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How Common Crop Yield Measures Misrepresent Productivity among Smallholder Farmers

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Common estimates of agricultural productivity rely upon crude measures of crop yield, typically defined as the weight of a crop harvested divided by the area harvested. But this common yield measure poorly reflects performance among farm systems combining multiple crops in one area (e.g., intercropping), and also ignores the possibility that farmers might lose crop area between planting and harvest (e.g., partial crop failure). Drawing on detailed plot-level data from Tanzania's National Panel Survey, this paper contrasts measures of smallholder productivity using production per hectare harvested and production per hectare planted. Yield by area planted differs significantly from yield by area harvested, particularly for smaller farms and female-headed households. OLS regression further reveals different demographic and management-related drivers of variability in yield gains – and thus different implications for policy and development interventions – depending on the yield measurement used. Findings suggest a need to better specify "yield" to more effectively guide agricultural development efforts.

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1. Introduction

Modern agricultural development largely focuses on raising the productivity of small scale farmers. Organization mission statements and budgets reflect this priority: the Food and Agriculture Organization of the United Nations' (FAO) mandate is to "raise levels of nutrition, *improve agricultural productivity*, better the lives of rural populations and contribute to the growth of the world economy" (emphasis added), while the United States Agency for International Development (USAID) identifies increased productivity as a key to "inclusive agriculture-led growth" (USAID, 2013). And the Bill & Melinda Gates Foundation Agricultural Development Program states its core goal as "to reduce hunger and poverty for millions of farming families in Sub-Saharan Africa and South Asia by *increasing agricultural productivity* in a sustainable way" (BMGF, 2014; emphasis added). Over the past several decades governments, non-profits and others have invested billions to raise crop yields in the pursuit of productivity related goals (Conway, 2012).

But despite good intentions, common yield-based crop output measures – used ubiquitously to identify successful interventions and target needy households – are a poor proxy for smallholder farm productivity. Various measures including land productivity, labor productivity, and total factor productivity are used to measure agricultural progress (Fuglie, 2008; Alston et al., 2010). But crop yield – defined as a simple ratio of quantity harvested divided by area harvested (e.g., kg/ha) – is most often used as the primary productivity indicator (Fermont & Benson, 2011). The merits of this indicator (henceforth "common crop yield") include its relative ease of calculation and intuitive interpretation, acceptance among agronomists and agricultural policymakers, and the relatively widespread availability of time-series data on crop production and harvested area, allowing monitoring and comparisons of yield estimates over time (FAO, 2014). However this common yield measure is also known to be imperfect – both in the reliability of the data used to generate yield (measurement error), and the appropriateness of the measure itself as an indicator of agricultural productivity (measure validity).

In terms of measurement error, common crop yield estimates are often based on rough estimates of aggregate production and area harvested. The FAO database – the most widely cited source of crop yield data – is based on annual estimates of total production and total area harvested from national Ministries of Agriculture (FAO, 2014). But as recent research has emphasized, such aggregate national production estimates may be fraught with error – both statistical and political (Sandefur & Glassman, 2015; Jerven, 2014). Moreover, owing to significant variation in farming practices and growing conditions across farming systems and agro-ecological zones, national-level yield estimates may differ starkly from yields realized by any given smallholder farmer, or even by smallholders as a group (Craig et al., 1997). Smallholder yield measurement in particular is complicated by numerous land-related factors common in smallholder plots, including intercropping, harvests spread over a long time period, irregular plot shapes, and non-planted areas due to trees, stumps, anthills/termite mounds and other obstructions (Fermont & Benson, 2011; Casley & Kumar, 1988).

