ARTICLE IN PRESS

World Development xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

World Development

journal homepage: www.elsevier.com/locate/worlddev

Empirical assessment of subjective and objective soil fertility metrics in east Africa: Implications for researchers and policy makers

Julia Berazneva [a,*], Linden McBride [b], Megan Sheahan [c], David Güereña [d]

[a] Department of Economics, Middlebury College, 305D Warner Hall, 303 College Street, Middlebury, VT 05753, USA
[b] Charles H. Dyson School of Applied Economics and Management, Cornell University, 410 Warren Hall, Ithaca, NY 14853, USA
[c] Precision Agriculture for Development, 32 Atlantic Avenue, Pilot House-Lewis Wharf, Boston, MA 02110, USA
[d] International Maize and Wheat Improvement Center (CIMMYT), CIMMYT South Asia Regional Office, NARC Botany Division, Khumaltar, P.O. Box 5186, Lalitpur, Nepal

ARTICLE INFO

Article history:
Available online xxxx

JEL classification:
O13
Q12
Q24
Q56

Keywords:
Natural resource management
Soil fertility
Agricultural productivity
Farmers' perceptions
Kenya
Tanzania

ABSTRACT

Bringing together emerging lessons from biophysical and social sciences as well as newly available data, we take stock of what can be learned about the relationship among subjective (reported) and objective (measured) soil fertility and farmer input use in east Africa. We identify the correlates of Kenyan and Tanzanian maize farmers' reported perceptions of soil fertility and assess the extent to which these subjective assessments reflect measured soil chemistry. Our results offer evidence that farmers base their perceptions of soil quality and soil type on crop yields. We also find that, in Kenya, farmers' reported soil type is a reasonable predictor of several objective soil fertility indicators while farmer-reported soil quality is not. In addition, in exploring the extent to which publicly available soil data are adequate to capture local soil chemistry realities, we find that the time-consuming exercise of collecting detailed objective measures of soil content is justified when biophysical analysis is warranted, because farmers' perceptions are not sufficiently strong proxies of these measures to be a reliable substitute and because currently available high-resolution geo-spatial data do not sufficiently capture local variation. In the estimation of agricultural production or profit functions, where the focus is on averages and in areas with low variability in soil properties, the addition of soil information does not considerably change the estimation results. However, having objective (measured) plot-level soil information improves the overall fit of the model and the estimation of marginal physical products of inputs. Our findings are of interest to researchers who design, field, or use data from agricultural surveys, as well as policy makers who design and implement agricultural interventions and policies.

1. Introduction

While many socio-economic factors contribute to poor crop yields across Sub-Saharan Africa (SSA), a major biophysical contributor is the depletion of soil fertility (Sanchez, 2002; Sanchez & Swaminathan, 2005; Tully, Sullivan, Weil, & Sanchez, 2015; Vanlauwe, Six, Sanginga, & Adesina, 2015). Across different agro-ecological zones in SSA, soils poor in nutrients and soil organic matter not only partially account for low yields but also limit the effectiveness of other inputs such as fertilizer and labor, and reduce farm households' resilience to external stressors and shocks (e.g., pests, crop diseases, climate change). Moreover, the direct links between soil fertility, agricultural productivity, food insecurity, and rural poverty can be self-reinforcing. Whether due to poor initial soil endowments or resource constraints that lead to low input use (fertilizers and/or organic soil amendments), the broad pattern across much of SSA is soil degradation over time (Güereña, Kimetu, Riha, Neufeldt, & Lehmann, 2016; Tittonell, Vanlauwe, Leffelaar, Rowe, and Giller, 2005). As a result, some farmers find themselves trapped in low productivity equilibria (Antle, Stoorvogel, & Valdivia, 2006; Barrett & Bevis, 2015; Shepherd & Soule, 1998; Stephens et al., 2012).

Despite the importance of soil fertility in the context of agricultural development, major barriers remain in our understanding of how farmers form perceptions about their soil fertility, and how soil fertility—subjective (reported) and objective (measured)—is related to farmers' management practices in terms of input use. Together with farmer ability, soil fertility is often unobserved by

* Corresponding author.
E-mail addresses: jberazneva@middlebury.edu (J. Berazneva), lem247@cornell.edu (L. McBride), msheahan@precisionag.org (M. Sheahan), d.guerena@cgiar.org (D. Güereña).

https://doi.org/10.1016/j.worlddev.2017.12.009
0305-750X/

Please cite this article in press as: Berazneva, J., et al. Empirical assessment of subjective and objective soil fertility metrics in east Africa: Implications for researchers and policy makers. *World Development* (2018), https://doi.org/10.1016/j.worlddev.2017.12.009

the researchers (and delegated to the error term of the econometric models). Yet both natural endowments like soil and farmer managerial abilities are highly heterogeneous and have been shown to explain the low adoption rates of agricultural inputs (Suri (2011), for example, demonstrates that heterogeneity in net returns explains the adoption patterns of hybrid maize seeds in Kenya). Without having access to detailed and reliable soil information it is impossible to assess the contribution of heterogeneous soil fertility to agricultural production, both in terms of crop yields and farmer management decisions.

A confounding factor in this relationship stems from the fact that heterogeneity in soil fertility occurs both at high and low spatial scales (Hengl et al., 2015; Tittonell, Vanlauwe, Leffelaar, Shepherd, & Giller, 2005). More is known about the heterogeneity at larger (e.g., provincial and up) scales where the sources of heterogeneity include underlying geological material, agroecological zone, and biome (e.g., rainforest, savannah, desert). Modern geospatial tools coupled with historic surveys have provided this information. What is less known is how this heterogeneity changes at increased spatial resolutions as the influence of human management decisions alters the underlying biophysical soil conditions. These include land-use change (e.g., clearing of forests for agriculture) (Recha et al., 2013), historic cropping patterns and input use (Chivenge, Vanlauwe, & Six, 2011), cropping intensity (Güereña et al., 2016), and nutrient cycling (Vitousek et al., 2009). When integrated together, all of these things have unknown effects on the various soil parameters that constitute soil quality and fertility.

