Proxy errors with policy consequences: How common crop yield measures can bias estimates of management-based agricultural productivity gains

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Abstract

Despite the longstanding centrality of agricultural productivity growth as a development goal, reliable productivity measures remain elusive and costly. Crop yield is widely used as the primary productivity indicator, though it ignores inputs other than land and can be a poor proxy, particularly for smallholder and women farmers who are more likely to farm marginal lands and to grow multiple crops on the same plot, practices which complicate per hectare yield measurement. Crop yield is commonly calculated as a measure of production per harvested area, rather than production on the full area planted to the crop. Yet small-scale farmers are more likely to experience a loss in crop area between planting and harvesting, leading to systematic overestimation of mean crop yields so long as the null production on abandoned cropland goes unaccounted for. As a result, common yield measures may not be reliable indicators of aggregate agricultural productivity among smallholder farmers. We use plot-level data from the Tanzania National Panel Survey to investigate the conditions and crops for which the choice of yield measure might introduce significant error into crop yield estimates, and thereby bias research findings. We focus on three crops: maize, rice, and sorghum. We find that the choice of yield measure may lead to consistent under- or over-estimates of yield for sub-populations and crops that experience frequent and substantial losses in plot area between planting and harvest, with implications for the design of policy interventions to increase agricultural productivity and to target the least productive and poorest farmers.

Keywords – Agricultural productivity; Crop yield; Proxy measures; Tanzania National Panel Survey

1 Introduction

Agricultural development in Sub-Saharan Africa has long been believed to hinge upon raising the productivity of rural small-scale farmers. Agricultural productivity growth has been empirically linked to poverty reduction across a range of measures for both staple and export crops (Timmer, 1995; Datt & Ravallion, 1998; Mellor, 1999; Fan, Hazell, & Thorat, 1999; Irz et al., 2001; Thirtle et al., 2001; Minten & Barrett, 2008; Byerlee et al., 2009; Muyanga et al., 2010; Pingali, 2012). Many governments and public and private organizations have thus made it a priority to increase farm productivity, and have invested billions toward this end (Coelli & Rao, 2005; Ludena et al., 2007; Fuglie, 2008; Fuglie & Schimmelpfennig, 2010; Nin-Pratt & Yu, 2010; O'Sullivan et al., 2014; FAO, 2015; USAID, 2015; BMGF, 2015).

But reliable productivity measurement in rural subsistence farming communities remains a costly and challenging endeavor (Carletto et al., 2015a; Fermont & Benson, 2011). Various measures of crop outputs and inputs including land productivity, labor productivity, and total factor productivity can be used to assess agricultural development progress. But common crop yield – defined as a simple ratio of production weight to harvested area – is most often used as the primary productivity indicator (Fermont & Benson, 2011).

$$\text{Common crop yield} = \frac{\sum \text{Quantity harvested in kg}}{\sum \text{Area harvested in ha}}$$

The merits of this simple indicator include its relative ease of calculation and intuitive interpretation, its widespread acceptance among agronomists and agricultural policymakers, and the relative abundance of time-series data on crop production and harvested area, allowing monitoring and comparisons of yield estimates over time.

A review of recent papers from high-profile food policy and agricultural economics journals suggests that in some cases, the terms "yield" and "productivity" have come to be used interchangeably in the academic and policy discourse surrounding rural agricultural development. Further, 11 of the 25 articles on agricultural productivity in developing countries published in six agricultural economics journals in 2015 used an undefined measure of yield to proxy for farm productivity (Harris et al., 2016). This lack of specificity suggests either that readers are assumed to understand that yield is calculated based on area harvested, or that yield measurement is not dealt with precisely. But, particularly in the case of rural smallholder farm communities, common crop yield can be a poor proxy for farm productivity in terms of both the reliability of the data used to generate yield (measurement error), and the validity of the measure itself as an indicator of agricultural productivity. In this paper, we set aside questions of the validity of common crop yield as a proxy and focus on the policy implications of decisions of how to measure this common indicator for agricultural productivity.