Meanwhile the validity of common crop yield as a measure of smallholder productivity is undermined by only capturing a single output from a single input at a particular moment in time: i.e., the weight of a given crop on a single parcel of land as measured at the end of the season (kg/ha at harvest). As highlighted in recent scholarship, overuse of this sole indicator risks under-emphasizing the value of multiple outputs and the costs associated with a host of other inputs to farm production ranging from labor to crop inputs to environmental services (Reynolds et al., 2015; Cassidy et al., 2013; Alston et al., 2010; Ehui & Pender, 2005). The measurement of output *per hectare harvested* also ignores the possibility that smallholder farmers might experience a loss in crop area between planting and harvesting, e.g., crop failure on some areas or some entire plots. Plot area harvested may also be substantially smaller than plot area planted due to poor germination, damage from pests or disease, floods, labor constraints, or lack of market opportunities – all common circumstances for small scale farmers (Fermont & Benson, 2011). In such cases, overestimates of mean crop yields are likely so long as the null production on abandoned cropland goes unaccounted for. In a sense, common measures of yield are thus not truly indicators of aggregate agricultural productivity per se, but might rather be more accurately construed as measures of "productivity among the productive." The least productive plots – those which produce no yields and thus constitute no area harvested – are omitted from common yield calculations.

In this paper, we investigate whether the failure to include area losses in common crop yield calculations might introduce significant error into smallholder crop yield estimates and thereby bias research findings based upon those estimates. In particular, does the use of "production per area planted" as a measure of crop productivity instead of "production per area harvested" change agronomic and policy recommendations for improving small-scale farmer productivity? Since productivity estimates are characterized by significant spatial and temporal variation, we focus on the specific case of smallholder rice farming in Tanzania. Rice is the second most common cereal cultivated in Tanzania behind maize, and its importance in the national diet is growing (Minot, 2010; Raes et al., 2007). Drawing on detailed plot-level data from the 2007-2008 Tanzania National Panel Surveys (NPS), conducted by the Tanzania National Bureau of Statistics with support from the World Bank's Living Standards Measurement Survey-Integrated Surveys on Agriculture (LSMS-ISA) we explore variation in long rainy season[1] rice yields using alternative yield calculations. In the presence of frequent and substantial losses in plot area between planting and harvesting, we hypothesize that analyses of factors explaining variability in common crop yield (kg/ha harvested) may be less useful than an alternative yield estimate (kg/ha planted) in designing interventions to increase agricultural productivity.

The paper is organized as follows. Section 2 summarizes challenges inherent in common crop yield measures, and outlines theoretical determinants of variability in rice yields among Tanzanian smallholders, including biotic, abiotic, management and socio-economic factors. Section 3 describes the study sample and the empirical model, and Section 4 follows with a presentation of results, including Ordinary Least Squares (OLS) regression illustrating the different conclusions arising from the same regression model using two different outcome measures from the Tanzania NPS data: total production per area harvested, and total production per area planted. The final sections summarize the main findings and conclusions.

2. Sources of Error in Common Crop Yield Measures

Common crop yield is the weight of harvested product divided by crop area harvested and is typically expressed in kilograms or metric tonnes per hectare (Fermont & Benson, 2011).

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

[1] The majority of Tanzania has one long rainy season that typically lasts from December through April. The North and Northeastern parts of the country have a long rainy season lasting from March through May and a short rainy season with lighter rainfall from October to December (Minot, N. (2010). *Staple food prices in Tanzania*. Washington, D.C. International Food Policy Research Institute).

There are, however, various methods of measuring both the numerator and the denominator of this seemingly simple equation.

Primary measures of quantity harvested include crop cutting (in which sample plots are systematically harvested by experts) and farmer estimates. While crop cutting was previously believed to be a superior method of measuring yields, Poatea (1988) followed by Boyko & Hill (2009) and Fremont & Benson (2009) cite evidence that suggests farmer estimates may be a better measure than crop cutting due to bias introduced in selecting the location for crop cutting. Fremont and Benson (2011) later also found that different disciplines may use the same terminologies when measuring crop production, but with different understandings of their definitions: sociologists, agronomists, and economists all have different uses for yield information and thus different specific yield concepts. Casley & Kumar (1988) identify at least three distinct yield measures associated with different accounting of quantity harvested: (1) *biological* (gross) *yield*, defined as yield before any harvest or post-harvest losses; (2) *harvested yield*, defined as yield subtracting harvesting losses; and (3) *economic yield*, defined as yield subtracting any harvesting or postharvest losses.