A paucity of research directly examines the relationship between soil fertility and existing farm management practices, especially in SSA. Agronomic studies that have precise measures of soil fertility and yields often ignore farmers' behavioral responses (see, for example, Chivenge et al. (2011)), while economic studies fail to account for soil fertility in estimation of agricultural profits and farmer welfare, at best including indicator proxy variables for soil fertility (e.g., Duflo, Kremer, and Robinson (2008), Sheahan, Black, and Jayne (2013)). Only a few studies with access to precise measures of soil fertility analyze farmers' knowledge of land quality and within-farm variability in resource allocation and yields (e.g., Tittonell, Vanlauwe, Leffelaar, Rowe, et al. (2005)). Therefore, in this paper, we attempt to bring together emerging lessons from the biophysical and social sciences as well as newly available data to take stock of what we can learn about the relationships among subjective (farmer-reported) and objective (researcher-measured or estimated) soil fertility and farmers' management practices.

Several other studies have examined these relationships, with mixed results. Cross-sectional data from the World Bank's Living Standards Measurement Study-Integrated Survey in Agriculture (LSMS-ISA) across six different countries, for example, suggest that farmers in SSA do not significantly vary input application rates according to perceived soil quality (Sheahan & Barrett, 2017). At the same time, evidence from Kenya indicates that farmers apply fewer external inputs on soils with objectively verified low soil carbon content (Marenya & Barrett, 2009a), and adjust planting timing and weeding intensity on plots with different land quality (Tittonell, Vanlauwe, Leffelaar, Shepherd, et al., 2005).

In order to better understand these empirical observations, we identify the input and output correlates of farmers' perceptions of soil fertility, and assess whether farmers' perceptions correlate with objective laboratory measurements of soil fertility characteristics. We also explore the extent to which publicly available geospatial soil data, estimated via sophisticated interpolation methods from point observations across the African continent, are adequate to capture local soil chemistry realities at the household, village, and data set levels. Such data sets are an incredible resource and their availability may obviate the need for detailed on the ground soil data collection, saving researchers, agricultural organizations, and governments both time and money. This exercise allows us to make recommendations to the broader research community about the relative trade-offs inherent in relying on one soil metric over another. Finally, we assess the role of soil information from a research standpoint by interchanging various soil metrics in a production function approach to the analysis of yields.

In particular, we address the following four research questions:

1. What can we learn from household survey data about the determinants of farmers' soil fertility perceptions? Do agricultural inputs and outputs vary with perceived soil quality and soil type?
2. To what extent do farmers' subjective perceptions of soil quality and type correlate with objective laboratory measurements of soil chemical fertility? In addition, can we identify any observable plot or household level characteristics that are correlated with farmers' soil quality perceptions?
3. Can new high-resolution and publicly available geo-spatial soil fertility data sets provide insight into the levels and variation of local (household, village, and data set level) soil fertility such as would obviate the expensive and time-consuming collection of detailed plot-level data?
4. What is the role of soil (mis)information in farmers' and researchers' estimation of yields and returns to fertilizer?

To answer these questions, we rely on three data sets that correspond with a small number of maize farming households in western Kenya and two data sets that correspond with a nationally representative sample of maize farmers in Tanzania. In both study regions, farmers' perceptions of soil quality[1] and their agricultural practices are drawn from household survey responses. Global positioning system (GPS) coordinates allow us to match these households with publicly available geo-referenced soil data at 250-meter spatial resolution from the Africa Soil Information Service (AfSIS) (Hengl et al., 2015). In western Kenya, additional laboratory measures of plot-level soil fertility are obtained from soil analyses based on the resource- and time-intensive collection of soil samples (Berazneva, Lee, Place, & Jakubson, 2017). Apart from geographic differences, both the Kenya and Tanzania data sets also offer different contexts in terms of data collection efforts: the Kenya data are from a small-scale detailed survey, while the Tanzania data are from a nationally representative large-scale project. Combining the two geographic locations allows us to compare across the contexts, provide limited external validity to our findings, and offer recommendations to researchers on soil data collection and use.

Our contributions are twofold. First, we evaluate three potential sources of soil information: farmer-reported perceptions, plot-level measurements, and geo-referenced soil data. Second, we provide some initial evidence as to whether the variation in inputs and crop yields can be explained by soil information. Our results offer evidence of correlation between farmer perceptions of soil quality and soil type with crop yields but no clear correlation with inputs. We also find that, in Kenya, farmer-reported soil type (soil texture) is a reasonable predictor of several objective soil fertility indicators drawn from plot-level measurements while farmer-reported soil quality is not. In addition, we find that the differences between the two objective soil data sets that we compare in Kenya—plot-level measured soil analysis data and geo-spatial AfSIS soil

[1] The term "soil quality" was used in the household surveys in Tanzania and Kenya and refers to general farmer perceptions of soil fertility. The term "soil fertility" is used throughout this paper to either represent the specific soil chemical and physical fertility tests measured or as a general term to describe the relationship between soil attributes and crop production.

Please cite this article in press as: Berazneva, J., et al. Empirical assessment of subjective and objective soil fertility metrics in east Africa: Implications for researchers and policy makers. *World Development* (2018), https://doi.org/10.1016/j.worlddev.2017.12.009