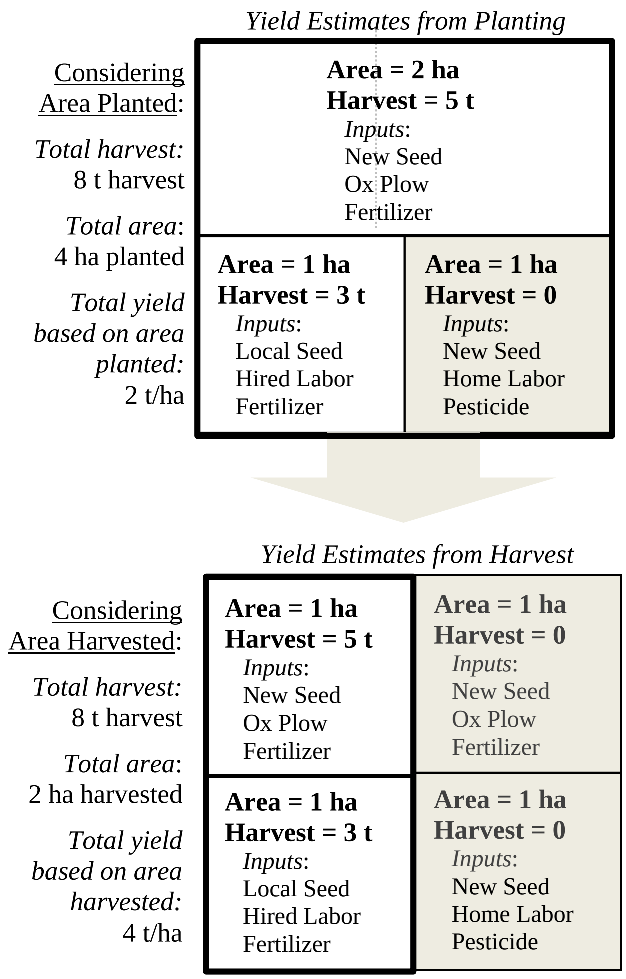
2 Implications of yield measure choice

Common crop yield calculations are often based on rough estimates of production and area harvested, and are subject to several sources of measurement error, including the presence of intercropping and crop mixing practices where farmers plant multiple crops on one plot (Golenko et al., 2013), challenges in accurate area measurement (De Groote & Traoré, 2005; Fermont & Benson, 2011; Carletto, Savastano, & Zezza, 2013; Carletto et al., 2015a, 2015b), unit conversion for area and quantity estimates (Fermont & Benson, 2011; Carletto et al., 2015a, 2015b), and, for measures based on household survey data, reliance on farmer recall estimates of area and quantity harvested (Beegle et al., 2012). In addition, plot area harvested may be smaller than plot area planted due to poor germination, damage from pests or disease, floods, labor constraints, or lack of market opportunities (Kaminski & Christiaensen, 2014) – all common circumstances for small scale farmers, and of prominent importance to the choice to denominate the yield calculation by area planted versus by area harvested.

Our goal is to understand measurement error with consequences by analyzing whether the choice of yield measure leads researchers to consistently under- or over-estimate yield for certain sub-populations. Inconsistent yield estimates present many challenges in designing appropriate policy interventions and distributing resources. Of greatest concern is when errors in common crop yield measures are not random, but rather result in biased yield estimates – particularly for low-productivity smallholder farmers, who are most likely to cultivate irregular marginal plots and to experience losses in cropping area during the growing season (Fermont & Benson, 2011), or for women farmers, who are more likely to engage in intercropping practices poorly captured by yield measures (Golenko et al., 2013).

In cases where smallholder farmers experience a loss in crop area between planting and harvesting, e.g., crop failure on some areas or some entire plots, overestimates of mean crop yields are likely so long as the null production on abandoned cropland goes unaccounted for. As a result, common yield measures may not be reliable indicators of aggregate agricultural productivity, but might rather be more accurately seen as measures of "productivity among the productive." The least productive plots – those with no area harvested – are omitted from the calculations.

Figure 1. How common yield measures can misrepresent mean yield and bias marginal yield gain estimates. (Hypothetical example: A farmer plants 4 hectares of crop, 2 hectares fail and are not harvested.)



Bias in Marginal Yield Gain Estimates: W*hen considering production per area planted (top) the "best combination" is local seed/hired labor/fertilizer, which offers a mean yield of 3 t/ha [planted] which is higher than 2.5 t/ha [planted] from the new seed/ox plow/fertilizer combination. However, when considering production per area harvested (common yield, bottom) the "best combination" appears to be new seed/ox plow/ fertilizer, with 5 t/ha [harvested]. Ignoring the failed crop plots results in biased estimates of management-based yield gains.*

In this paper, we compare yield calculated by area planted and by area harvested in order to investigate for which crops and conditions the exclusion of area losses from yield calculations might introduce significant error into estimates, and thereby bias research findings based upon those yield estimates. We focus on three crops, namely maize and rice—important subsistence and market crops—and sorghum—an important subsistence crop (Rowhani et al., 2011; Arce & Caballero, 2016). Since productivity estimates are characterized by significant spatial and temporal variation, we focus on the case of smallholder farming in Tanzania. Detailed plot-level data from the 2012 Tanzania National Panel Survey (TNPS) allow us to explore variation in smallholder crop yields using two alternate methods of calculating plot-level yield over time. Though area loss between planting and harvest may be infrequent in field trials, farmers in the TNPS frequently report harvesting less area than planted due to drought, rains, fire, insects, animals, crop theft, diseases and community problems, lack of labor, and other factors, and yield estimates between the two measures differ substantially.

Our research question is, "Does the choice of yield measure change conclusions about agronomic and policy recommendations for improving small-scale farmer productivity?" The answer appears to be an unequivocal "Yes." For example, comparing plots owned by households with total daily consumption under $1.25/day per adult and wealthier households we find that differences between yield by area planted and yield by area harvested are significantly larger for plots owned by poorer households where maize was cultivated, but significantly smaller for plots owned by these households where sorghum was cultivated. We also find significant differences on plots where rice was cultivated between households that cultivated less than 2 hectares in total and households that cultivated more and between female-headed and male-headed households. For efforts directed toward these subpopulations, there may be a need to better specify "yield" to more effectively guide agricultural development efforts.