Common yield measures may contain additional error owing to intercropping and crop mixing practices, where farmers plant multiple crops on one plot (Craig et al., 1997). This poses particular problems for estimating yields on women's plots – since women in Tanzania are more likely to intercrop and also tend to plant smaller plots (EPAR, 2013). When common crop yield is calculated without accounting for density of the intercrop, yields appear lower – misrepresenting the "true productivity" of women smallholders (Cassidy et al., 2013).

In spite of such known inaccuracies in common yield measures, common yield-based data from the United Nations Food and Agriculture Organization – FAOSTAT – remain among the most commonly used data for evaluating country-level crop production trends. FAO defines crop yield as "harvested production per unit of harvested area for crop products".[2] Perhaps even more surprisingly, in spite of the widely differing accepted methods of calculating yield (as described

[2] In Tanzania, FAOSTAT data generally comes from national government statistical agencies. Tanzania's data are drawn from agricultural census information collected by the Tanzania National Bureau of Statistics (NBS) and NBS's quarterly collection of data from the Ministry of Agriculture, Food Security, and Cooperatives. Collected information relies on "eye estimation", projective-forecasting, and Food Crop Production Forecasting Sample Survey (CountrySTAT).

above) and collecting yield data (e.g., through household surveys or forecasting from simple models and field checks), in a review of 14 articles published over the past decade on the topic of rice yields in Africa, only one paper specified that it was using area harvested as the baseline for yield calculations. The others did not provide a description of how yield was measured. The 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 (see Table 1).

[TABLE 1 HERE]

Inconsistent yield information presents challenges in designing appropriate interventions and distributing resources. The spatial and temporal pattern of yields appears to vary considerably by source and method, making it difficult to understand when and why yields fall below their potential. But perhaps even more importantly, the above discussion implies that errors in common crop yield measures are not random, but rather more likely to result in biased yield estimates among low productivity smallholder farmers (most likely to cultivate irregular marginal plots and to experience losses in cropping area over the growing season), and women farmers (more likely to engage in intercropping practices poorly captured by yield measures).

By ignoring the possibility that smallholder farmers might experience a loss in crop area between planting and harvesting, e.g., crop failure on some of the area planted, overestimates of mean crop yields are likely using common crop yield calculations so long as the null production on abandoned cropland goes unaccounted for. Figure 1 illustrates how common yield measures may systematically overestimate mean yield relative to one alternative yield measure – production by area planted – by omitting lost crop area planted from yield calculations. The figure further illustrates how common yield measures might also bias estimates of the marginal returns to productivity-enhancing interventions – by omitting information about "failed" management practices when calculating the relative productivity only looking at cropping area at the time of harvest.

[FIGURE 1 HERE]

Based on the preceding discussion, we posit and empirically test the following hypotheses:

Hypothesis 1: Crop productivity estimates based on crop harvest quantity per area harvested will differ significantly and systematically from productivity estimates based on crop harvest quantity per area planted for certain subsets of smallholder rice farmers in Tanzania; and

Hypothesis 2: Estimates of the marginal gains to productivity-enhancing strategies in Tanzanian smallholder rice farming will differ depending upon the measure of productivity used.

