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# Revisiting innovation practices in subsistence farming: the net effects of land management, pesticide, herbicide and fungicide practices on expected crop harvest in Ethiopia

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**Abstract:** To settle inconsistent findings in the farming innovation and productivity nexus, this inquiry examines the land management practices of 7,625 households in rural Ethiopia. Specifically, the net effects of: 1) improved seeds; 2) mixed cropping; 3) row planting on the use of; 4) pesticides; 5) herbicides; 6) fungicides are assessed. Using a structural equation technique, the study probes how these six practices predict households' expected harvest. It is found that while improved seeds increase pesticide, herbicide and fungicide use, mixed cropping and row planting generally reduce these practices. Moreover, mixed cropping moderately increases expected harvest while improved seeds and row planting have the reverse effect. The interrelations of these factors increase knowledge in contingency-driven agronomics, and provoke reflection on the sustainability of land management practices. Particularly, opposed to prevailing views, it is demonstrated that sowing traditional seeds will reduce households' reliance on pesticides, herbicides and fungicides. The inherent findings speak to policy-makers tasked with supporting peasant life in rural Ethiopia and similar contexts.

**Keywords:** improved seeds; mixed cropping; row planting; pesticides; herbicides; fungicides; expected harvest; farming innovation; subsistence farming; structural equation modelling; Ethiopia.

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## 1 Introduction

In Africa, as in other underdeveloped settings, suitable conditions and access to resources for subsistence farming are key to household survival (Baiphethi and Jacobs, 2009). Local practices for food production and preservation ensure availability of nutrition and the reduction of poverty (Rankoana, 2017). In spite of mounting urban migration, the United Nations' FAO (2015) still cites subsistence farming by families as a key

determinant for well-being and a source of livelihood in rural Africa. Similarly, Jayne et al. (2019) indicate that small-scale holdings managed by families comprise the vast majority of Africa's rural dwellers, and Bjornlund et al. (2020) estimate this to be in the range of 50–70% of the population. To somewhat quantify their contribution, smallholdings engaging family labour feed and employ two-thirds of the African population and cultivate 62% of the land (FAO, 2021a).

Notwithstanding households' immense endeavour, agricultural production across Sub-Saharan Africa has lagged behind global output since the 1960s (FAO, 2009a), and crop harvests remain significantly lower than in other developing regions to the extent that food security is presently threatened (Bjornlund et al., 2020). To be sure, there is no shortage of enterprise on the part of households but general underperformance can be explained by poor harvests arising from factors including crop phenology, pests, herbivores, poor soil, rodents, wildlife trespassing and unpredictable rainfall (Runo et al., 2011; Stokstad, 2017; Gross et al., 2018). Recently, *Spodoptera Frugiperda* (or fall armyworm), a pest previously found only in North and South America, has been sighted in Africa (Sisay et al., 2018). If left uncontrolled, fall armyworms can destroy maize and other staple crops up to a value of US\$3 billion in one year (Stokstad, 2017).

Strikingly, fall armyworms are only one of several invasive alien species (or IAS hereafter) causing crop damage in Africa. Other IAS on the continent are *Zonocerus Variegatus* (variegated grasshopper), *Spodoptera* (black armyworm), *Cryphonectria Parasitica* (chestnut blight), *Phytophthora Cinnamomic* (root rot), *Odontotermes Obesus* (fungus-farming termites), *Acacia Mearnsii* (black wattle) desert locust, brown streak and wheat rust (Banjo et al., 2010; Graziosi et al., 2020; FAO, 2021b). In East Africa, the five leading microbes plaguing maize farms are *Chilo Partellus* (spotted stem borers), Maize Lethal Necrosis Disease (MLND), *Parthenium Hysterophorus* (flowering plant), *Liriomyza* (leaf miner flies) and *Tuta Absoluta* (tomato leaf miner) (Loha et al., 2018). In 2016, these five IAS were jointly responsible for a combined crop loss valued at US\$0.9–1.1 billion across Ethiopia, Kenya, Malawi, Rwanda, Tanzania and Uganda (Pratt et al., 2017). This was a direct squeeze on the productivity and sustenance of rural households.

To manage IAS pitfalls, subsistence households resort to the use of pesticides, herbicides and fungicides (or xenobiotics hereafter) to increase harvests (Tolera, 2020). This practice follows other low-tech and pragmatic choices made to optimise crop production such as improved seedlings (versus traditional seedlings) (Ahmed et al., 2017), mixed cropping (versus monocropping) (Demlew et al., 2019) and row planting (versus broadcast planting) (Vandecastelen et al., 2018). These routines are of particular import because of the increasing scarcity of fertile ground as “over 75% of arable land in Africa is considered degraded” [Orchard et al., (2017), p.46]. Furthermore, to heed Emerton and Snyder (2018), it is vital for scholars to understand households' sustainable land management practices and the economic effects that arise as a consequence.

Ensuing from the above, the aim of this study is to test the effect of improved seeds, mixed cropping and row planting on the use of xenobiotics and the extent to which these correlations explain expected harvest. Along these lines, we offer a novel link to advance scholars' understanding of land management practices in a setting where crop damage is an issue of serious concern to world bodies not limited to the FAO. Our consequent contributions are fourfold. First, we provide original evidence on the influence of improved seeds, mixed cropping and row planting on the use of xenobiotics. To the best

of our knowledge, no prior studies have assessed the interplay of these practices. Second, we examine how improved seeds, mixed cropping and row planting distinctly impact on expected harvest. In spite of the prevalence of these land practices, their association with expected harvest has also not been conceptualised in extant work. Third, to explain households' behaviour, we leverage the contingency and sustainability lens to add theoretical perspective to the interpretation of the findings. Last, we examine rare first-hand data from a large sample of household farmers in Ethiopia. The granular nature and size of this sample yields both direct and representative insights into land management practices to better steer policy-making.

To press forward, the overarching question addressed in this inquiry is: "How do improved seeds, mixed cropping and row planting affect the use of xenobiotics and expected harvest in turn?" The rest of this article is arranged as follows: Section 2 presents the research context while Section 3 appraises the six land management practices currently conceptualised to predict expected harvest. Subsequently, Section 4 explains the measurement variables, items and scales before findings are offered in Section 5. In Section 6, the findings are then compared with prior findings by way of a discussion. We conclude with theoretical contributions, practical implications and areas for future research in Section 7.

