How Is Farm Income Affected When Each Farm Has To Produce Its Own Animal Feed?

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1 Introduction

One of the questions that Peter proposed for his memorial conference was "What happens to agricultural yields when farms are relatively autarkic and use animals? For instance, how is yield affected when each farm has to produce its own animal feed? How can this help explain why African yields are so much lower than American?"

In sub-Saharan Africa, a majority of people subsist on small-scale farming, and the effects of increased temperature and uncertain rainfall are especially severe. Even without the challenge of adapting to climate change, sub-Saharan African smallholder farming is far below the production possibilities frontier: "The technologies that can increase farm production in response to climate change are, to a great extent, the same technologies that would increase farm productivity even

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if climate change were not an issue."[1] Moreover, agriculture should be considered in the broader development context: "Adoption of modern technologies, whether in farming or other sectors, is constrained by inadequacies in ... human capital, infrastructure and institutions ...."[2]

This chapter builds on research on agricultural practices among smallholder subsistence farmers in sub-Saharan Africa (SSA), who account for about two-thirds of the population of the region and are at high risk from a changing climate (Berck et al., 2018).

2 Mixed Crop-Livestock Systems

Many smallholder subsistence farmers in SSA earn their livelihoods in mixed crop-livestock systems. They raise cattle for dairy, meat, savings, and cash income; oxen for draft power (traction to pull the plow); and goats and sheep for milk, wool, and meat (for sale and household consumption), as well as savings and cash income (Gizaw et al., 2010; Hadush, 2017; Teklewold et al., 2019).

Crops and livestock are closely integrated in these mixed systems. As well as pulling the plow, livestock produce a by-product in the form of manure, which fertilizes crops. And crops produce a by-product in the form of postharvest residue, which is eaten by livestock. This ancient synergy is under pressure from many directions, including increasing population, decreasing availability of arable land, conversion of grazing land for cultivation, and declining soil quality.

While chickens,[3] horses, mules, etc. are kept as well, we focus on ruminants for several reasons. Cattle-keeping is "a way of life and of great cultural importance" in SSA (NEPAD, 2005). Ruminants can convert grass and crop residue into milk and meat, although not as efficiently as they can with additional nutrition in their diets. Ruminant livestock is a form of savings in many countries in SSA, and ruminants provide manure for fertilizer and fuel (Gebremariam & Gebreegziabher, 2018).[4]

We focus on Ethiopia for a number of reasons, including institutional connections and extensive development activity. Ethiopia is the second-most populous nation in Africa.[5] The Environment for Development Center in Addis Ababa, Ethiopia, was the first member of a now-global sustainable development initiative funded by

[1] Berck et al. (2018), p. 11.

[2] Berck et al. (2018), p. 10.

[3] Chickens may play an increasing role globally as a source of animal protein with less emission of climate-forcing gases, compared to ruminants (Gerber et al., 2013).

[4] We focus on mixed crop-livestock systems rather than solely pastoralist livelihoods. Bachewe et al. (2018) note that 90% of cattle holding is in mixed crop-livestock systems.

[5] https://www.worldatlas.com/articles/the-10-most-populated-countries-in-africa.html. Accessed December 9, 2020.

the Swedish International Development Cooperation Agency (Sida), growing out of academic and development relationships between Sweden and Ethiopia.

In Ethiopia, "almost all farmers own some livestock" (Bachewe et al., 2018). Livestock production contributes substantially to farmers' income and to the nation's agricultural GDP (Hadush, 2017).

About three-fourths of Ethiopian livestock holdings (measured by value) are dairy cattle and oxen (Bachewe et al., 2018). However, the share of cattle relative to small ruminants (goats and sheep) has been decreasing over time (Bachewe et al., 2018). The reasons for this include the commercial potential of small ruminants (Gizaw et al., 2010), the ability of goats to survive by scavenging (Gizaw et al., 2010), and goats' tolerance for increasing temperatures (Gebremariam & Gebreegziabher, 2018).[6]

Compared to farmers in developed nations, subsistence farmers in SSA have to be relatively self-sufficient in obtaining inputs. The need for self-sufficiency is due to cash and credit constraints. Transportation barriers and limited access to markets are also present. In Ethiopia, for instance, as of 2001, 44% of farm households had to walk to markets (one hour on average), while 56% used a bicycle, cart, horse, donkey, or public transportation (Teklewold et al., 2013b).