3. Smallholder Rice Yields in Tanzania

According to FAOSTAT the Tanzanian food supply per capita of paddy rice[3] (unmilled weight) was 30.1 kg in 2009, compared to only 24.8 kg/capita in 1999. The agricultural census in 2007/2008 reported a 20% increase in the number of households cultivating rice in the country compared to 2002/2003 (National Bureau of Statistics, 2012). And the 2008 Tanzania National Panel Survey (NPS) found 17% of households in cultivated the crop nationally (Bergh, et al., 2012). Rice consumption furthermore appears to be income elastic in Tanzania, that is, as households increase their income they spend even greater shares of earnings on rice (Minot, 2010). Rice imports have also increased in recent years (Raes et al., 2007).

In spite of growing demand for rice small scale farmers in Tanzania regularly harvest yields far below the world average. But the diversity and complexity of production systems in Tanzania poses a significant challenge to researcher and agricultural development practitioners trying to understand this apparently poor performance. About three quarters of rice in Tanzania is grown in the rainfed lowland system, on non-irrigated fields that are flooded for at least part of the season; another 20-23% of rice is grown in the rainfed upland system, and the remaining 4-8% is grown in irrigated flood plains (Balasubramanian et al., 2007; Meertens et al., 1999; Kanyeka et al., 1994). The Tanzania NPS, which provides agricultural statistics at a zonal level, found mean plot sizes for rice ranging from 0.26 ha in Zanzibar Zone to 1.5 ha in Western Zone (Bergh et al., 2012). The Morogoro, Shinyanga, Mwanza, and Tabora regions of Tanzania account for 62.7% of the total area cultivated with rice. Morogoro has the largest proportion of land cultivating rice (31%), followed by Zanzibar (22.2%) (NBS, 2012).[4] However, on a per household basis,

[3] The degree of milling is another area of imprecision in the literature. FAO and the TNPS report yield of paddy or rough rice, before the hull is removed in milling. Removing the hull reduces weight by approximately 20% (http://www.fao.org/docrep/t0567e/T0567E07.htm).
[4] Morogoro (18.7%%), Shinyanga (19.3%), Mwanza (13.7%), Tabora (11%).

Zanzibar has the lowest acreage planted with rice (0.37 ha), while Rukwa has the highest (1.34 ha) (NBS, 2012).

Irrigation is rare among Tanzanian farmers. In 2007/2008 7.8% of households cultivating rice irrigated according to the Agricultural Census, while the Tanzania NPS found 5% of paddy plots were irrigated in the long rainy season (NBS, 2012). On average, households planting rice used 0.5 to 0.9 hectares for rice; in most regions this accounts for about a third of the household's landholdings, suggesting that rice is one of multiple crops cultivated by the household (National Bureau of Statistics, 2006). While both women and men participate in rice cultivation, women form a majority in most of the day-to-day activities (National Rice Development Strategy, 2009; Mwakalila, 2005; Kiagho et al., 2004; Meertens et al., 1999). Of households cultivating rice in the 2008 long rainy season, 23% of the households had female majority ownership of the crop (NBS, 2012).

[FIGURE 2 HERE]

According to FAOSTAT (2014), Tanzanian rice yields averaged 1900 kg/ha between 2001 and 2011. However there are significant disparities in rice yield estimates across published data sources in any given year. Figure 1 contrasts yield estimates from FAOSTAT, the Tanzanian Agricultural Census, and the Tanzanian NPS. Rice yields increased 37.5% between the 2002/2003 census (1000 kg/ha) and the 2007/2008 census (1600 kg/ha) and range from a low of 700 kg/ha in Dodoma to 3400 kg/ha in Manya (NBS, 2012). NBS Agriculture Census data separate smallholder farmers from commercial farmers, which in part may explain the difference from FAOSTAT estimates (Table 2). But even within the NBS data there is substantial variation in yield estimates depending on whether an area harvested or area planted measure is used.

