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Research paper

State-conditioned soil investment in rural Uganda

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ABSTRACT

While poor soils limit agricultural production across rural, sub-Saharan Africa, most smallholder farmers fail to invest in their soils in the way that soil scientists and policy makers prescribe. A small but growing literature examines biophysical constraints on soil investment, and in particular state-conditioned soil investment – the manner in which current soil fertility drives investment in soils in poor, agricultural contexts. While some research finds that farmers invest more in low fertility soils, other authors find the opposite. We model two types of state-conditioned soil investment, and show that while organic amendments in the form of manure or compost are optimally applied on low fertility plots, structural investments to halt soil degradation may not be optimal on any plots, or may be optimal only on high value, high fertility plots. Using plot-level panel data from Uganda, we find that soil fertility measures from 2003 do predict subsequent soil management practices a decade later. Farmers are more likely to apply organic amendments to low fertility plots, as predicted by our analytical model. Laborious conservation practices and structural investments in plots are quite rare, indicating that these measure may not be effective enough to be profitable in Uganda. Even so, certain conservation practices are predicted by 2003 soil fertility conditions. These associations, and the associations regarding organic amendment, are highly stable in the face of many controls – it appears that soils starting conditions do matter for subsequent soil investment decisions and soil fertility trajectories. Together, the model and empirical investigation bring nuance to the previous discussion on state-conditioned soil investment, and help to resolve seemingly inconsistent empirical findings in the literature.

1. Introduction

Declining soil fertility is frequently cited as the primary biophysical reason for stagnant per capita food production in sub-Saharan Africa (Morris, 2007; Place et al., 2003; Sanchez et al., 1996), and as a potential mechanism for trapping rural, semi-subsistence agricultural communities in poverty (Barrett and Bevis, 2015; Dasgupta and Mäler, 1990). Increases in soil organic carbon, a common measure of soil fertility, have the capacity to sharply increase yields; Lal (2006) estimates that for every ton/ha increase in soil organic carbon, maize, wheat and rice yields increase by 30–300, 20–70, and 10–50 kg/ha, respectively, across the developing world. Yet farmers in poor, semi-subsistence settings tend to under-invest in soil conservation measures and apply less than optimal levels of organic and inorganic fertilizer (De Graaff et al., 2008; Hagos and Holden, 2006).

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A small body of literature examines the determinants soil investment.[1] Extension contacts and education, for instance, are associated with increased adoption of soil conservation practices in Tanzania (De Graaff et al., 2008), and larger farms adopt these measures more intensively in Peru and Bolivia (Posthumus, 2005) and in Ethiopia (Amsalu and De Graaff, 2007). In the Philippines, farmers are more likely to adopt costly soil conservation practices if crop intensification or cash cropping was possible (Lapar and Pandey, 1999). In India, households with more adult males, more farm servants, and less land invest more in soil conservation (Pender and Kerr, 1998). Plot level factors impact soil conservation practices too – for example, farmers are less likely to adopt conservation measures on plots farther from households in Ethiopia, maybe due to increased labor requirements or less security of tenure (Bekele and Drake, 2003).

Additionally, an even smaller group of papers find soil characteristics themselves (e.g., fertility, erosion, color, perceived quality) to be associated with soil investment (Amsalu and De Graaff, 2007; Antle et al., 2006; Marenya and Barrett, 2009a; Yirga and Hassan, 2014). If soil investment is truly state-conditioned in this way, the relationship has important implications for long-term fertility dynamics. If a farmer is most likely to invest, or if he/she invests most, in low fertility plots, while neglecting to invest in higher fertility plots, then we might expect a long-run regression to farm-mean soil fertility. However, if farmers only find it profitable to invest in higher fertility plots, neglecting lower fertility plots as a lost cause, then we might expect divergent trends – degradation for low fertility plots and rehabilitation for high fertility plots.