## **2 The Ethiopian context**

This study is set in a landlocked country in the horn of Africa formally recognised as the Federal Democratic Republic of Ethiopia. It is bordered by Eritrea to the north, Sudan to the north-west, South Sudan to the west, Djibouti and Somaliland to the northeast, Somalia to the east and Kenya to the south. Its largest city and capital is Addis Ababa and, with 12 cities in total, Ethiopia covers a total land area of 420,000 square miles (Ayalew et al., 2016). It is home to 112 million inhabitants (World Bank, 2021a), making it the second most populous African country after Nigeria. Its gross domestic product (GDP) was US\$95.9 billion in 2019 and the economy is forecast to grow by 8.7% in 2022 (World Bank, 2021a). The agriculture, fishing and forestry sector generated US\$870 million in 2018, eclipsing the previous high of US\$790 million in 2009 (World Bank, 2021b).

Ethiopia warrants attention for a number of reasons. Notably, the vast majority of the 112 million Ethiopians reside in rural areas and remoteness is still a dominant characteristic of life (Abate et al., 2020). Schmidt et al. (2018) estimated that, in 2015, over 20% of Ethiopians lived in areas that required more than five hours of travel to a city of 50,000 people. Ethiopia is also interesting to study because African observers and commentators view the country as the archetypal developmental state and a model for social mobilisation on the continent (Berhanu and Poulton, 2014; Clapham, 2018). Jayne et al. (2019) affirm that Ethiopia is the closest example of smallholder-led agricultural growth in Africa with a 6% real annual average increase in production from 2000 to 2015. Yet, while there is evidence of technological solutions aiding the delivery of social services in Ethiopia, agriculture has not kept pace with this advancement (Berhane et al., 2018). Indeed, numerous multi-country studies have shown that the adoption rate of improved technology is much lower in rural areas where the need is greatest (Jacoby, 2000; Christiaensen et al., 2003; Deichmann et al., 2009; Stifel and Minten, 2017;

Damania et al., 2017). This is a plausible assumption in the context of Ethiopia's largely rural population.

Turning to xenobiotics, although the use of pesticides in Ethiopia was historically low, recent growth in food production and the expansion of the floriculture industry (Getu, 2009) have resulted in higher utilisation to the extent that the country now has "the largest accumulation of pesticides in Africa" [Dawud et al., (2019), p.197]. According to the MoARD in 2007, there were an estimated 250 sites holding 1,500 tons of pesticides. More recently, Shita et al. (2018) enumerated common areas of farming innovation in Ethiopia including seed varieties, water irrigation, inorganic fertilizers and pesticides. On the latter, "the total pesticide applied area reached 3.2 million hectares [22.32% of the total farmed land] in 2014/15 which has increased over time" [Shita et al., (2018), p.101]. Kebede et al. (2017) also cited row planting as a popular farming innovation supported by the Ethiopian government.

Thus, the above-mentioned undercurrents aggregate to make Ethiopia a fertile ground for investigating land management practices that will advance understanding of households' productivity. The resulting analysis and findings will support scholarly reflections on national output from the ground up in a country believed in some quarters to be Africa's beacon of prosperity (Demiessie, 2021).

### 3 Theoretical background and hypotheses development

Schoar (2010) draw attention to the distinctiveness of subsistence entrepreneurship as activities undertaken mainly to sustain family units. Indeed, Venugopal et al. (2015, p.235) assert that "more than a billion entrepreneurs worldwide live in subsistence contexts and run microenterprises to meet life's basic consumption needs." Accordingly, there is a view that subsistence farmers in Africa do not exhibit the entrepreneurial propensity that is needed for growth or more transformational entrepreneurship (Cieslik and D'Aoust, 2018). Therefore, Schoar (2010) believes that the motivations for persisting with subsistence entrepreneurship, like household farming, are

- 1 capital constraints in terms of the resources available for production
- 2 the labour market or manpower that can be committed to such activities.

These dimensions and related factors can be further understood through the contingency theory and sustainability perspective.

#### 3.1 Contingency theory and sustainability

Recognising the scale of damage that could be caused by IAS, households' use of xenobiotics, in spite of added costs and other perceived disadvantages, can be explained by pressing circumstances causing them to seek satisfactory rather than optimal results. To understand this behaviour, there is a time-honoured belief that it is normal for economic agents to incessantly assess their situation and adapt, discard and replace their practices to increase rent (Sargent, 1993; Arthur, 1994). This evokes the contingency perspective which suggests that the "most effective technique depends on the set of circumstances at a particular point in time" [Luthans and Stewart, (1977), p.182]. Luthans and Stewart (1977, p.183) added that contingency is generically situational in orientation

and warrants “identifying and developing functional relationships between environmental, management and performance variables.” In this vein, households’ use of xenobiotics to reduce crop damage and increase harvest upholds contingency logic. Thus, espousing Luthans and Stewart’s (1977) general contingency framework, the current inquiry views households as entities with limited resources operating within an environment where sustenance is dependent on maximising the performance of the land.

Furthermore, Luthans and Stewart’s (1977, p.186) general contingency framework embraced environmental variables ‘with which the manager must interact and operate’. To some degree, this conjures Elkington’s (1994) sustainability theory for ensuring the welfare of people, protecting the natural environment and raising profitability/performance. Although there are myriad definitions of sustainability, sustainable communities scholars describe the domain as economic growth that simultaneously solves environmental and local problems faced by people (Hempel, 1999). On this basis, Slaper and Hall (2011) expand Elkington’s (1994) sustainability stance as having economic, environmental and social dimensions. According to Slaper and Hall (2011), the measures of the economic dimension are personal income, firm size, employment distribution and revenue generation. For the environmental dimension, the measures comprise pollutants, solid and hazardous waste management, and change in land use. In terms of social measures, Slaper and Hall (2011) specified employment rate, female labour force participation, average household income, relative poverty and health-adjusted life expectancy. Altogether, these three dimensions and their measures correspond with Sissons et al.’s (2019) understanding of inclusive growth. Even for rural households, meeting current needs without compromising the ability of future generations to meet theirs is imperative.

Moreover, bearing in mind improved seeds, mixed cropping, row planting and the use of xenobiotics as contingent antecedents, it may be possible to explain findings on the extent to which these practices predict expected harvest through the economic, environmental and social dimensions of sustainability. This follows precedent in previous research investigating similar outcomes (e.g., van der Meulen et al., 2014; Armanda et al., 2019). We now proceed to appraise the antecedents in view of hypotheses development.