[TABLE 2 HERE]

4. Modeling Determinants of Smallholder Rice Yield

Myriad theories seek to explain variation in crop yields across smallholder farmers, and many studies seek to estimate "yield gaps" between the observed yield and the theoretically attainable yield for a crop in a given ecological (e.g., soil types and rainfall) and institutional (e.g., access to inputs and markets) context. Waddington et al. (2010) attempted to quantify the relative significance of various constraints and associated yield losses for six food crops in 13 farming systems, using survey data from 672 experts, including geneticists, plant protection scientists, agronomists, social scientists, economists, extension agents, input suppliers, and farmers. In the two systems where rice farming is prevalent – the Sub-Saharan Africa Root Crop and Cereal-Root Crop Mixed systems – the authors found socio-economic constraints accounted for the largest share of yield losses (38% and 51% respectively).[5] Similarly, the top constraint in both systems came from the socio-economic category: namely the limited and expensive supply of fertilizer.

However many other constraints clearly play significant roles in determining crop production – we therefore adopt the four categories of production constraints developed by a panel convened by the CGIAR Generation Challenge Programme: abiotic, biotic, management, and socioeconomic (Waddington, Li, Dixon et al., 2009). Abiotic constraints include environmental factors such as soil and climate. Biotic constraints come from living organisms such as weeds, pests, and diseases. Management and socioeconomic constraints are human-made but differ in scope from each other: management constraints include fertilizer and water management, while socioeconomic constraints focus on input prices and credit access. These proposed constraints to yield form the basis for our empirical investigation on variability in Tanzania.

4.1. Abiotic Constraints

The primary abiotic constraints relevant for rice production in Tanzania are soil quality, soil type, and climate. Farmers in Tanzania consistently report poor soil quality, and soil tests confirm these reports (Meertens et al., 1999; Meertens, 2003; Meertens et al., 2003; Mghase et al., 2010). Lowland soils in Tanzania are classified as vertisols, described as "heavy clay soils" with high potential for rice cropping (Balasubramanian et al., 2007; Raes et al., 2007; IUSS, 2006). Upland soils in Tanzania have less clay and are classified as inceptisols, rich in organic material (Balasubramanian et al., 2007). Heavy clay soils are preferable for rice cultivation because they are less permeable, and therefore retain better moisture than more sandy soils; as a result, expected yields for heavy clay soils are higher (Raes et al., 2007). Soil tests of upland rice

[5] While fertilizer and improved variety use is included under management, high prices and availability of these inputs are included in socio-economic constraints, which explains the large share of yield losses associated with the socio-economic category.

in four districts in southern Tanzania (Ulanga, Kyela, Morogoro, and Korogwe) found that while the soil was "medium to very high[ly] capable of supporting the growth of rice," low to medium nitrogen and phosphorus levels restricted rice yields (Mghase, 2010). Soils in northern Tanzania, both upland and lowland, were found to be similarly deficient, indicating a potential for fertilizer use to increase soil nutrients and rice yields (Ndakidemi & Semoka, 2006). In some places in the Shinyanga region of northwest Tanzania, rice has been cultivated for 30-40 years on the same soil, with very little fertilizer use (Meertens et al., 2003).

Lack of rainfall can also severely limit yields. Studies focusing on rainfall found that a dry year for lowland rice typically averages 500 kg/ha yields, a normal year averages 1000 kg/ha, and a wet year averages 2000 kg/ha (Raes et al., 2007). In a study in the drought-prone Mwanza region Meertens et al. (1999) found rice fields were left to fallow one out of every three years due to insufficient rainfall. Two recent studies using different datasets from Tanzania concluded that higher temperatures further decrease yields (Rowhani et al. 2011; Ahmed et al. 2011).

4.2. Biotic Constraints

Primary biotic constraints to rice production in Tanzania are weeds, pests, and disease. Weeds have long ranked as one of the biggest problems for rice farmers in Tanzania (Meertens et al., 1999). The parasitic weed *Striga* in particular represents an increasingly serious problem in upland rice regions of Tanzania (Riches et al., 2005). The degree of weed infestation relates to the method and quality of land preparation and soil type, but water depth is the most important determinant; if there is permanent, sufficient water depth then weeds cannot grow, but if fields are dry for an extended period then the weeds will grow faster than the rice plants (Meertens et al., 1999). A series of studies across West Africa and Tanzania showed that well-weeded plots had yields 1000 to 2000 kg/ha higher on average (Fofana & Rauber, 2002; NERICA, 2008; Becker & Johnson, 1999; Becker & Johnson, 2001; Becker et al., 2003; Adigun et al., 2005).