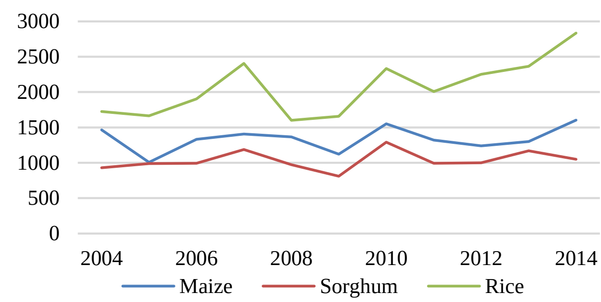
3 Smallholder crop yield in Tanzania

In 2010, maize was the most commonly planted crop—measured by area planted—in Tanzania. Rice production has also increased recently and is now one of the most important crops in the country (Arce & Caballero, 2016). Sorghum is especially important in the central and northwestern regions of Tanzania, which were responsible for over 40% of overall sorghum production in Tanzania from 1992-2005 (Rowhani et al., 2011). All three crops are important subsistence crops in Tanzania, while maize and rice are also important market crops.

Estimated national average estimates of common crop yield for maize, sorghum, and rice in Tanzania for 2004 to 2014 are shown in Figure 2. While yields of maize and sorghum have been relatively constant over the last ten years, there seems to have been a slight increase in rice yield in the last few years. This trend was forecast to continue through 2016 due to favorable climactic conditions (NMB, 2016).

Climatic and socioeconomic factors affect the yield of cereal crops in Tanzania. Gibbon et al. (2007) find low soil fertility, low soil nitrogen, droughts, and weeds

Figure 2. Crop yields in Tanzania (kg/ha)



Source: FAOSTAT, 2016

contribute to decreases in maize and sorghum yield in Africa. Sileshi et al. (2010), in a meta-review of articles examining maize yields, similarly find that fertilizer application improves maize yield and that soil type is important in determining yield, especially when no soil fertility management inputs are used.

Waddington et al. (2010) surveyed more than 670 experts in an attempt to quantify the significance of various constraints associated with yield loss for six different crops across a number of different farming systems. In Sub-Saharan Africa, the authors find that socioeconomic factors, including high seed prices, labor shortages, and other market failures, are responsible for 38 and 51 percent of rice yield loss in two farming systems common in Africa, and for 15 to 30 percent of sorghum yield loss, depending on the farming system. They further find that abiotic factors are responsible for between 25 and 32 percent of sorghum yield losses, while biotic factors are responsible for between 18 and 28 percent of yield loss. Seed selection may also affect yields: one experiment in Tabora, Tanzania, found that the use of an improved variety almost doubled sorghum yields (Bucheyeki et al., 2010).

In a survey of farmers in Tanzania, Mghase et al. (2010) find that farmers blame rice losses on diseases, pests, and poor inputs. In addition, they report challenges with insufficient access to water and the underutilization of fertilizer. The latter can be especially important, as the soils are potentially low in nitrogen. An additional study found that improved weed management, in particular, could increase rice yields and, presumably, decrease area losses (Nhamo et al., 2014). However, Giller et al. (2011) stress that any potential interventions to increase yields must also address socioeconomics constraints and the specific contexts in which farmers operate.

Because socioeconomic factors, in addition to environmental factors, have been found to contribute to yield loss, there is reason to believe that the choice of yield measure may substantively affect conclusions regarding the drivers of crop yield. Productivity-enhancing interventions that seek to address yield constraints may be designed based on biased estimates of yield determinants. Since smallholder and women farmers are more likely to experience area loss between planting and harvesting, this may prevent policy interventions from effectively targeting the most vulnerable populations.

4 Data and methods

4.1 Survey design

Our analysis uses detailed plot-level data from the Tanzania National Bureau of Statistics National Panel Survey (TNPS), conducted in conjunction with the World Bank's Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA). The TNPS relies on a multi-stage stratified random sample where the primary sampling unit is the enumeration area (EA). The sample consists of eight administrative zones, each with a rural and an urban cluster, for a total of 16 sampling strata. EAs are based on the 2002 Census and eight households per EA were randomly selected to participate in the survey. Agricultural households completed an additional questionnaire covering farm characteristics. The survey data is representative at the national, urban/rural, and agro-ecological zone levels, however, sample size limitations preclude reliable statistics at the regional or district level.

We use the latest of 3 survey panels in our analysis, which includes all members of original panel households. Panel 3 includes 3300 agricultural households, surveyed between October 2012 and November 2013 about the 2012 growing season. Agricultural households each cultivated between one and 12 plots in each year, and we trimmed the top 1 percent of plots for both yield by area planted and yield by area harvested to eliminate potential outliers. This trimming resulted in a total sample size of 2773 maize plots, 733 rice plots, and 301 sorghum plots.

4.2 Regression analysis and methods

We aim to understand how yield measurement methodology might impact both mean yield estimates and also shape explanations of yield drivers. We calculate area planted by multiplying the reported size of the plot and the proportion that was planted with the crop in question (100%, 75%, 50% or 25%). Farmers directly reported the area harvested. Some observations therefore have differences between area planted and area harvested due to reporting differences rather than actual area differences. Where farmers reported harvesting more area than planted, area harvested was capped at total area planted. Quantities harvested were collected based on farmer estimations of weight. These estimates are an imperfect but empirically-accepted measures of quantity.