Self-sufficiency is the case for inputs to livestock production. In fact, lack of access to modern inputs may be more of a challenge for livestock management than for crop production. Bachewe et al. (2018) note that crop production has benefited more than animal production from increased use of modern inputs.

3 Sources and Methods of Feeding Livestock

Unlike farmers in developed economies, smallholder farmers in SSA have little access to crops that are grown specifically as animal feed, let alone varieties that have been improved to provide optimal nutrition. Both cattle and small ruminants fend for themselves to a large degree, by foraging at roadsides and in natural pastures and by grazing on stubble (crop residue), either in fallow fields or postharvest.

3.1 Natural Pastures

Rural Ethiopians have managed natural pastures for thousands of years under traditional rules (Alemayehu et al., 2017). Until recently, natural pastures contributed 80–90% of nutrition for livestock in Ethiopia (Alemayehu et al., 2017).

[6] The last point is an example of farmer-initiated ("autonomous") adaptation to climate change, which can be supported by public policies and agricultural extension (training) services.

This proportion is shrinking as grazing land is being converted for crop cultivation (Alemayehu et al., 2017). This trend reflects pressure to feed a growing population on degraded cropland and has the consequence of further degrading the remaining natural pasture through overgrazing (Alemayehu et al., 2017). It also represents a shift of animal forage toward a greater proportion of crop residue, which can be less nutritious than natural pasture. On the other hand, Bachewe et al. (2018) note that one response to declining pasture land has been a rapid increase in the use of commercial feed, although this increase is starting from a very low base, as discussed below.

3.2 Crop Residue and Postharvest Grazing

Traditionally, livestock in Ethiopia graze on postharvest crop residue on a reciprocal, open-access basis (Teklewold et al., 2019). Crop residue is what's left after the part that's nutritious for humans has been removed.[7] It can be taken out of the field or left in the ground, and it helps sustain farmers' livelihoods, whether collected or left in place.

Crop residue (stubble) is a major feed source for ruminants in subsistence farming systems. Ruminants eat the residue that remains after the harvest of staple crops, including cereals such as teff, wheat, barley, and sorghum (Owen, 1994) and legumes such as beans (Yilma et al., 2011). Crop residue accounts for 28% of feed for livestock when averaged across Ethiopia, with higher and lower proportions across Ethiopia's diverse agroecological systems (Yilma et al., 2011; Alemayehu et al., 2017). In addition, the averages mask seasonal variation: crop residue may be the only source of nutrition for animals during a one- to two-month dry season when natural pastures are diminished (Yilma et al., 2011). Therefore, dry season forage is a particular need (Alemayehu et al., 2017).

The stubble that remains after staple crops are harvested is not "waste." It is a limited resource that is available to poor farmers facing cash and credit constraints. The competing uses include burning the residue as fuel, using or selling straw as building material, and leaving the residue on the field after harvest—either as food for animals or as part of conservation agriculture, which is discussed below. Especially in light of these competing uses, availability of crop residue is a constraint on both keeping livestock and adopting climate-smart (sustainable) agricultural practices.

Grazing has traditionally been open access on both natural pastures and postharvest or fallow land. Open access grazing entails minimal management, minimal inputs, and low productivity (NEPAD, 2005). In generally, livestock in Ethiopia "are

[7] Straw is an example of crop residue. Hay, by contrast, has the seed head still in place, and ruminants eat naturally-growing hay. What's limited is access to hay that's grown (and adapted) for the specific purpose of providing nutrition to livestock.

kept under traditional extensive systems with no or minimal inputs and improved technologies, which results in characteristically low productivity" (Gizaw et al., 2010, p. 1, discussing livestock in general and smaller ruminants in particular).

3.3 "Cut and carry" Feeding

Some parts of Ethiopia use a different system, at least for goats and sheep. Where communal land is scarce and perennial crops need to be protected from damage by grazers, farmers may tether the animals and use a "cut and carry" method of bringing fodder to them—although frequently the fodder is of low nutritional value (Gizaw et al., 2010). Variations on "cut and carry" include stall feeding or limiting the animal's movement to a demarcated area (Hadush, 2017).