Yet both theoretical and empirical evidence is mixed with regards to how current or “starting” soil fertility impacts soil investment decisions. Some researchers find that higher soil fertility boosts yield response to compost, mulch or fertilizers, making farmers more likely to invest in their highest fertility soils (Antle et al., 2006; Bayala et al., 2012; Jama et al., 1998; Marenya and Barrett, 2009a; 2009b; Stephens et al., 2012; Vanlauwe et al., 2006; Zingore et al., 2008b). Other researchers find that farmers are more likely to build conservation structures or invest in long-term conservation practices on poor soils than on fertile soils (Amsalu and De Graaff, 2007; Yirga and Hassan, 2014).

This diversity of conclusions is partially explained by the research context from which these papers spring. Most papers on state-conditioned soil investment stem from one of four threads of the technology adoption literature: (i) adoption of soil and water conservation, (ii) adoption of conservation agriculture, (iii) adoption of fertilizer, and (iv) adoption of organic amendments. The first two bodies of literature tend to focus on arid or semi-arid, erosion-prone regions, where soil investment is meant to mitigate topsoil loss. The second two bodies of literature focus more generally on smallholder agriculture in the tropics, and soil investment is meant to increase soil organic carbon or nutrient stocks, and sometimes to increase agricultural productivity. Thus, the relevant dimension of soil fertility and also the relevant measures of soil investment differ by context/literature.

Soil and water conservation (SWC) is an umbrella term for the construction and maintenance of plot-level structures that halt or mitigate soil erosion: primarily terracing, ridging, soil bunds, strip cropping, agro-forestry, and drainage ditches. These practices are most often promoted in hilly areas that are likely to suffer from erosion. Therefore, much of the research on SWC is in mountainous regions – e.g., the highlands of Ethiopia (Kassie et al., 2008; Shiferaw and Holden, 1998), the mountains of Tanzania (Mbaga-Semgalawe and Folmer, 2000), or the Andes (Aad, 2006; Antle et al., 2006). In such contexts, it seems that SWC is most often adopted on soils that are sloped or perceived as eroding (Amsalu and De Graaff, 2007; Bekele and Drake, 2003; Yirga and Hassan, 2014). Additionally, Gebremedhin and Swinton (2003) suggest that SWC is most valuable and most likely to be adopted on soils that are potentially quite fertile but also highly erodible, in areas with good rainfall and therefore high potential productivity.

Conservation agriculture (CA) is an umbrella term for agricultural practices that similarly seek to mitigate soil erosion and nutrient leakage: primarily cover cropping, no till farming, intercropping, fallowing, rotation and mulching. Crop and soil scientists generally find that the yield response to CA is highest on lower fertility soils (Bayala et al., 2012; Buerkert et al., 2000; Buerkert and Stern, 1995; Buerkert et al., 1995; Sileshi et al., 2010). In a review of literature on CA adoption, Knowler and Bradshaw (2007) find that across a number of studies, farmers seem more likely to adopt CA on “highly erodible land” and less likely to adopt CA on “high-productivity” soils. This is in line with the marginal returns documented by soil scientists.

Fertilizer refers to inorganic fertilizer, often containing only nitrogen, potassium and phosphorous but sometimes including an additional mix of trace minerals. A large literature exists on the determinants of fertilizer adoption, but only two papers examine the effect of soil fertility on fertilizer adoption. Marenya and Barrett (2009b) find that the yield returns to fertilizer increase with soil organic carbon, and Marenya and Barrett (2009a) find that farmers in Kenya are more likely to adopt fertilizer on plots with higher soil organic carbon. This is, again, in line with crop and soil science research showing that better soil structure, higher levels of soil organic carbon, and increased levels of secondary micronutrients all boost the yield response to fertilizer (Kihara et al., 2016; Vanlauwe et al., 2006; Zingore et al., 2008a).

Organic amendments include any amendments that increase soil organic carbon: most often compost, crop residue, food residue, and manure. There is little evidence on the determinants of organic amendment adoption – in part because household-level surveys, even those focused on agriculture, often neglect to gather information on such amendments. However, research by Duncan et al. (2016) and Dawe et al. (2003) suggest that organic amendments contribute most to productivity on very low fertility soils, deficient in soil organic carbon. Thus, it seems likely that in many tropical contexts

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[1] An extensive body of literature examines adoption of fertilizer, but fertilizer is largely an investment in current period yields, rather than an investment in long-term soil fertility.