### *3.2 Improved seeds*

Seeds are a basic agricultural input and access to this commodity in its traditional or adapted form is a prerequisite for sustainable production (Abebe and Alemu, 2017). Abebe and Alemu (2017) add that the availability of seeds combined with other inputs is important for guaranteeing household food security, and improved seeds are essential for raising crop productivity. The widespread adoption of improved seeds stemmed from the ‘technical package’ of the green revolution first conceived in the USA in the late 1960s [Lakshman, (1993), p.259]. The FAO (2009b) has since defined improved seeds as the genetic modification of seedlings aimed at increasing the quality and production of crops through increased drought tolerance, high yields and early maturity. Indeed, genetically improved seeds are “widely understood to be a beneficent technology that dramatically increases agricultural output” [Lakshman, (1993), p.255]. Thus, “in the last decade, the number of African countries researching and growing genetically modified seeds has increased fourfold” [Rock, (2019), p.15]. The two kinds of improved seeds are hybrid and open-pollinated (Bachewe et al., 2018). Although hybrid seeds increase yields

considerably, the gains rapidly decline after the first year and this induces farmers to acquire new seeds. However, open-pollinated seeds do not exhibit such sharp decline in yield and are recommended to be replenished once every 3–4 years (Bachewe et al., 2018).

In Ethiopia, the adoption of improved seeds is generally low (Abay et al., 2017; Gebre et al., 2019), but national initiatives like the Tropical Legume Development Program have nevertheless increased the rate of use (Verkaart et al., 2019). The basis for investigating the effect of improved seeds on exigent land management practices is supported by McGuire and Sperling's (2011) contention. They stress that "seed is a vital input but farmers' production and food security are likely to be affected more by ownership of assets, use of other inputs, or climate than by small fluctuations in seed availability" [McGuire and Sperling, (2011), p.498]. Furthermore, consistent with complementarity effects, agricultural yields could be higher when inputs are adopted simultaneously rather than separately (Feder, 1982). Besides, "in the context of Ethiopia, agricultural input supply strategies in the last decade encouraged farmers to adopt chemical fertilisers and improved seeds as a package" [Bachewe et al., (2018), p.288], signalling the interrelatedness of farming innovation. Prior research including Dorfman (1996), Gebremariam and Tesfaye (2018) and Bachewe et al. (2018) have modelled farmers' adoption of improved seeds alongside chemical fertilisers and irrigation inputs. Mirroring their precedent, the first set of hypotheses seek to estimate whether households' seed selection practices predict specific xenobiotic use:

H1 Improved seeds are positively associated with the use of pesticides.

H2 Improved seeds are positively associated with the use of herbicides.

H3 Improved seeds are positively associated with the use of fungicides.

### 3.3 *Mixed cropping*

Mixed cropping is the established practice of inter-planting crops in smallholdings (Maxwell and Fernando, 1989; Omamo, 1998). Proponents believe that mixed cropping systems reduce exposure to pests and the probability of total crop damage (Ezulike and Igwatu, 1993; Fondong et al., 2002). Other reported benefits of mixed cropping are an improvement in soil cover (Howeler and Cadavid, 1990), the suppression of weeds (Olasantan et al., 1996), improved soil fertility (Lusembo et al., 1998) and greater labour efficiency (Odurukwe and Ikeorgu, 1994). Subsistence farmers may also gain from a more diverse diet and the possibility of additional income (Gold, 1993). In spite of these claims, there is a counter argument that "yields of cash-crops appearing in mixed stands often fall well below those in pure stands" [Omamo, (1998), p.155]. In fact, Daellenbach et al. (2005) showed that mixed cropping systems reduce total production when compared to mono cropping. Yet, Yigezu et al. (2019) think otherwise and assert that, at least in legume-cereal mixed stands, there are clear economic advantages over pure stands as mixed stands provide higher yields and gross margins. All things considered, it would seem that these outcomes and overall performance are farm specific and contingent on other inputs like specialised machinery (Cook and Weller, 2004).

Acknowledging the heterogeneity of mixed versus pure stands, the correlations of alternate stand types with other ancillary practices have long drawn scholars' interest. Theoretically, Rhoades and Bebbington (1990) took an ecological and economic view to

explain farmers' intercropping decisions. First, for ecology, they considered the pursuit of environmental reliance, stability and diversity as motivators. Second, for the economic stance, they cited risk reduction and the efficient use of land and labour as reasons for tending single or multiple crops. There is also a nutritional view, albeit from an intensive farming context, extolling an increase in "nutrient productivity due to beneficial interactions between neighbouring plants" [Zhang et al., (2019), p.2]. Jacques and Jacques (2015) concur that there are nutritional implications and biodiversity advantages that may accrue from making appropriate stand (monocropping versus mixed cropping) choices. In terms of the measurement of this practice, previous works have operationalised stand type to understand its effects on seed germination (Dubey and Fulekar, 2011), pests and weeds (Li et al., 2019) and pesticides (Gockowski and Ndoumbe, 2004). Accordingly, there is empirical basis to test the effect of stand type on all forms of xenobiotic use:

H4 Mixed cropping is positively associated with the use of pesticides.

H5 Mixed cropping is positively associated with the use of herbicides.

H6 Mixed cropping is positively associated with the use of fungicides.

### 3.4 *Row planting*

Row planting, as opposed to broadcast planting, is one of two sowing techniques for placing seeds in the soil for germination (Aguilar and Jacobsen, 2003). Beginning with the latter, broadcast planting is performed, first of all, by preparing seedbeds and, secondly, dispersing seeds over the seedbeds by hand or using broadcast spreading equipment (Orth et al., 2009). To complete the broadcast process, soil surface is swept over the seedlings to improve soil contact, fend off seed-eating pests and reduce solar radiation which preserves vitality and aids the uniform emergence of crops (Aguilar and Jacobsen, 2003). On the other hand, row planting requires the placement of seeds in furrows that are centimetres apart in defined rows which are then covered with surface soil (Fahong et al., 2004). This method is often preferred for even distribution of plants which makes weeding and hoeing less of an ordeal down the line (Aguilar and Jacobsen, 2003). Selecting an ideal planting method is of genuine essence in arid regions (like Ethiopia) where water conservation and irrigation are real issues (Lalitha and Chhabra, 2020). Making appropriate decisions in this regard not only affects crop yield and quality, but also impacts on soil health (Iqbal et al., 2019). Also, sowing technique has an apparent bearing on labour requirement (Vandercasteelen et al., 2018), with row planting said to be more labour-intensive than broadcast planting.