Based on area values we calculated crop yield for each crop on each plot two ways: first, using the quantity harvested divided by the area harvested and then using the quantity harvested divided by the area planted. Based on the literature review on yield constraints, we include a variety of variables meant to measure abiotic, biotic, management, and socioeconomic constraints, together with district-level control variables, in our yield regression analyses. We compared two models for each crop and survey panel. Model 1 is an ordinary least squares regression on yield by area harvested and Model 2 uses the same independent variables suggested by the literature review, but regresses on yield by area planted. We next run the same models for subsamples of plots owned by smallholder farms with two hectares (ha) or less of cultivated area, and for plots owned by households with more than 2 ha of cultivated area. Certain variables found to be important in earlier literature were excluded from the regression due to insufficient observations or unavailability of data. These include access to credit, weeds, and input prices.

4.3 Description of the sample

Table 1 presents summary statistics for our sample in 2012. The first two columns correspond to plots planted with maize, the third and fourth columns correspond to plots planted with paddy rice, and the last two columns correspond to plot planted with sorghum. A relatively large portion of the sample—for all crops—reports facing substantial abiotic constraints. For example, fewer than 40 percent of households cultivating all three types of crops face no or only slight soil nutrient and workability constraints. It is clear from our sample that relatively few households used any type of fertilizer or pesticides/herbicides. While 16 percent of maize plots received some inorganic fertilizer, fewer than ten percent of plots of all crops received any pesticide or herbicide, and fewer than ten percent of paddy rice and sorghum crops received any inorganic fertilizer. Use of improved seeds varies by crop and is more common for maize (39 percent of plots) than for rice plots (18 percent) or sorghum (10 percent).

More than half of maize and sorghum plots are intercropped, compared to just 15 percent of rice plots. Rice plots received more days of hired labor per hectare on average (23.46) than maize plots (8.54) or sorghum plots (4.88), which may be related to the greater likelihood of rice sales among households with rice plots, compared to households with maize or sorghum plots.

Appendix A presents cross-tabulations of area loss across subsamples of farmers who may be particularly susceptible to area loss between planting and harvest. The top panel tabulates whether the plot faced any area loss by whether the household is a smallholder household (cultivated less than two hectares in total) or not. Three separate cross-tabulations are performed, one for each crop, and a Pearson's chi-squared test is performed for each. The results suggest that the probability of suffering any area loss is significantly correlated ($p<0.10$) with being a smallholder farmer for maize, but not for rice or sorghum.

The second panel tabulates area loss by whether the household head was female or male. The results of the chi-squared tests suggest that the gender of the household head is correlated with the probability of suffering a loss for both maize ($p<0.01$) and sorghum ($p<0.10$).

Finally, the bottom panel tabulates area loss by whether the household was below the poverty line of $1.25 per day of total consumption per adult equivalent. Being below the poverty line is significantly correlated with the probability of facing any area loss for all three crops.

These preliminary results suggest that household characteristics are correlated with area loss between planting and harvest, reinforcing the importance of thoroughly considering the choice of land area in yield measures.

Table 1. 2012 Summary Statistics

Plot-Level Characteristics – 2012

	Maize		Rice		Sorghum	
	mean (sd)	min /max	mean (sd)	mean (sd)	min /max	mean (sd)
Yield by area planted (kg/ha)	737.66	0	1351.13	0	391.91	0
	(763.47)	5765.79	(1465.46)	9884.21	(386.13)	2223.95
No to slight soil nutrient constraints	0.38	0	0.30	0	0.38	0
	(0.49)	1	(0.46)	1	(0.49)	1
No to slight soil workability constraints	0.47	0	0.59	0	0.36	0
	(0.50)	1	(0.49)	1	(0.48)	1
Average annual temp (C)	21.78	15	23.98	20	22.63	18
	(2.42)	27.60	(1.64)	27.80	(1.67)	27.60
Rainfall at least 50mm above 10-year average	0.49	0	0.52	0	0.71	0
	(0.50)	1	(0.50)	1	(0.46)	1
Rainfall at least 50mm below 10-year average	0.18	0	0.24	0	0.15	0
	(0.39)	1	(0.43)	1	(0.36)	1
Planted improved variety seeds on plot	0.39	0	0.18	0	0.10	0
	(0.49)	1	(0.39)	1	(0.30)	1
Used pesticide or herbicide on plot	0.08	0	0.12	0	0.03	0
	(0.27)	1	(0.32)	1	(0.17)	1
Used inorganic fertilizer on plot	0.16	0	0.12	0	0.03	0
	(0.37)	1	(0.32)	1	(0.18)	1
Cultivation intercropped	0.63	0	0.15	0	0.58	0
	(0.48)	1	(0.36)	1	(0.49)	1
Consecutive years plot left fallow the last time it was fallowed	0.06	0	0.07	0	0.07	0
	(0.36)	12	(0.34)	3	(0.39)	4
Farmer-reported plot area, hectares	1.12	0.04	1.11	0.04	1.22	0.04
	(2.30)	52.61	(2.02)	40.47	(2.22)	40.47
Total number of plots cultivated by the household	2.86	1	2.82	1	2.65	1
	(1.67)	12	(1.31)	9	(1.31)	10
Household used ox plough, planter, or cart	0.32	0	0.34	0	0.43	0
	(0.47)	1	(0.48)	1	(0.50)	1
Days of household labor per hectare for this plot	132.00	0	198.97	0	120.37	5
	(181.03)	3336	(200.12)	1705	(115.91)	1112
Days of hired labor days per hectare for this plot	8.54	0	23.46	0	4.88	0
	(21.10)	257	(54.02)	914	(12.52)	131
Household received agricultural extension advice[a]	0.12	0	0.11	0	0.11	0
	(0.32)	1	(0.31)	1	(0.31)	1
Crop was sold by the household	0.35	0	0.56	0	0.22	0
	(0.48)	1	(0.50)	1	(0.41)	1
Female head of household	0.23	0	0.21	0	0.25	0
	(0.42)	1	(0.41)	1	(0.44)	1
Age of household head	49.35	19	49.05	20	49.43	20
	(15.65)	93	(15.07)	108	(15.38)	108
Education of household head (years)	5.04	0	4.92	0	4.34	0
	(3.26)	18	(3.33)	17	(3.32)	12
Daily per capita consumption (USD)	1.84	0	1.93	0	1.38	0
	(1.27)	12.50	(1.30)	11.43	(0.87)	8.37
Total area cultivated by the household on all plots (ha)	2.44	0	2.76	0	2.45	0
	(4.55)	110.88	(4.90)	89.84	(3.16)	40.47
Household in Zanzibar	0.005	0	0.07	0	0.01	0
	(0.04)	1	(0.26)	1	(0.07)	1
Observations	2773		733		301	