"Cut and carry" feeding (using either hay from natural pastures or intentionally grown crops), rather than unmanaged grazing of nutritionally poor feed, is seen as the future of maximizing income and welfare from livestock (Alemayehu et al., 2017). Toward that end, there have been efforts in Ethiopia to identify species that can be used to rehabilitate degraded pastures and to provide forage on farms (Alemayehu et al., 2017). However, "stall feeding only" (no free grazing) has not been widely adopted in Ethiopia (Hadush, 2017). Until recently, supplemental feeding (except for fattening) has been very rare among smallholder farmers (Gizaw et al., 2010).

3.4 Crops Grown as Animal Feed

It is not common for smallholder farmers in Ethiopia to grow crops specifically as animal feed (Yilma et al., 2011). This is not for lack of interest; Teklewold et al. (2019) found that farmers would like subsidies for seeds, labor, and insurance in order to grow forage crops. Lack of knowledge on how to manage animal nutrition and limited availability of land are also constraints (Yilma et al., 2011). Reviewing the situation in Ethiopia in 2011, FAO researchers found that "There is a critical shortage of animal feed in the country and when available it is expensive and of poor quality" (Yilma et al., 2011, pp. x–xi).

Commercial feed, such as improved varieties of forage and nutritious by-products of industrial food production, is more likely to be available for large-scale commercial agriculture, particularly for operations in the vicinity of the capital city (Yilma et al., 2011). In addition, smallholders who live near urban markets have some opportunity to purchase improved inputs (Bachewe et al., 2018). They also have an opportunity to sell food to urban consumers, as increasing income in Ethiopia has increased demand for dairy and meat products (Bachewe et al., 2018).

Production of improved forage was described as almost nonexistent in Ethiopia in 2010 (Gizaw et al., 2010). A rapid increase in commercial use of feed has been noted

recently, although it has started from a very low base (Bachewe et al., 2018). The proportion of households using improved feed almost doubled between 2005 and 2015—from 7.2% to 13.6% (Bachewe et al., 2018). In terms of purchasing versus producing feed, Bachewe et al., (2018) note a slower trend away from autarky: 6% of feed was purchased in 2005, 7.8% in 2015. Putting these two statistics together, we can infer some increase in both production and marketing of improved forage at the smallholder level.

The lack of inputs and active management keeps the productivity of the livestock sector far below that in developed economies. Crop residue and natural pasture do not provide optimal nutrition, nor optimal productivity of either milk or meat, compared to crops intentionally grown as feed. In addition, the growth in the quantity of livestock has resulted in more density of animals per unit of land (Bachewe et al., 2018), which undermines the productivity per unit of land and unit of livestock.

Reframing the initial question, then, there are limited markets for livestock feed among subsistence farmers in Ethiopia because there is limited growing of crops specifically as animal feed in these communities. Constraints include limited land, labor, cash, credit, and knowledge to utilize improved feed as an input to production. However, the recent trends noted by Bachewe et al. (2018) and the successful field experiments noted by Alemayehu et al. (2017) suggest the potential for improved markets and improved livestock feeding. Moreover, land titling programs have encouraged investment on privately owned crop land (Holden et al., 2016). This will be a multi-part process, including promoting the growing of forage crops as well as promoting their marketing.

4 Relationship Between Animal Feed and Sustainable Agriculture

We now turn to the relationship between animal feed and conservation agriculture, followed by a discussion of what farmers would need in order to grow forage crops. Teklewold et al. (2019) found that the current open-access system discourages farmers from adopting conservation agriculture (which depends on leaving residue on the fields). This practice persists despite recent land titling programs and despite a finding that a majority of smallholders surveyed[8] would prefer restrictions on postharvest grazing rather than the traditional open-access system.

In the past 30 years, Ethiopia has been the site of numerous attempts to implement and evaluate agricultural intensification. Intensification refers to increasing productivity per hectare, as opposed to increasing overall production by cultivating additional hectares or shortening fallow periods. Arable land is limited in Ethiopia and other densely populated SSA nations. Because many productivity-enhancing

[8] The survey was conducted among mixed crop-livestock smallholders in Ethiopia's Nile Basin.

measures can place stress on soil and other resources (Teklewold et al., 2013b), there is growing interest in sustainable intensification practices. These tend to dovetail with "climate-smart" agricultural adaptation practices (Teklewold et al., 2017) because similar strategies are needed to increase production with or without a changing climate.