Reverting to the theoretical links, during the sowing process, there is a common practice of coating seeds with pesticides and/or fungicides to control pests irrespective of broadcast or row planting (Nuyttens et al., 2013). In one study, Reddy (2003) stated that row planting has the potential to reduce herbicide inputs. Yet, in another study, Gessesse (2020) wrote that since row planting allows more space for the growth of weeds compared to broadcasting, farmers are advised to apply herbicides. These claims are a clear contradiction that warrants investigation for a definitive perspective on the link between row planting and xenobiotic use. Devi et al. (2018) and Mahajan et al. (2019) offer empirical precedent of association between row planting and xenobiotic use.



Altogether, these factors are considered within a package of farming innovation (Kebede et al., 2017). Thus, the next hypotheses evaluate whether:

H7 Row planting is positively associated with the use of pesticides.

H8 Row planting is positively associated with the use of herbicides.

H9 Row planting is positively associated with the use of fungicides.

### 3.5 Pesticide

Pesticides are bioactive substances that are applied in farmlands to deter, incapacitate or discourage pests while increasing crop yield, quality and economic returns (Imfeld and Vuilleumier, 2012). In order of kilograms per hectare, Japan recorded the highest annual pesticide use between 2010 and 2014, followed by China, Mexico, Brazil, Germany, France, the UK, the USA and India (Zhang, 2018). There are records dating back to 1921 on the regulation of pesticide use in Kenya (Wandiga, 2001), suggesting that this method of pest management has been practiced in Africa for more than a century. Post-independence, there have been several government programs promoting the use of pesticides to African smallholders and commercial farmers, leading to a pesticide dependency (Williamson, 2003). For 28 years between 1966 and 1994, cotton farmers in Ivory Coast, had free (unpaid) access to pesticides because their produce was deemed to be of national importance (Ajayi et al., 2009). The use of pesticides on the continent continued to grow to a point where Africa accounted for 2–4% of the \$31 billion global pesticide market (Agrow, 2006). In West Africa alone, figures from the FAO showed that pesticide imports exceeded \$800 million in 2012/2013 (Haggblade et al., 2021). Just now, the global pesticides market is forecast to grow from \$75 billion in 2017 to \$90 billion by 2023 (TechSci, 2021).

In Ethiopia, common pesticides procured by small scale farmers include permethrin, cypermethrin, deltamethrin, chlorpyrifos ethyl, malathion and diazinon (Mekonen et al., 2014). Theoretically, there is a plethora of papers associating pesticide use with expected harvest. Cooper and Dobson (2007, p.1340) affirm that “the use of pesticides has undoubtedly played a very significant role” in the spectacular increase in crop yields in the USA. Williamson et al. (2008) indicate the same trend in Ghana, as Bonner and Alavanja (2017, p.89) contend that “for the near and foreseeable future, pesticides may be an important component of a comprehensive strategy to increase crop yield.” Hence pesticide adoption rate is still seeing an upswing in Ethiopia (Negatu et al., 2017), to the extent that it now poses a risk to surface water and aquatic life; following concerns raised by the Ethiopian Pesticide Risk Reduction Programme (Teklu et al., 2015). Similar to Hossard et al.’s (2014) premise that pesticide use affects crop yield, a tenth hypothesis is formulated:

H10 The use of pesticides is positively associated with expected harvest.

### 3.6 Herbicide

Herbicides, often called weed killers, are chemical substances sprayed to control unwanted plants without injuring cultivated crop (Davies and Caseley, 1999; Kebede and Anbasa, 2017). Weed management in this way began in the latter part of the 1940s, and glyphosate, first introduced in 1974, emerged as the herbicide of popular choice (Rüegg

et al., 2007; Duke and Powles, 2008). In order of kilograms per hectare, Japan recorded the highest annual herbicide use between 2010 and 2014, followed by Brazil, the USA, Mexico, Germany, Canada, France, the UK and India (Zhang, 2018). Worldwide, herbicides now represent 60% of all xenobiotic use in farmlands (Dayan, 2019). This is mainly because glyphosate, in particular, is said to be toxicologically and environmentally safe (Duke and Powles, 2008). Other obtainable herbicides are phenoxy hormone, triazines, amides, carbamates, dinitroanilines, urea derivatives, sulfonyl ureas, bipiridils and uracil. Zhang (2018) noted that triazines, urea derivatives, uracil and bipiridils use increased between 1990 and 2007, but the application of bipiridils has declined since 2007. In Africa, claims have been made of the obvious but overlooked ‘opportunity for herbicides’ [Gianessi and Williams, (2011), p.211], because “smallholder farms do not use herbicides and adoption rates are less than 5%” [Gianessi, (2013), p.1102]. It seems that the vast majority of farmers manage the problem by hand weeding (Rodenburg et al., 2019).

In Ethiopia, Tamru et al. (2017) have observed the rapid adoption of herbicides among smallholders since 2004, following a rise in the importation of glyphosate and other substances mainly from China and India. This trend is theoretically explained by herbicides being damage control agents that can minimise crop losses and maximise yield potential. Thus, Kebede and Anbasa (2017) have demonstrated the efficacy of herbicides for boosting maize yields in Ethiopia, similar to Tessema et al. (2018). In other crops, the effectiveness of herbicides for increasing teff yield has been cited (Tamru et al., 2017), while Mitiku and Dalga (2014) reached the same conclusion for wheat. Scholars have mostly associated herbicide use with labour productivity (Gebissa et al., 2019; Bouwman et al., 2021). However, following the suggestion by Hailu et al. (2017) that, as a production input, herbicides are also an explanatory variable for crop productivity, a further hypothesis is contemplated:

H11 The use of herbicides is positively associated with expected harvest.