Disease and pests are also significant biotic constraints. Banwo (2003) reports rice yellow mottle virus (RYMV) as the most important disease affecting rice production in Tanzania, particularly in rainfed lowlands. High RYMV incidence has been reported in all rice-cultivating areas, but affects the highest producing regions (Morogoro, Mbeya, Shinyanga and Mwanza) at a higher rate (Kanyeka et al., 2007). Yield losses of up to 100% have been reported in West Africa and Tanzania due to RYMV (Luzi-Kihupi, 2009; Abo et al., 1997). Rice blast, another rice disease, also negatively affects rice, particularly in upland regions (NERICA, 2008; Luzi-Kihupi et al., 2009). Animal and insect pests, including primates, birds, rats, and a variety of insects negatively affect rice yields in Tanzania (Mghase et al., 2010; Balasubramanian et al., 2007; Banwo, 2002). Damage from birds is higher for rice plots that are planted early, contain early-maturing cultivars, and/or lack sufficient labor for birdscaring (Meertens et al., 1999).[6] Insects are particularly problematic because they also act as vectors for both plant and human diseases (Banwo et al., 2002).

Finally, research in Tanzania and Uganda has also illustrated significant yield gaps between improved variety (IV) seeds and traditional rice varieties in all ecosystems (Bucheyeki et al. 2011; Waddington et al., 2010; NERICA, 2008; Kijima et al., 2006; Mwaseba, 2005; Msomba et al., 2004; Kanyeka, 2004; Meertens et al., 1999). Traditional varieties may be vulnerable to certain pests or diseases, and are often prone to lodging[7] or crop failure under the marginal rainfall patterns of Tanzania (Luzi-Kihupi et al., 2009). In the development of IV seeds, higher yields can be achieved by improving resistance to disease and insects (Bucheyeki et al., 2011) as well as abiotic constraints such as drought. Despite the increased yield potential of IV seeds, significant barriers to widespread adoption are evident. First, focusing exclusively on characteristics related to yield may overlook other traits that are important to farmers. For example, one farmer survey in southeast Tanzania found that smallholders' holistic rating (including factors such as ease of milling and eating qualities) of many IV seeds was lower than many traditional varieties (Kafiriti et al., 2003).[8] A second important constraint in Tanzania is poor channels for seed distribution; 18% of rice farmers in one survey cited lack of seed availability as a problem affecting yields (Bucheyeki et al., 2011). Even when farmers use improved variety seeds, other management constraints may prevent increases in yield or income from IV seed. Nakano and Kajisa (2012) found that modern variety seed did not have a statistically significant impact on yield or income under rainfed conditions and that even under

[6] Meertens et al. (1999) found that farmers spent an average of 25 labor days per hectare birdscaring.
[7] Lodging "is the permanent displacement of the stem of a free-standing crop plant from the vertical" (Oladokun & Ennos, 2006).
[8] Farmers included in study mostly had irrigated rice fields.

irrigation, proper water management, including improved bunds, was necessary for improved yields and incomes.

4.3. Management Constraints

Management constraints to rice production in Tanzania include planting method, irrigation and water management, fertilizer use, and fallowing or intercropping.