Soil conservation is a key goal of sustainable or climate-smart practices to enhance production. One approach that's been piloted in Ethiopia is conservation tillage, also known as no-till or low-till agriculture. Traditionally, Ethiopian farmers plow their fields three to five times per season, in order to prepare the soil for seeds and remove weeds. However, excessive plowing causes surface runoff and soil erosion, which contribute to soil degradation and loss of water in the soil (Teklewold et al., 2013a).

By contrast, "conservation tillage eliminates plowing, or reduces its frequency to only one pass per growing season, and lets crop residue remain on the ground. This practice promotes soil aeration, reduces erosion and loss of nutrients, reduces the loss of water through evaporation, and promotes sequestration of carbon in the soil" (Berck & Teklewold, 2018).

Low-till agriculture requires leaving the crop residue from staple crops on the ground. This reduces the need for tilling (plowing) in the next season of cereal/staple crops. Low-till is a sustainable practice for intensifying yield. It has been shown to increase yield, especially as part of a sustainable intensification package (Teklewold et al., 2013b). However, it takes a few years before the soil conservation benefits of low-till are translated into increased crop yield (Teklewold et al., 2019).

A disadvantage is that plowing is a way to remove weeds. Over the longer term, leaving residue on the ground as part of conservation tillage controls weeds. In the short run, however, weeds have to be removed either through hand labor or using an herbicide (such as glyphosate). In addition to environmental concerns about herbicide, it is difficult for credit-constrained households to purchase such inputs (Kassie et al., 2015). As for hand-pulling weeds, this is normally done by women and girls (Teklewold et al., 2013a). This interferes with the opportunity for women and girls to engage in other productive activities, whether work or schooling.

The use of crop residue as livestock feed poses a direct trade-off with its use in no-till or low-till agriculture (Teklewold et al., 2019). Low-till agriculture is only practical if livestock (the farmer's own animals or other animals) don't eat the residue. In particular, it doesn't work with open-access grazing. So, farmers are limited in their ability to simultaneously feed livestock and adopt low-till/no-till agriculture.

5 Potential to Grow Fodder Crops

Even if a farmer had full control over the crop residue on her farm plots, she would have to decide among letting her own livestock eat it; selling it as straw for building; leaving it on the ground as soil conservation; or using it as fuel or building material.

To loosen these constraints, farmers need other sources of fodder, such as better management of open pastures, opportunities to buy commercial feed, or access to land and inputs needed to grow forage crops.

Legumes are promising as a potential source of animal feed, because they also put back nitrogen in the soil after it's been depleted by cereal crops (Alemayehu et al., 2017). Certain perennial legumes have deep roots and thus can provide forage in the dry season (Alemayehu et al., 2017). Even the crop residue from legumes can be more nutritious than the residue from cereals (Alemayehu et al., 2017). Sometimes known as "double-cropping," planting legumes after a cereal crop is harvested can get more production out of a single plot in a given year (Ethiopian Panel on Climate Change, 2015).

Forage crops suited to Ethiopia's various agroecological areas have been grown on government demonstration plots (Alemayehu et al., 2017). These include oats, beets, and vetches (leguminous grasses). Mixed cereal and forage systems, as well as production of seeds for forage, have been successful in certain regions, on an experimental basis (Alemayehu et al., 2017). However, there has been little autonomous adoption by individual smallholders, due to the constraints discussed above.

6 Potential of Livestock and Forage to Increase Income

Production and consumption are tightly connected in the relatively autarkic setting of subsistence farming. In other words, subsistence farming households have to decide whether to eat or sell whatever they produce. In fact, studies of the impact of farming innovations in these communities often evaluate household welfare change rather than using a production function to evaluate changes in profit.[9] These considerations hold true for mixed crop-livestock systems in sub-Saharan Africa.

However, farmers do sell some of their production for cash income, and increasing that income is an important development goal. Similarly, it is possible that increased cultivation of forage crops by small-scale farmers will stimulate markets, so that neighboring farmers have an additional option for feeding their livestock.

Commercialization of the dairy side of cattle-keeping has been a development goal in Ethiopia. As of 2011, dairy production accounted for over half a million full-time jobs in Ethiopia (Yilma et al., 2011). Shortage of feed has been identified as a constraint on the dairy industry (Yilma et al., 2011).