### 3.7 Fungicide

Fungicides are chemical compounds diffused for the control of parasitic fungi or their pathogens during crop cultivation (Oliver and Hewitt, 2014). The history of fungicide use predates 1755 when it was discovered that a seed-borne fungi (*Tilletia Laevis*) in wheat could be controlled by treating seeds with lime and salt (Morton and Staub, 2008). Fungicides have since become more sophisticated in their composition and include common names such as benomyl, iprodione, lime sulfur, mancozeb and propineb (Kang and Jung, 2017). In order of kilograms per hectare, between 2010 and 2014, the highest annual fungicide use by country was in Japan followed by Mexico, France, the UK, Germany, Brazil, the USA and India (Zhang, 2018). Zhang (2018) adds that the use of fungicides increased from 1990 to 2007, but has oscillated ever since. This fluctuation could, in part, be explained by the increasing resistance of pathogens to fungicides for which “new anti-fungal compounds need to be discovered” [Steinberg and Gurr, (2020), p.1]. Notwithstanding, the global fungicide market was worth approximately \$13.4 billion in 2018 (Çıldır and Liman, 2020). Where they are used, fungicides are deemed to be effective and low in toxicity (Zhang et al., 2018). Although fungicide use is generally

low in Africa (Ochieng et al., 2019), they are sprayed in potato plantations in South Africa (Muzhinji et al., 2018) and Uganda (Namugga et al., 2017). They are also mainly used by vegetable farmers in Benin, Ethiopia, Ghana and Senegal (Williamson et al., 2008).

One of the main attractions to fungicides in Ethiopia is the mitigation of wheat rust fungus which, according to Allen-Sader et al. (2019), poses one of the greatest threats to global food security. Ethiopia harvests 1.7 million hectares of wheat annually and this produce is relied on by 4.2 million households (Central Statistics Agency, 2018). Yet in the 2013–2014 period, an estimated 40,000 hectares were diseased by wheat rust (Olivera et al., 2015). To offset such outcomes, fungicides are also leveraged in the production of garlic (Endalew et al., 2020) and sugarcane in Ethiopia (Kecha, 2020). Relatedly, Kassaw et al. (2021) indicate that greater yields accrue from the use of fungicide in Ethiopian potato plantations. In fact, there is no shortage of theoretical links between fungicide use and improved farm harvests (Danso-Abbeam and Baiyegunhi, 2017). Inspired by previous tests probing how fungicides correlate with crop yield (Haverkort and Bicamumpaka, 1986; Dalla Lana et al., 2015), the penultimate hypothesis checks the extent to which:

H12 The use of fungicides is positively associated with expected harvest.

### 3.8 *Expected harvest, improved seeds, mixed cropping and row planting*

There are extensive claims that improved seeds (e.g., Lakshman, 1993), mixed cropping (e.g., Yigezu et al., 2019) and row planting (e.g., Vandercasteelen et al., 2018) separately enhance farm productivity. As a proxy for productivity, expected harvest is depicted here as the estimated units of produce predicted by households for forthcoming harvest. The inclusion and review of this factor harps on the expectancy-value theory of motivation. First conceived by Atkinson (1957), the expectancy-value perspective postulates that the degree of success envisaged by individuals and their inner beliefs will occasion subsequent behaviour (Wigfield, 1994). The theory also helps to explain individuals' level of persistence during the performance of tasks (Eccles and Wigfield, 2020). There is an argument that because of the relatively long lead time between planting and harvest seasons, households pre-plan their land management practices in order to maximise expected harvest. In other words, the expected value of crop yield will instigate the performance of specific land management practices from the outset. Thus, McMaster et al. (2000) pondered the relationship between expected harvest resulting from soil and water conservation. Also, recalling that expectancy-value also encompasses inner beliefs, Dennis (1989) considered individual characteristics as a function of expected timber harvest. In the same spirit, drawing on the farming innovation techniques appraised in this study, the last set of hypotheses test the extent to which:

H13 Improved seeds are directly and positively associated with expected harvest.

H14 Mixed cropping is directly and positively associated with expected harvest.

H15 Row planting is directly and positively associated with expected harvest.

## 4 Method

### 4.1 Data and measures

The data examined in this study were collected from the 2018–2019 living standards measurement study of Ethiopian households conducted by the World Bank (2021c) using stratified random sampling. This follows Peet et al. (2015), Aregbeshola and Khan (2018) and Gebremariam and Tesfaye's (2018) precedent. The scope of the data covered household characteristics, community infrastructure, livestock information, post planting and post harvest information. Out of 16,914 cases in the sample, only 7,625 households that indicated the use of all three xenobiotics were extrapolated. For measurement, seven main variables were examined namely improved seeds (IMPSEED), mixed cropping (MIXCROP), row planting (ROWPLAN), use of pesticides (PEST), use of herbicides (HERB), use of fungicides (FUNG) and expected harvest (EXPHARV). The control variables were type of farm (FARMTYP), name of town (REGION) and type of crop (CROP). All factors were measured using single item questions as outlined in Table 1.

**Table 1** Measurement details

<i>Variable</i>	<i>Items</i>	<i>Scales</i>
IMPSEED	What type of seed/seedling was used for crop on the field?	Traditional/improved
MIXCROP	Was the area planted with crop on the field pure stand or mixed?	Pure stand/mixed stand
ROWPLAN	What type of crop sowing techniques was used for crop on the field?	Broadcast planting/row planting
PEST	Did you use any pesticide to prevent damage of crop on this field?	Yes/no
HERB	Did you use any herbicide to prevent damage of crop on this field?	Yes/no
FUNG	Did you use any fungicide to prevent damage of crop on this field?	Yes/no
EXPHARV	How much of crop (units) do you expect to harvest from this field?	Continuous
FARMTYP	What is the holder's farm type?	Crop production only/both livestock and crop production
REGION	Name of town	Continuous
CROP	Type of crop	Continuous

### 4.3 Sample characteristics

Of the 7,625 households in the sample, 89% were both crop and livestock smallholders while 11% cultivated only crops. Geographically, 29% of the households resided in the northern Amhara area followed by 20.8% in the Southern Nations, Nationalities and People's (SNNP) region. Other territories were Oromia spanning from the mid-west to the south of the country (15.9%), Benishangul-Gumuz in the north-west (12.7%) and Tigray in the northernmost part (10.7%). The remaining territories each represented less than 4% of the sample but 9 out of the Ethiopia's 12 regions and chartered cities have

been surveyed. The crops cultivated were mostly maize in 19.2% of households, followed by sorghum and teff in 12.6% and 11.5% respectively. Table 2 presents a full list and proportion of other produce including wheat, barley and kale.