Observations are at the plot level. As such, household-level variable (e.g. “Female head”) can be interpreted as the characteristics of the household that owns the plot.

[a] Sources include government, NGOs, coops, and other farmers.

5 Regression results

Results of regression analysis are shown in Tables 2 (maize), 3 (rice), and 4 (sorghum). Maize plots constitute the majority of the sample and thus provide the most predictive power. Use of inorganic fertilizer is a significant predictor of higher yield in all models, but with a larger magnitude in models of yield by area harvested. On the other hand, size of the plot was much more strongly related to yield by area planted than area harvested. Household and hired labor use is also significantly associated with yield in many models, and more so for plots of smallholder farmers, suggesting that labor constraints may be especially severe on smallholder farms. This is reinforced by the non-significant finding that plots of farms headed by smallholder farms experience smaller yields as the number of plots on the farm increases, to a greater extent than do plots in larger farms. Selling maize has a significant positive relationship with yield in all models, as does use of ox implements in most models. Intercropping maize is associated with lower maize yield for plots on large farms, but surprisingly less so for plots on small farms. Conversely, receiving extension advice is associated with higher maize yields only for smallholder plots. Soil nutrient availability and workability show little relationship to maize yield by either measure.

Rice plots make up a smaller sample but are common in certain regions of the country such as Zanzibar. Use of improved variety seed is significantly associated with lower yield in several models, especially for smallholder plots and when yield is calculated by area harvested. Intercropping is also related to lower yields. Use of household and hired labor is associated with higher yields in most models, including for smallholder plots. Finally households that sold rice tend to have higher yields, especially among smallholder households.

For sorghum plots, sample sizes are quite small, limiting predictive power. Plots with good nutrient availability tend to have significantly lower sorghum yields on smallholder farms, which may indicate that higher-quality sorghum plots tend to be intercropped, complicating productivity measurement. Use of household labor has a significant positive relationship with both yield measures in the smallholder models, again suggesting that labor may be a substantial constraint for smallholder farmers in Tanzania. Use of pesticide and herbicide is associated with significantly higher yields on non-smallholder plots only, though agrochemical use is very low among smallholders. Fallowing sorghum plots has a similar relationship – significantly tied to higher yields on non-smallholder plots, but not smallholder plots. Sorghum plots in households headed by women have significantly lower yields in several models. Finally, plots of households that received extension advice have significantly higher yields in the area planted models, which indicates that the exclusive use of the yield by area harvested measure may underestimate the relationship of agricultural extension programs to sorghum yield gains. In contrast to maize and rice, selling sorghum is not significantly associated with either yield measure, perhaps because sorghum is less frequently marketed than other cereal crops.

6 Conclusions

Small scale farmers in Tanzania regularly harvest yields far below the world average. To increase production, yield constraints must be accurately identified and remedied. The choice of crop yield measure provides different estimates of mean agricultural productivity, and analyses based on those different results will lead to different conclusions regarding factors that explain yield variability.

In our sample of Tanzanian farmers, over a third of plots experienced area loss between planting and harvest. We find that considering only yield calculated by area harvested and relying exclusively on mean estimates that belie heterogeneity among subpopulations conceals several patterns in the data that could inform policy interventions. For example, fertilizer use is more closely related to maize yield by area harvested while plot area is more closely related to yield by area planted, suggesting that use of the area harvested measure may overstate the need for soil fertility interventions and understate time and labor constraints present on larger plots.