A number of studies from Tanzania and West Africa found that lower yields were associated with larger plots, likely due to the increased labor and inputs required to manage large plots (Carletto et al., 2015; Nakano et al., 2011; Nakano, Bamba, Diagne et al., 2011; Sakurai, T., 2006). Another study from Tanzania found that larger plots decreased the likelihood that farmers would adopt IV seeds or fertilizers (Nakano et al., 2011). The literature is mixed regarding the impact of broadcast seeding compared to transplanting seeds. Anecdotal evidence and summary statistics from a survey of rice farmers in Tanzania suggest that transplanting seeds[9] is associated with higher yields (Mwaseba, 2005; Nakano, 2011), and in studies in Nigeria and The Gambia, optimal plant spacing was found to be 20 x 20 cm, which cannot be achieved with the broadcast method of planting (Oikeh et al., 2009; Ceesay & Uphoff, 2006). However, regression analysis in two studies in West Africa found transplanting seeds had no significant effect on production (Saito et al., 2010) and that transplanting may be constrained by labor availability. Meertens et al (1999) found that 20 more labor days per hectare were used for transplanting compared to direct seeding[10] (Meertens et al., 1999).

Because of rice's hydrological needs, water management is among the most important determinants of yields. Typically, yields are around 1000 kg/ha in upland areas and 2000 kg/ha in lowland areas and rise to 3400 kg/ha in irrigated areas, with a possible range of 600 to 10000 kg/ha (NERICA, 2008; Raes et al., 2007). However, a study of irrigation in Tanzania found low sustainability of current irrigation schemes due to poor local-level operation and maintenance (Therkildsen, 2011). Bunded fields in Tanzania that store rainwater and limit runoff have been shown to increase yields by 10% in permeable soils and 75% in heavy clay soils (Raes et al.,

[9] Transplanting seeds means that seeds have already germinated in a nursery before being planted in the field.
[10] Direct seeding means seeds are directly planted into the field via broadcasting, dibbling, or drilling. One study found no significant differences in rice yields resulting from these different methods (Oyewole et al., 2010).

2007; Hatibu et al., 2006). In an experimental study in the Senegal River Valley, researchers found the labor-intensive System of Rice Intensification (SRI) had higher water productivity and similar yields compared to rice grown under modern management practices, but only when weeds were adequately controlled (Krupnik et al., 2012).

Fertilizer access and use is yet another key determinant of rice production: several studies in West Africa and Tanzania have found that fertilizer use generally increased yields relative to control groups (Becker et al., 2003; Buah et al., 2011; Meertens, 2003; Meertens et al., 2003; Becker et al., 2001; Becker et al., 1999; Saito et al., 2010; Oikeh et al., 2009). Research across Sub-Saharan Africa has found potentially large benefits to the application of nitrogen fertilizer, accounting for 1500 kg/ha increase in irrigated conditions in Benin (Saito et al., 2010), 1200 to 2400 kg/ha increase in lowland rice in Tanzania (Meertens, 2003b), and 950 kg/ha in upland rice in Nigeria (Oikeh et al., 2007). Many studies have further suggested particular environmental and management conditions affect the magnitude of impact fertilizer had on rice yields. The amount of fertilizer, rainfall, and weeding have all been found to affect the degree to which fertilizer increases yields. In two studies in Tanzania and Nigeria, plots receiving a high nitrogen application (60 kg/ha or 120 kg/ha) had lower yields than both the 30 kg/ha and no-treatment plots (Meertens, 2003; Oikeh et al., 2009). Higher levels of precipitation accounted for larger yields among fertilized plots in Nigeria (Oikeh et al., 2007; Oikeh et al., 2009; Meertens, 2003). Inorganic fertilizer was shown to be more effective than synthetic fertilizer on irrigated plots in Côte d'Ivoire (Becker et al., 1999 & Becker et al., 2001). This same study also warned that without weeding, synthetic fertilizer may only increase weed biomass.

Organic fertilizers such as farmyard manure or rice husks both have increased yields by as much as 1000 kg/ha in lowland rice in Tanzania. Limitations to organic fertilizer use include difficulty in transporting manure and limited availability of rice husks and manure. While studies have shown that the application of 10 tons of manure per hectare increases yields by 880 to 1000 kg/ha, the average farmer in Tanzania has only enough manure to cover 0.36 ha at that rate (Meertens, 2003). Moreover like synthetic fertilizer, manure application can result in more weeds (Meertens et al., 2003).

