uses 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. 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
Log (rainfall variability)	5.7	5.1	5.5
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.

2.2 Estimation strategy

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:

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

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;[4] 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 in 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[5] unobserved factors, μ_i, such as individual farmer abilities in the management of input use and 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).

[4] For simplicity, we drop the plot-level subscript but note that crop-level attributes as soil quality are important & included in our estimation.
[5] To account for time-varying unobserved heterogeneities, we use the control function (CF) method in some of our regressions.

3 Trends in input intensification

We measure intensification both relative to area cultivated (units or value of agricultural inputs per unit of cultivated land). The area intensification measures include adoption and use of fertilizer, improved seed, agrochemical, and agricultural machineries. We also examine measures of productivity, output per unit of land (yield) since this is the intermediate objective of agricultural intensification. This section briefly discusses the descriptive evolution of the 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.

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 21 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).

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	52.4	64.3	72.6	17.1	20.3	23.1	71.6	113.5	156.8
Barley	53.3	61.1	64.5	39.6	41.9	43.9	62.9	103.3	120.9
Maize	42.1	59.2	67.9	30.0	44.3	48.1	71.7	125.4	161.0
Sorghum	11.8	17.8	29.1	8.6	13.2	21.1	9.5	14.8	34.5
Teff	71.4	80.3	84.5	42.6	46.3	47.7	83.3	124.4	170.7
Wheat	76.3	83.8	88.0	50.1	51.9	52.1	120.1	164.8	217.6
Pulses	12.2	19.4	23.2	9.8	13.5	15.8	14.6	25.3	34.1
Oilseeds	15.2	13.9	26.8	9.8	10.7	19.6	8.2	10.8	20.9
Vegetables	23.5	41.0	60.4	18.6	32.4	50.9	58.9	129.2	223.4
Root crops	9.8	12.7	22.5	6.8	8.9	16.8	16.1	27.6	47.5
Fruits	0.0	0.5	2.7	0.0	0.5	2.1	0.0	1.0	3.5

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., 2010). 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. 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 18 percentage points for maize and 8 percentage points for vegetables. Teff and fruits have 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 12.4 percentage points for maize and by 10.7 percentage points for vegetables. The share of area covered by root crops and fruits 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 6.5 kg per hectare) and fruits (an increase by 4.5 kg per hectare) showing some improvements over the same period (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.

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	21.9	25.1	24.6	8.3	9.8	9.7	25.9	31.3	32.4
Barley	19.7	17.3	16.9	15.9	13.8	12.5	47.6	49.7	50.9
Maize	41.9	51.9	59.8	29.5	39.1	41.9	28.3	28.4	36.2
Sorghum	8.1	9.5	6.7	6.8	8.0	5.2	3.6	4.9	4.3
Teff	12.9	17.1	13.9	9.5	12.5	9.5	12.2	13.1	13.7
Wheat	20.2	23.6	18.9	16.0	17.2	13.4	52.3	69.7	59.4
Pulses	22.6	23.2	16.6	16.7	17.2	11.9	24.4	30.9	23.7
Oilseeds	22.0	21.3	16.4	17.5	17.9	13.8	8.0	6.4	8.8
Vegetables	37.8	43.5	45.7	29.1	34.3	39.8	55.8	36.8	40.6
Root crops	19.6	15.1	19.0	14.8	11.0	16.0	99.5	76.1	88.0
Fruits	2.7	0.3	3.3	1.8	0.3	2.6	7.2	1.9	11.7

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.

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	14.7	19.7	20.6	5.5	7.5	7.9
Barley	11.1	11.6	12.3	8.9	9.6	9.0
Maize	30.7	43.4	51.9	21.3	32.2	36.0
Sorghum	0.8	1.8	1.5	0.6	1.5	1.1
Teff	8.7	13.3	11.3	6.3	9.3	7.5
Wheat	15.6	21.1	17.4	12.1	15.3	12.0
Pulses	4.1	6.4	5.5	3.3	4.9	4.0
Oilseeds	2.7	2.6	5.0	2.1	2.2	4.0
Vegetables	9.1	20.9	31.4	7.0	16.3	27.9
Root crops	4.7	6.3	8.1	3.6	4.8	6.7
Fruits	0.0	0.2	0.3	0.0	0.2	0.3

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 recycled maize seeds 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 a steady growth over the last decide, albeit from a low base (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. 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 (79 birr per hectare) than machinery use (2.7 birr per hectare).