When yield determinants are examined separately for vulnerable groups like smallholder farmers, a strong relationship between labor availability and yield is apparent for all crops, pointing to an opportunity for labor-saving, -sharing, or -provision interventions to improve yields among small farmers. Further, receipt of extension is associated with higher sorghum and maize yield only among smallholders, indicating that dissemination of knowledge and farming best practices may be particularly important to achieve successful smallholder yields

These findings suggest value in better specified yield measures in published findings, with yield by area planted potentially offering a more accurate indication of where investments are most likely to improve smallholder productivity.

Table 2. Maize Regression Results	**All Plots**		**Smallholder (<= 2ha)**		**Non-Smallholder**	
	Yield by area planted	Yield by area harvested	Yield by area planted	Yield by area harvested	Yield by area planted	Yield by area harvested
	β (se)	β (se)	β (se)	β (se)	β (se)	β (se)
No to slight soil nutrient constraints	59.32	87.40	33.67	-69.41	133.18	368.27***
	(71.85)	(98.86)	(99.75)	(117.55)	(85.79)	(116.42)
No to slight soil workability constraints	87.79	112.79	47.60	27.47	145.69	220.68
	(54.42)	(98.28)	(66.30)	(114.66)	(96.04)	(153.79)
Improved (new or recycled) variety maize planted on plot	52.00	-48.52	32.99	-125.18	144.21**	67.31
	(37.38)	(57.22)	(40.60)	(79.26)	(60.57)	(90.15)
Used pesticide or herbicide on plot	10.27	155.35	149.02	210.79	-85.71	104.08
	(96.77)	(138.20)	(138.20)	(153.98)	(143.33)	(228.01)
Used inorganic fertilizer on plot	262.15***	359.16***	252.83**	359.56**	252.10**	348.95**
	(76.69)	(106.88)	(97.13)	(162.52)	(99.83)	(134.52)
Cultivation intercropped	-104.27***	-102.80*	-56.93	-11.15	-169.51***	-222.67***
	(39.29)	(56.47)	(55.60)	(76.63)	(54.00)	(79.75)
Consecutive years plot left fallow the last time it was fallowed	-34.79	-40.09	-4.79	26.80	-86.00	-106.23*
	(36.41)	(48.54)	(36.87)	(91.39)	(66.35)	(61.97)
Farmer-reported plot area (ha)	-23.39***	-8.91	-166.34***	7.50	-13.13***	-3.75
	(7.64)	(9.66)	(63.26)	(106.72)	(4.94)	(6.94)
Total number of plots cultivated by the household	-18.61	-20.00	-37.50	-63.54*	15.64	54.50
	(16.40)	(19.57)	(26.97)	(36.04)	(23.49)	(33.95)
Household used ox plough, planter, or cart	80.16*	282.06**	65.65	221.83*	144.06**	395.40*
	(46.20)	(114.40)	(54.41)	(127.23)	(64.63)	(202.27)
Days of household labor per hectare for this plot	0.90***	0.76***	0.84***	0.79***	0.48*	0.17
	(0.11)	(0.14)	(0.14)	(0.17)	(0.28)	(0.33)
Days of hired labor days per hectare for this plot	2.73**	2.20*	3.22***	3.57**	2.04	-0.01
	(1.06)	(1.22)	(1.19)	(1.49)	(1.43)	(1.79)
Household received agricultural extension advice	110.97	99.39	229.97**	226.14*	38.40	-83.35
	(70.79)	(97.14)	(106.05)	(115.94)	(88.93)	(158.89)
Crop was sold by the household	339.54***	360.23***	347.47***	355.13***	310.86***	356.30***
	(40.17)	(59.29)	(57.89)	(87.29)	(59.64)	(101.65)
Female head of household	-62.80	-103.04*	-90.01*	-131.43	-113.12	-77.03
	(37.92)	(60.13)	(46.64)	(81.16)	(71.93)	(103.84)
Age of household head (years)	-1.78	-1.49	-1.94	0.69	-3.04	-8.28*
	(1.12)	(1.93)	(1.69)	(2.89)	(2.04)	(4.18)
Education of household head (years)	9.76*	20.21**	2.88	27.92**	9.75	4.67
	(5.85)	(9.36)	(7.10)	(13.32)	(8.65)	(17.84)
Daily per capita consumption (USD)	37.31**	54.33*	33.44	48.85	25.73	56.53
	(14.86)	(29.41)	(23.05)	(32.51)	(27.69)	(52.39)
Total area cultivated by the household on all plots (ha)	4.87	3.09				
	(4.07)	(5.10)				
Constant	432.08***	593.88***	643.74***	657.98***	362.58**	661.98***
	(76.53)	(166.41)	(116.34)	(223.94)	(154.92)	(228.53)
Observations	2791	2791	1597	1597	1195	1195
Adjusted R^2	0.273	0.226	0.309	0.224	0.255	0.291