**Table 2** Sample characteristics

<i>Farm type</i>	<i>Frequency</i>	<i>Percent</i>
Both livestock and crop production	6,790	89.0
Crop production only	835	11.0
<i>Total</i>	<i>7,625</i>	<i>100.0</i>
<i>Region</i>	<i>Frequency</i>	<i>Percent</i>
Amhara	2,213	29.0
SNNP	1,586	20.8
Oromia	1,214	15.9
Benishangul-Gumuz	972	12.7
Tigray	817	10.7
Dire Dawa	282	3.7
Harar	279	3.7
Gambela	235	3.1
Afar	27	0.4
<i>Total</i>	<i>7,625</i>	<i>100.0</i>
<i>Crop</i>	<i>Frequency</i>	<i>Percent</i>
Maize	1,464	19.2
Sorghum	957	12.6
Teff	936	12.3
Wheat	540	7.1
Barley	476	6.2
Kale	276	3.6
Horse beans	271	3.6
Red kidney beans	224	2.9
Godere	211	2.8
Red pepper	215	2.8
Millet	196	2.6
Sweet potato	167	2.2
Garlic	138	1.8
Groundnuts	123	1.6
Pumpkins	101	1.3
Potatoes	102	1.3
Soya beans	99	1.3

**Table 2** Sample characteristics (continued)

<i>Crop</i>	<i>Frequency</i>	<i>Percent</i>
Field peas	99	1.3
Other root crops	77	1.0
Sesame	67	0.9
Lentils	69	0.9
Rice	65	0.9
Vetch	72	0.9
Chickpeas	70	0.9
Green pepper	58	0.8
Rapeseed	63	0.8
Nueg	63	0.8
Linseed	52	0.7
Onion	51	0.7
Cassava	52	0.7
Ginger	29	0.4
Mung bean/masho	30	0.4
Other vegetables	20	0.3
Sunflower	26	0.3
Cabbage	22	0.3
Spinach	19	0.2
Tomatoes	12	0.2
Beer root	18	0.2
Carrot	19	0.2
Oats	12	0.2
Other spices	10	0.1
Cardamom	8	0.1
Coriander	5	0.1
Tobacco	9	0.1
Other pulses	5	0.1
Lettuce	5	0.1
Turmeric	9	0.1
Other cereal	4	0.1
Cotton	2	0.0
Cauliflower	3	0.0
White cumin	2	0.0
Gibto	2	0.0
<i>Total</i>	<i>7,625</i>	<i>100.0</i>

## 5 Analysis

A nonlinear regression-based partial least squares structural equation modelling (PLS-SEM) technique was adopted to analyse the household data. The specific software and version used was WarpPLS 7.0 (Kock, 2019). This approach was deemed appropriate because of its greater predictive power over covariance-based structural equation modelling (CB-SEM). To explain, “in a direct comparison with CB-SEM, the variance explained in the dependent variable is substantially higher [in PLS-SEM]” [Hair et al., (2017), p.119]. WarpPLS is also suitable for analysing constructs with binary data (Sajid et al., 2020).

### 5.1 Measurement model

Preparatory to path analysis, it is important to assess the reliability and validity of variables. However, all variables in the current study are single item variables for which reliability and validity tests do not suffice. In terms of collinearity, variance inflation factor (VIF) scores were generated for all variables to confirm the absence of linear combinations in the structural model. As demonstrated in Table 3, all VIF values were lower than the 5 limit recommended by Hair et al. (2011).

**Table 3** Collinearity diagnostic

	<i>IMPSEED</i>	<i>MIXCROP</i>	<i>ROWPLAN</i>	<i>PEST</i>	<i>HERB</i>
VIF	1.120	1.152	1.231	1.080	1.129
	<i>FUNG</i>	<i>EXPHARV</i>	<i>REGION</i>	<i>CROP</i>	<i>FARMTYP</i>
VIF	1.105	1.068	1.194	1.086	1.006

### 5.2 Structural model and hypothesis testing

The structural model is examined through the path coefficients ( $\beta$ ) and p-values of the associations hypothesised. Figure 1 shows the obtained results.

From Figure 1, beginning with land management practices, the path analysis of improved seeds indicates that the factor positively correlates with the use of pesticides ( $\beta = 0.18$ ), herbicides ( $\beta = 0.07$ ) and fungicides ( $\beta = 0.20$ ). However, mixed stands have a negative association with pesticide ( $\beta = -0.04$ ), herbicide ( $\beta = -0.19$ ) and fungicide ( $\beta = -0.06$ ) use. There are mixed findings in how row planting affects household’s use of xenobiotics. It (row planting) has a weak but positive influence on the use of pesticides ( $\beta = 0.02$ ) but a negative impact on herbicide ( $\beta = -0.13$ ) and fungicide ( $\beta = -0.04$ ). In turn, all types of xenobiotic use reduce expected harvest [pesticides ( $\beta = -0.00$ ), herbicides ( $\beta = -0.10$ ) and fungicides ( $\beta = -0.04$ )]. Furthermore, the path analysis revealed that both broadcast planting ( $\beta = -0.15$ ) and improved seeds ( $\beta = -0.06$ ) decrease expected harvest, while mixed stands ( $\beta = 0.06$ ) moderately increases the outcome. All control variables, region ( $\beta = -0.06$ ), crop ( $\beta = -0.07$ ) and type of farm ( $\beta = -0.00$ ) are negatively correlated to expected harvest. Overall, the model explains 6% of households’ expected harvest in rural Ethiopia.

Table 4 further summarises the hypotheses testing and results.