In relative terms, on average, the intensity of agrochemical use is greatest on vegetables (226 birr per hectare) followed by wheat (180 birr per hectare), and teff (130 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 (31 birr per hectare), followed by wheat (24 birr per hectare) and sorghum (20 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.

Table 6 Trends in agrochemicals and machinery use

Crop group	Agrochemical (birr/ha)			Machinery use (birr/ha)	
	2012	2016	2019	2016	2019
Cereals	26.1	57.3	109.1	6.4	9.9
Barley	20.6	44.8	87.1	2.0	5.4
Maize	6.6	26.2	67.7	2.0	5.8
Sorghum	16.4	38.3	65.6	12.2	20.4
Teff	38.2	73.2	129.7	2.8	4.6
Wheat	53.1	108.5	179.6	20.4	23.6
Pulses	16.7	49.9	93.5	0.5	2.1
Oilseeds	5.7	32.6	60.5	32.2	30.8
Vegetables	13.5	81.7	226.1	3.2	6.2
Root crops	8.5	10.1	41.1	0.6	2.7
Fruits	0.0	6.5	9.3	0.3	0.8

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

4 Agricultural intensification, productivity, and welfare

Ethiopia has pursued for over two decades a policy of fertilizer-seed technology push focusing mainly on cereal intensification to increase productivity and hence agricultural household incomes and achieve food security (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 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., 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 and heterogenous across crops and households. What explains these heterogeneities in input intensification? To what extent are these improvements associated with productivity increases? Does yield growth and input intensification bring about welfare changes to the household level? 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).

4.1 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 7 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.

Table 7 Determinants of input intensification (CRE estimates)

Correlates	Log inorganic fertilizer (Qt/ha)	Improved seed (kg/ha)	Log agrochemicals (birr/ha)	Log machine use (birr/ha)
Ratio of organic fertilizer applied area	-0.505***			
	(0.183)			
Log fertilizer use (Qt/ha)		1.918**		
		(0.824)		
Log labor use, ages 15 -59, per ha	0.303***	12.823***	0.242***	0.063**
	(0.073)	(2.230)	(0.064)	(0.031)
Gender of household head (1=male)	0.252**	0.980	0.095	-0.011
	(0.117)	(4.103)	(0.113)	(0.068)
Age of head (years)	0.001	-0.022	-0.000	-0.004
	(0.004)	(0.162)	(0.004)	(0.003)
Education of head	-0.002	1.230*	0.042*	-0.008
	(0.017)	(0.648)	(0.022)	(0.012)
Rainfall, variance	-0.316**	-10.461***	-0.409*	-0.073
	(0.129)	(3.467)	(0.217)	(0.136)
Distance to parcel, hours	-0.360***	5.206	0.223	0.368***
	(0.136)	(3.999)	(0.162)	(0.107)
Distance to cooperatives	-0.001	-0.095**	0.000	-0.003***
	(0.002)	(0.041)	(0.002)	(0.001)
DA access improved (yes)	0.148***	4.899**	0.105	0.021
	(0.052)	(2.223)	(0.070)	(0.047)
Owns cellphone	0.320***	8.127***	0.547***	0.092***
	(0.064)	(2.480)	(0.080)	(0.034)
Owns radio	0.156***	3.281	0.173**	0.075*
	(0.058)	(2.935)	(0.079)	(0.039)
Distance to any weather road	-0.063*	0.214	-0.010	0.004
	(0.032)	(0.553)	(0.018)	(0.009)
Distance to small city	-0.019	0.358	0.006	0.013
	(0.027)	(0.490)	(0.020)	(0.011)
Plots poor quality (of total ha planted)	-0.527****	-3.773	-0.253*	-0.179***
	(0.157)	(3.549)	(0.149)	(0.066)
Region	Yes	Yes	Yes	Yes
Round	Yes	Yes	Yes	Yes
Observation, by panel	4,756	4,756	4,758	4,758
Observation, by round	1,605	1,605	1,605	1,605

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.