Table 3. Rice Regression Results	**All Plots**		**Smallholder (<= 2ha)**		**Non-Smallholder**	
	Yield by area planted	Yield by area harvested	Yield by area planted	Yield by area harvested	Yield by area planted	Yield by area harvested
	β (se)	β (se)	β (se)	β (se)	β (se)	β (se)
No to slight soil nutrient constraints	-124.11	-225.79	37.48	-78.73	-139.31	-328.80
	(178.71)	(172.65)	(258.18)	(275.15)	(146.83)	(264.38)
No to slight soil workability constraints	191.17	295.64	509.54**	423.85	-22.69	203.82
	(177.58)	(187.33)	(245.60)	(282.87)	(346.58)	(376.36)
Improved (new or recycled) variety rice planted on plot	-242.26	-450.17**	-446.86*	-648.74**	-25.70	-512.35*
	(162.42)	(193.02)	(268.01)	(307.02)	(214.64)	(263.67)
Used pesticide or herbicide on plot	202.70	246.56	365.84	420.67	-95.98	-171.95
	(328.19)	(323.90)	(361.83)	(379.80)	(526.56)	(550.79)
Used inorganic fertilizer on plot	73.72	287.59	163.59	180.65	11.96	444.84
	(295.31)	(353.22)	(461.14)	(519.89)	(400.46)	(495.57)
Cultivation intercropped	-411.29**	-559.78***	-222.83	-428.39	-129.46	-552.41*
	(175.74)	(192.64)	(148.12)	(309.98)	(288.48)	(312.43)
Consecutive years plot left fallow the last time it was fallowed	-282.97*	-326.14	-329.37	-213.65	-496.38***	-622.59
	(153.23)	(197.37)	(324.91)	(345.82)	(164.19)	(391.39)
Farmer-reported plot area (ha)	-44.68*	7.55	-383.41	-146.28	-51.55	-6.59
	(23.98)	(23.80)	(294.29)	(375.12)	(34.92)	(32.80)
Total number of plots cultivated by the household	-68.52	-39.71	-145.54	-146.38	-78.47	-107.30
	(51.11)	(43.00)	(106.10)	(122.64)	(76.81)	(92.13)
Household used ox plough, planter, or cart	94.57	51.87	-466.12	-335.20	879.37**	605.31
	(260.15)	(294.93)	(384.41)	(399.53)	(334.94)	(429.09)
Days of household labor per hectare for this plot	1.98***	1.52***	1.45***	1.16**	2.82***	2.59**
	(0.40)	(0.45)	(0.49)	(0.56)	(0.94)	(1.26)
Days of hired labor days per hectare for this plot	4.91***	4.04**	3.69**	3.48*	7.28	4.80
	(1.77)	(1.61)	(1.81)	(1.84)	(5.28)	(6.13)
Household received agricultural extension advice	211.17	370.51	482.02	416.00	-147.79	330.62
	(294.80)	(372.78)	(410.91)	(449.91)	(394.02)	(683.40)
Crop was sold by the household	739.19***	652.79***	984.11***	1032.23***	278.03	160.07
	(193.78)	(195.85)	(309.69)	(337.51)	(288.05)	(296.53)
Female head of household	-140.21	-138.82	-330.62	-252.14	333.08	380.94
	(173.48)	(205.30)	(263.11)	(304.09)	(392.42)	(467.09)
Age of household head (years)	2.91	4.78	-3.96	-0.07	-0.15	-0.50
	(5.82)	(6.45)	(5.38)	(7.02)	(7.96)	(10.25)
Education of household head (years)	-11.21	-9.52	-56.51**	-60.23*	22.19	47.74
	(16.21)	(19.92)	(27.23)	(33.38)	(36.11)	(35.22)
Daily per capita consumption (USD)	42.62	44.59	71.90	72.05	94.09	67.70
	(60.33)	(68.59)	(82.22)	(89.22)	(121.50)	(137.04)
Total area cultivated by the household on all plots (ha)	-7.00	-12.31				
	(10.93)	(16.11)				
Constant	511.80	718.45*	1197.56**	1259.56**	421.80	1017.72
	(351.61)	(427.80)	(476.17)	(599.22)	(689.54)	(842.05)
Observations	734	734	446	446	288	288
Adjusted R^2	0.375	0.319	0.551	0.483	0.394	0.256