[9] It is common to use consumption as a measure of both income and welfare in subsistence households, because this includes food that the household raises for its own consumption. Of course, increased cash income and profit from farming improvements are certainly important to household welfare. For example, the measures of household welfare in Hadush (2017) include milk production and consumption expenditures, as well as market participation.

Stall feeding, with supplemental feeding in addition to residue, has been shown to increase dairy production in Ethiopia, in the rare situations where it is practiced (Hadush, 2017). Stall feeding alone includes both fodder sources of low nutritional quality, brought to the animal in a "cut and carry system," and some addition of crops specifically grown as animal feed (Hadush, 2017).

Despite the legendary ability of goats to eat anything, their commercial potential is hindered by the limited nutritional quality of their scavenging and foraging diet (Gizaw et al., 2010). Yet, the commercial potential of small ruminants is worth developing, in part because of goats' tolerance for a changing climate (Gebremariam & Gebreegziabher, 2018) and in part because of the market potential of both goat and sheep products (Gizaw et al., 2010). "Development of feed resources and improved feeding practices are the key to increasing per capita animal output" (Gizaw et al., 2010, p. 2).

Even though cattle are a mark of wealth and prestige, more livestock is not always better. Livestock holdings are measured in tropical livestock units (TLU), in which different species are given different weights. The quantity of livestock holdings has been increasing in Ethiopia, but productivity has not (Bachewe et al., 2018). Despite its importance to the Ethiopian economy, the livestock sector grew at a slower rate than other sectors during Ethiopia's recent period of economic growth (Bachewe et al., 2018). The situation may be parallel to agricultural extensification versus intensification: more hectares under cultivation (or more TLU) do not address the issue of maximizing productivity per hectare (or TLU) in a sustainable manner.

If farmers were to adopt conservation tillage, there would be less need for oxen to pull the plow. Fewer oxen could decrease pressure on fodder resources, so that more fodder would be available for livestock that provide milk and meat. Note that oxen have to eat year-round but are only needed seasonally for traction. If some agricultural work could be mechanized, there also would be less need for oxen (Alemayehu et al., 2017). While mechanization is beyond the reach of smallholder farmers, this points out the nexus between agricultural productivity and overall development.

7 Conclusion

This chapter has shown that livestock productivity could be improved if smallholder farmers faced fewer constraints on growing forage crops. Increased access to credit, labor, and information would give farmers more choices that might or might not include planting improved forage or selling or buying improved forage. Farm-level decisions tend to be specific to local ecological conditions and farm household characteristics. Limited cash, credit, labor, education, and information create a poverty trap that constrains all of the choices that farm households make. This is why it's important to consider farmers' decisions in the overall development context.

Adoption of modern inputs into agriculture in general, and livestock in particular, is associated with the farmer's education level, access to extension services, and proximity to markets and urban areas (Bachewe et al., 2018). Extension services and modern inputs have contributed to growth in the crop sector but have not focused as much on the livestock sector (Bachewe et al., 2018). Larger households have adopted more modern inputs related to livestock, apparently because they have labor available (Bachewe et al., 2018). In particular, adoption of modern feeds is associated with a farmer's contacts with extension services—although Bachewe et al. (2018) point out that the causation may run either way (farmers may seek advice after they've decided to adopt a new input).

Some have questioned whether the income-producing potential of smallholder livestock production has received enough attention in development planning. Just as livestock and crop production are interdependent in traditional mixed farming systems, it will be important for policy makers to pay attention to the integrated nature of these systems.

The original question was "How can [autarky] help explain why African yields are so much lower than American?" It's a difficult comparison to make with modern American farming, which is dominated by large-scale, commercial, specialized production. Small family farmers have faced a precarious existence in all times and places.

In addition, some modern American farming practices raise sustainability questions. Informative comparisons might be made between larger-scale agriculture in developed and developing countries.

It's likely that subsistence farmers in sub-Saharan Africa will rely heavily on their own resources for some time to come. At the same time, growth in income, transportation, and education have been gradually changing the Ethiopian economy and other African economies. Over time, as more improved forage crops are grown, it is reasonable to expect more buying and selling of animal feed.

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