First, as expected, improvements in access to extension services, proximity to producer cooperatives, and ownership of modern information sources as mobile phones and radio are statistically significant determinants of intensification of most of these inputs.

Ownership of mobile phones and radio, tools that have become increasingly important in circumventing information barriers in rural Ethiopia, are also important for the intensification of all inputs (except radio ownership on improved seeds).

Second, rainfall variability as proxied by variance of rainfall, 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. Education of the head of the household is also weakly associated with intensification of improved seeds and agrochemicals.

Fourth, as expected, there is statistically strong association between intensification of improved 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.

4.2 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. Our estimation follows a standard reduced form production functions where yield is defined as a 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 8 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 while improved seed is not statistically significant. 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.

Table 8 CRE estimates of determinants of land productivity (yield)

	Dependent variable: land productivity (log, birr/ha)	
Correlates	Fixed effect model	CRE model
Log fertilizer application, (qt/ha)[6]	0.035***	0.035***
	(0.008)	(0.008)
Improved seed application, (kg/ha)	-0.000	-0.000
	(0.000)	(0.000)
Log agrochemical use, (birr/ha)	0.018***	0.020***
	(0.007)	(0.007)
Oxen use, number/ha	0.032***	0.031***
	(0.004)	(0.004)
Log labor use, ages 15 -59, per ha	0.093***	0.096***
	(0.013)	(0.013)
Rainfall, variance	0.109**	-0.046*
	(0.043)	(0.024)
Gender of household head (1=male)	-	-0.144***
		(0.037)
Age of head (years)	0.004**	0.004**
	(0.002)	(0.002)
Education of head	0.003	0.005
	(0.008)	(0.007)
Education of spouse	-0.000	-0.000
	(0.010)	(0.010)
DA access improved	-0.009	-0.007
	(0.024)	(0.021)
Applied organic fertilizer	0.168***	0.232***
	(0.061)	(0.050)
Share of output sold (%)	0.011***	0.011***
	(0.001)	(0.000)
Poor quality plots	-0.254***	-0.250***
	(0.058)	(0.051)
Cellphone ownership	0.005	0.010
	(0.030)	(0.023)
Radio ownership (yes)	0.052*	0.060***
	(0.029)	(0.022)
Distance to parcel, hrs	-	-0.180***
		(0.036)
Remoteness – distance to town	-	-0.040**
		(0.015)
Distance to any road	-	-0.009***
		(0.003)
Region	yes	Yes
Round	yes	Yes
Observations, by panel	4,724	4,724
Observations, by round	1,605	1,605

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.

[6] Quantity per ha of planted area.

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).

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 8).

4.3 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. 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 consumption expenditures per adult equivalent. 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), 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 9 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).

Table 9 Effect of yield and input intensification on household welfare using correlated random effects (CRE) and control function

	Household level welfare indicators		
Intensification measures	HDDS	Consumer durables	Daily consumption expenditure per adult equivalent, log
Yield, log	0.323**	-0.012	0.023
	(0.151)	(0.204)	(0.064)
Fertilizer intensification (qt/ha), log	0.314***	0.279***	0.035
	(0.091)	(0.088)	(0.038)
Improved seed intensification (kg/ha)	0.005**	0.004*	0.000
	(0.002)	(0.002)	(0.001)
Fertilizer and improved seed intensification (birr/ha)	0.000***	0.000***	0.000
	(0.000)	(0.000)	(0.000)
All inputs (birr/ha)	0.000***	0.000***	0.000
	(0.000)	(0.000)	(0.000)
Other controls	yes	yes	yes
Region	yes	yes	yes
Round	yes	yes	yes

Note: Estimation based on three-round balanced panel data. Birr/ha and kg/ha of planted area; all inputs include fertilizers, improved seed, agrochemicals, and use of machines., ***p<0.01, **p<0.05 *p<0.1.
Source: Analysis of data from the ATA-ACC Survey.