Table 4. Sorghum Regression Results	**All Plots**		**Smallholder (<= 2ha)**		**Non-Smallholder**	
	Yield by area planted	Yield by area harvested	Yield by area planted	Yield by area harvested	Yield by area planted	Yield by area harvested
	β	β	β	B	β	β
	(se)	(se)	(se)	(se)	(se)	(se)
No to slight soil nutrient constraints	-13.28	-224.03	-186.73**	-373.49***	156.12	10.66
	(131.59)	(178.47)	(84.94)	(126.34)	(163.17)	(191.04)
No to slight soil workability constraints	12.43	-76.24	31.84	-106.96	-151.26	-107.98
	(84.73)	(130.52)	(116.51)	(155.92)	(174.91)	(227.91)
Improved (new or recycled) variety	32.20	35.06	27.69	35.16	23.23	-117.37
sorghum planted on plot	(61.61)	(94.80)	(120.67)	(165.82)	(110.91)	(231.76)
Used pesticide or herbicide on plot	62.71	118.20	-104.94	-216.54	350.59**	537.88**
	(192.28)	(301.74)	(379.54)	(555.09)	(147.12)	(222.38)
Used inorganic fertilizer on plot	-11.03	332.09	9.89	179.09	151.03	714.06*
	(132.44)	(300.27)	(239.23)	(243.37)	(98.78)	(375.73)
Cultivation intercropped	-10.84	-155.83	-132.49	-205.36**	17.05	-242.84
	(54.57)	(102.20)	(103.49)	(90.35)	(123.06)	(244.06)
Consecutive years plot left fallow the last	72.26	-7.74	2.61	-66.80	1175.85**	1385.88**
time it was fallowed	(97.60)	(124.99)	(88.63)	(149.04)	(443.81)	(625.13)
Farmer-reported plot area (ha)	-6.50	-12.52	-44.70	51.26	-15.74	-10.24
	(18.89)	(21.68)	(196.45)	(207.74)	(9.44)	(15.11)
Total number of plots cultivated by the	-5.40	-5.89	40.05	136.49	-20.82	-48.57
household	(21.53)	(45.90)	(39.96)	(94.85)	(27.17)	(50.06)
Household used ox plough, planter, or	108.51	168.97	179.33	321.29*	-6.61	15.89
cart	(131.23)	(147.57)	(251.75)	(180.34)	(92.11)	(167.17)
Days of household labor per hectare for	0.92**	0.88*	1.31**	1.48**	0.18	0.17
this plot	(0.41)	(0.44)	(0.65)	(0.68)	(0.15)	(0.32)
Days of hired labor days per hectare for	1.70	1.54	1.81	2.15	1.89	1.15
this plot	(1.31)	(1.89)	(2.48)	(3.69)	(2.38)	(3.08)
Household received agricultural	355.79**	210.66	655.81**	394.91	182.17*	-62.64
extension advice	(167.35)	(205.58)	(265.77)	(352.32)	(96.42)	(216.50)
Crop was sold by the household	103.36	-3.01	-12.02	-186.94	23.41	-90.52
	(81.85)	(113.54)	(92.67)	(132.34)	(90.31)	(228.58)
Female head of household	-84.29	-188.91**	-194.02**	-316.02***	90.95	114.54
	(62.56)	(86.69)	(82.38)	(106.00)	(105.12)	(140.70)
Age of household head (years)	0.36	0.11	0.37	2.95	1.89	-1.52
	(1.15)	(2.40)	(2.73)	(4.47)	(2.37)	(4.67)
Education of household head (years)	14.63	20.36	10.15	6.87	5.75	-13.05
	(9.63)	(13.75)	(12.07)	(14.39)	(11.12)	(24.00)
Daily per capita consumption (USD)	21.76	90.61	33.90	138.36	-123.96**	-115.58
	(34.92)	(62.86)	(55.51)	(89.77)	(47.70)	(88.67)
Total area cultivated by the household on	-19.43	2.48				
all plots (ha)	(17.60)	(24.71)				
Constant	142.47	380.01*	126.75	-71.87	305.64	1037.12**
	(127.73)	(214.91)	(215.38)	(277.49)	(233.77)	(397.31)
Observations	301	301	164	164	137	137
Adjusted R^2	0.290	0.240	0.381	0.402	0.527	0.373

We intend to build on this paper by incorporating multiple panels of the TNPS household survey data and using geographical and wave fixed effects to better exploit the panel nature of the data. We will also investigate potential differences between female- and male-headed households, female- and male-managed plots, and households above and below the poverty line, to explore whether the choice of yield measure leads to significantly different recommendations for increasing yields among these sub-populations.

Calculating yield by area planted and separately considering sub-groups of farmers may offer a more accurate accounting of agricultural productivity to help prioritize investments for increasing yields of the most marginal farmers. If intervention goals include improved nutrition, higher incomes, and lower risk among all rural poor, in addition to increased crop output, then a broader set of measures covering more than just land productivity will be needed.

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Appendix A. Chi square tests for subpopulations

Smallholder farmers (total farm size 2 hectares or less)									
	Maize			Rice			Sorghum		
	No area loss	Some area loss	**Total**	No area loss	Some area loss	**Total**	No area loss	Some area loss	**Total**
Non-smallholder	828	408	1236	199	99	298	95	53	148
Smallholder	1074	618	1692	312	159	471	103	68	171
Total	1092	1026	2928	511	258	769	198	121	319
	Pearson chi2=3.87		Pr=0.05	Pearson chi2=0.02		Pr=0.88	Pearson chi2= 0.53		Pr=0.47

Female-headed households									
	Maize			Rice			Sorghum		
	No area loss	Some area loss	**Total**	No area loss	Some area loss	**Total**	No area loss	Some area loss	**Total**
Male household head	1533	754	2287	404	208	612	156	84	240
Female household head	370	272	642	107	50	157	42	37	79
Total	1903	1026	2929	511	258	769	198	121	319
	Pearson chi2=19.46		Pr=0.00	Pearson chi2=0.26		Pr=0.61	Pearson chi2=3.54		Pr=0.06

Below poverty line (Total daily consumption per adult equivalent $1.25 per day or less)									
	Maize			Rice			Sorghum		
	No area loss	Some area loss	**Total**	No area loss	Some area loss	**Total**	No area loss	Some area loss	**Total**
Above poverty line	1256	641	1897	354	157	511	96	70	166
Below poverty line	647	386	1032	157	101	258	102	51	153
Total	1903	1026	2929	511	258	769	198	121	319
	Pearson chi2=3.63		Pr=0.06	Pearson chi2=5.46		Pr=0.02	Pearson chi2=2.64		Pr=0.10