Figure 1 The structural model

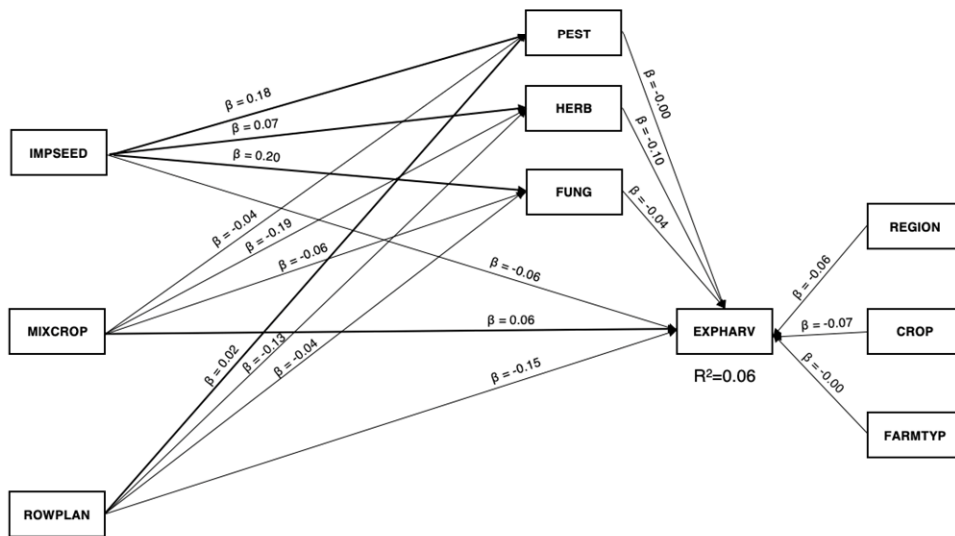


Table 4 Hypothesis testing

Hypothesised relationships	Path coefficients	P-values	Test
H1 Improved seeds ⇒ pesticides	0.18	<0.01	Significant
H2 Improved seeds ⇒ herbicides	0.07	<0.01	Significant
H3 Improved seeds ⇒ fungicides	0.20	<0.01	Significant
H4 Mixed cropping ⇒ pesticides	-0.04	<0.01	Not significant
H5 Mixed cropping ⇒ herbicides	-0.19	<0.01	Not significant
H6 Mixed cropping ⇒ fungicides	-0.06	<0.01	Not significant
H7 Row planting ⇒ pesticides	0.02	0.02	Significant
H8 Row planting ⇒ herbicides	-0.13	<0.01	Not significant
H9 Row planting ⇒ fungicides	-0.04	<0.01	Not significant
H10 Pesticide ⇒ expected harvest	-0.00	00.35	Not significant
H11 Herbicide ⇒ expected harvest	-0.10	<0.01	Not significant
H12 Fungicide ⇒ expected harvest	-0.04	<0.01	Not significant
H13 Improved seeds ⇒ expected harvest	-0.06	<0.01	Not significant
H14 Mixed cropping ⇒ expected harvest	0.06	<.01	Significant
H15 Row planting ⇒ expected harvest	-0.15	<.01	Not significant

## 6 Discussion

By way of interpretation, this study demonstrates that the higher the use of pesticides, herbicides and fungicides, the lower households' expected harvest will be. Of the six land



management practices examined, households' best chance of increasing expected harvest is by tending mixed crops. To be sure,

- 1 cultivating more than one crop moderately increases expected harvest
- 2 sowing improved seeds using row planting will decrease expected harvest. It has also been shown that using improved seeds increases households' tendency to apply pesticides, herbicides and fungicides in their smallholdings.

Likewise, row planting very slightly increases households' use of pesticides but reduces the application of herbicides and fungicides. Based on these findings, Lakshman's (1993, p.225) claim that improved seeds 'dramatically increase agricultural output' is disproved in the context of rural households in Ethiopia. Also, Daellenbach et al.'s (2005) assertion that mixed cropping systems reduce total production is challenged, while Yigezu et al.'s (2019) stipulation that mixed cropping provides higher yields is somewhat upheld. Furthermore, Reddy's (2003) argument that row planting reduces herbicide use is sustained, negating Gessesse's (2020) recommendation that farmers practicing row planting should apply herbicides. Instead of increasing crop yield as claimed by Cooper and Dobson (2007), Williamson et al. (2008) and Bonner and Alavanja (2017), this study finds that spraying pesticides reduces crop yield. Similarly, the view that herbicides increase yield in maize (Kebede and Anbasa, 2017; Tessema et al., 2018), teff (Tamru et al., 2017) and wheat (Mitiku and Dalga, 2014) does not seem to be true when the expected harvest of all crops is considered. Kassaw et al.'s (2021) finding that fungicides increase yields is also contested by the current findings. It is now opportune to reflect on these findings through the contingency and sustainability lens.

By and large, Luthans and Stewart (1977) believe that pressing environmental, resource and management influences are at the core of how economic agents operate. Beginning with environmental factors beyond households' control, in Ethiopia, agricultural extension programs compel the use of improved seeds and other inputs as a condition for government support. Unequivocally, Bachewe et al. (2018, p.288) affirm that "in the context of Ethiopia, agricultural input supply strategies in the last decade encouraged farmers to adopt chemical fertilizers and improved seeds as a package, at times bundled with input credit, making adoption of these two inputs an inherently simultaneous decision or one between sets of possible technology bundles." There is also evidence that loyalty to the defunct political party, the Ethiopian People's Revolutionary Democratic Front (EPRDF), has been a condition for farmers receiving seeds, credit and other inputs (Berhanu and Poulton, 2014). Characteristically, cooperative societies are organised to work with extension programs to cascade government support to grassroot farmers. Consequently, Abebaw and Haile's (2013, p.87) indication that "membership of agricultural cooperative [in Ethiopia] has a significant positive and larger impact on pesticide adoption" as well as improved seeds is hardly surprising.

In terms of the influence of resources or the lack of in rural households, there is immense poverty among this social group (Demissie and Kasie, 2017). A large proportion of farming families in Ethiopia are barely able to supply the labour required for subsistence activity (Vandecasteele et al., 2018). Being in a dire situation, these households are heavily reliant on external support for inputs such as seeds and other inputs (Abebaw and Haile, 2013). Invariably, the seeds on offer are of the improved variety which, as this study demonstrates, increases the likelihood of pesticide, herbicide

and fungicide use. In turn, these practices reduce expected harvest, further constraining the resources available to rural households.

The above environmental and resource pressures converge to determine the quality of farm management decisions made by rural households. In the face of environmental and resource limitations, they may be obliged to obtain improved seeds and use different kinds of xenobiotics without regard to expected harvest because the alternative to this could be a lack of subsistence activity. By contrast, it can be expected that rural households that are resistant to the overtures of extension programs and non-reliant on farming inputs from external sources will exhibit greater expected harvest. Therefore, self-sufficiency or the delivery of 'technical packages' with no strings attached is deemed to be an important criterion for raising rural households' productivity.