Three important findings are drawn from this analysis. First, controlling for a host of household and location characteristics, yield growth has positive and statistically significant effect only on household diet diversity score (HDDS) and not on durable assets and consumption expenditures per adult equivalent. We also run the same estimation for food and non-food consumption expenditures and results remain the same. This may suggest that on average increases in yield are not necessarily leading to increases in household income that can bring about changes in consumption or household durable asset building. However, yield or productivity increases are strongly associated with improvements in diet quality as measured by the index perhaps through improvements in access to diverse diet at the household level. Second, all intensification measures, mainly fertilizer, seed, and fertilizer and improved seed combined as well as all input intensification measures including agrochemicals and machinery have positive statistically significant effects on HDDS and consumer durable assets. Although statistically strong, these relationships do not exhibit strong economic meaning except for fertilizer and improved seeds. Again, all of these four intensification measures are not statistically associated with consumption expenditure per adult equivalent. In sum, it can be concluded that intensified use of inputs and subsequent improvements in yield do not seem to have meaningful impacts on household welfare, at least as measured by changes in consumer durables and consumption expenditures.

5 Conclusions and policy implications

Ethiopia has made substantial efforts in the last three decades to increase agricultural productivity through modern input intensification and stimulate overall economic growth. 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 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 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. This study examines the 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 of modern input intensification (e.g., inorganic fertilizers, improved seeds, agrochemicals, use of farm machinery and mechanization) in the context of Ethiopia? 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?

Three rounds of data from the Ethiopian Agricultural Commercialization Clusters (ACC) survey conducted by the International Food Policy Research Institute (IFPRI) for the Ethiopian Agricultural Transformation Agency (ATA) covering 13,302 sample households, of which 1,899 are panel households are used . 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. We provide summary of the main findings. We begin with the descriptive results.

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 21 percentage points between 2012 and 2019. Likewise, the share of cereal area fertilized increased by about 6 percentage points and intensification has doubled.

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 18 percentage points for maize and 8 percentage points for vegetables. The rest of the crops have had small increments. The share of area covered by improved seeds increased by 12.4 percentage points for maize and 10.7 percentage points for vegetables.

The descriptive results indicated a positive trend in input intensification, albeit from a low base 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 increases to farm households?

What explains heterogeneities in input intensification? Among important positive determinants of all input intensification include improvements in access to extension services, proximity to producer cooperatives, 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 seed is not statistically significant, which is plausible given the limited use of this input as shown in the descriptive results. Other production inputs 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 as are poor soils, remoteness and lack of access to markets. 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).

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 not on durable assets nor consumption expenditures per adult equivalent. Yield increases are not necessarily leading to statistically important increases in household consumption or household durables. However, yield growth is strongly associated with improvements in diet quality as measured by the index, perhaps through improvements in access to diverse diets at the household level. Second, all intensification measures, mainly fertilizer, seed, and fertilizer and improved seed combined (as well as all input intensification measures including agrochemicals and machinery) have positive and statistically significant effects on HDDS and consumer durable assets but not on consumption expenditures per adult equivalent.

In sum, it can be concluded that intensified use of inputs and subsequent improvements in yield have improved household level diet diversity, an important proxy for food security, but do not seem to have statistically meaningful impacts on household income proxied by expenditure on consumer durables and overall consumption. This may suggest that Ethiopia’s agricultural intensification has had important implications to improving availability of diverse foods, but perhaps associated income increases might not have been sufficient to bring about qualitative improvements in expenditures.

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 be also 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 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 low base. 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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