Revisiting Elkington's (1994) sustainability theory, consideration of Slaper and Hall's (2011) economic, environmental and social dimensions is appropriate here. In relation to economic measures, this study maintains that the land management practices examined do not yield sufficient output nor do they optimise the labour of rural households. Take row planting for example, this sowing technique requires greater effort from households yet it reduces expected harvest significantly more than other farming innovations. This result concurs with Zhai et al.'s (2018) verdict that broadcasting does indeed increase grain yield. It is also worth acknowledging evidence that pesticide use correlates more positively with the cultivation of cash crops for commercial purposes (Matthews et al., 2003), rather than for domestic consumption. Household farmers in Ethiopia also deem herbicides to be ineffective (Gessesse, 2020). According to Mariyono et al. (2018), xenobiotics are only needed if and when pest and disease infestations occur otherwise they are mostly a wasteful insurance policy. Overall, the six land management practices inherent in this review are suboptimal and do not make economic sense for rural households in Ethiopia.

Taking the environment into account, the ecological hazards posed by pesticides, herbicides and fungicides have been widely reported in different countries (De la Cruz et al., 2014; Tamru et al., 2017; Kapsi et al., 2019). In Africa, there are serious shortcomings in the handling practices of these toxic substances (Williamson et al., 2008). Even when used proportionately, the leaching of xenobiotics into the soil and groundwater causes long-term pollution (Arias-Estévez et al., 2008). Above ground, xenobiotics also disrupt biodiversity and much needed ecological balance. For example, Ethiopian farmers have been alleged to handle pesticides very indiscriminately without consideration of the effect on honeybees, threatening the essential pollination cycle (Fikadu, 2020). In fact, over 90% of Ethiopian farmers are unaware that pesticides could damage water bodies (Mengistie et al., 2017). Through oblivion, land quality is compromised by the toxic content of xenobiotics such as sulphur in herbicides.

To conclude, to be sustainable, land management practices and xenobiotic use ought to improve rural households' quality of life but this does not appear to be the case. For instance, there are doubts surrounding the positive effect of fungicides on the nutritional composition of crops (Mbah et al., 2018). Worse still, Banjo et al. (2010) report that 25 million land workers in developing countries suffer from pesticide poisoning every year. This leads to diagnoses such as respiratory difficulty, memory loss, various cancers, skin conditions and other acute diseases that cause 18,000 annual deaths (Banjo et al., 2010). These statistics are inconsistent with the social health and life expectancy principles of sustainability. Land management practices and xenobiotic use are only beneficial if they have, as Green (2012, p.1324) best puts it, "the ability to bring benefits to growers and

satisfy society's expectations for safe, abundant and affordable food ... in an environmentally sustainable way."

## **7 Implications, future research and limitations**

### *7.1 Theoretical contributions*

This paper is one of the first to conceptualise multiple land management practices vis-à-vis expected harvest for empirical validation. Specifically, it breaks new ground by linking row planting to the use of pesticides, herbicides and fungicides. Its core contribution to the literature is the isolation of specific practices that will increase expected harvest in rural Ethiopia and, possibly, similar contexts. It reconciles contradictory findings in the farming innovation and productivity nexus and reduces theoretical ambiguity by offering definitive perspectives in two areas:

First, it has been determined that the ingredients for increasing expected harvest are, in order of coefficient strength, mixed cropping, use of traditional seeds and broadcast planting. Moreover, the use of traditional seeds will reduce reliance on xenobiotics, which also bodes well for maximising harvests. Accordingly, supported by expectancy-value theory, the evidence of mixed cropping, traditional seeds and broadcast planting as viable predictors of expected harvest introduces fresh antecedents to the farming innovation and productivity nexus. Second, by isolating and separately examining pesticides, herbicides and fungicides, we offer exactitude and theoretical specificity on the distinctive effect of different xenobiotics. This is an improvement on previous studies that assess herbicides and fungicides as a composite construct of pesticides. Undoubtedly, the use of composite constructs when multi dimensions can be interrogated leads to the underestimation of correlations (Bracken, 1996; Craven et al., 2003; O'Mara et al., 2006). The current structural model and the ensuing findings effectively address this problem.

### *7.2 Practical implications*

For rural households, the chief contribution of this inquiry is that, from the outset,

- 1 they are better off sowing traditional seeds using broadcasting method
- 2 the tending of crops sprouting from traditional seeds will reduce the inclination to use pesticides, herbicides and fungicides.

This insight should incentivise households to spurt xenobiotics more consciously and less habitually. This point is especially pertinent as Genet et al. (2020) identify pesticides as one significant variable costs incurred by Ethiopian farmers. The findings also refute the wisdom of government support programs encouraging rural households to sow improved seeds and dispense xenobiotics. On the current evidence, these factors reduce households' expected harvest. In fact, their increased use in Ethiopia and Africa as a whole may partly explain why the continent's agricultural output lags behind global production. Therefore, attention is also drawn to foreign donors of agricultural inputs in Africa including the Bill and Melinda Gates Foundation, the International Fund for Agricultural Development, the World Health Organization and the United Nations

Population Fund (Shaw and Wilson, 2020). These entities can reconsider their benevolence by sourcing and gifting traditional seeds to rural households, at the same time as promoting awareness on the hazards of xenobiotics and the potential benefits of broadcast planting. In addition to surface water and aquatic life, the Ethiopian Pesticide Risk Reduction Programme should also consider rural households' expected harvest to be an area of concern.

### *7.3 Limitations and future research*

There are a few shortcomings in this study that prompt follow-up research. First, the parallels drawn with contingency and sustainability theory are only reflective and conceptual. Nevertheless, this paves way for new studies to empirically measure and report contingent and sustainable behaviour. Second, the structural model did not check the type of xenobiotics used and how their toxicological properties affect expected crop harvest not just in terms of quantity but also in quality. In the interest of empirical specificity, future studies could be predicated on this thesis as such results will deepen insights on the exact effects of xenobiotic use. Third, in new studies, researchers may also examine actual harvest rather than expected harvest as the dependent variable. Fourth, although the findings may also be useful in countries neighbouring Ethiopia in East Africa, other studies are invited to adopt the path diagram and possibly validate the current results for generalisability. Finally, in the grand scheme, the current findings hint at the benefits of organic farming without the need for improved seeds and xenobiotics. Future research can conceptualise organic farming practices in the farming innovation and productivity nexus to advance knowledge in this area.

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