Lastly, different fallowing methods have been shown to affect rice yields. In a study of upland fields in Côte d'Ivoire, leguminous fallowing (cultivating wild-growing legumes during the dry season) accounted for a 29% increase in rice yields over the more common weedy fallow (Becker et al., 1999). Another study of upland fields in Côte d'Ivoire showed that as fallow periods became shorter (less than five years followed by five straight years of cultivation), yields decreased an average of 300 kg/ha (Becker et al., 2001). The study of upland rice fields in Côte d'Ivoire found that intercropping legumes and rice decreased yields for both crops, despite increasing soil nitrogen and reducing weed growth (Becker et al., 1999). An experiment in Nigeria found that intercropped rice intercropped with groundnuts performed favorably compared to monocropped rice in regards to pest infestation (stem borer and green stink bug). However, the authors note that only some crop combinations and densities outperformed mono-cropped rice (Epidi et al., 2008).

4.4.Socioeconomic Constraints

Credit access, labor, livestock, input access and prices, extension, and individual characteristics such as age and gender make up the primary socioeconomic constraints to rice production. A recent study of rice farmers in Tanzania suggested that credit access had a significant effect on rice yields. The simple presence of a farmer co-op within the village was associated with a 190 kg/ha increase in rice yields (Nakano & Kajisa, 2011). The study found credit was increasingly important for inputs or practices that regularly require cash on hand, such as chemical fertilizer use and tractor use for constructing a bund or leveling land, but did not have a significant effect on adoption of improved seed varieties. The study suggested that in many cases the farmer's past production record was used as an indicator of credibility, thus limiting the ability of many rainfed farmers to access credit.

Availability of labor is another key management factor that explains variability in rice yields. In one study in Tanzania, total labor days per hectare ranged from 210-269 for rice farmers in the lowland ecosystem, depending on the intensity of cultivation and access to an ox plough, which was comparable to the labor requirements for rainfed lowland and upland cultivation (Meertens et al., 1999). Since most households harvest rice by cutting each head separately, harvesting alone accounted for an average of 126 labor days per hectare; for comparison, in other rice-growing countries like Laos, Nepal, and Madagascar, harvesting only requires between 11 and 27.5 labor days per hectare on average (Meertens et al., 1999). Rice also has high labor requirements because of the intensity of weeds (Adigun et al., 2005). Finding labor for weeding is particularly difficult because it must be done at the height of the season, when laborers are more likely to be working on their own fields; therefore, a study in Tanzania found that the price of hired labor increases during a point in the season where households are particularly likely to have cash constraints (Meertens et al., 1999).

Ownership or access to livestock can also have a significant impact on labor requirements. Meertens et al.'s study in Tanzania (1999) found that having access to an ox plough reduced the labor days per hectare from 48 to 9 for land preparation, and that land preparation may be delayed if households need to hire or borrow an ox plough. Bucheyeki et al. (2011) hypothesize that high rates of rice cultivation among members of the Sukuma ethnic group may be related to high rates of cattle ownership, which makes it possible to use ox ploughs for land preparation and ox carts for transportation. Livestock also increases access to farmyard manure.

High input prices were also among the most commonly cited yield constraints by rice farmers in Tanzania (Bucheyeki et al., 2011; Meertens et al., 1999). The Tanzanian government previously subsidized fertilizers, but prices have increased since those subsidies ended in the early 1990s (Meertens, 2003). Access to affordable inputs is particularly difficult for farmers who live in remote villages where the roads are in poor condition, and therefore few traders come to buy and sell goods. This lack of competition allows them to pay lower prices for crops and charge higher prices for inputs, which reduces the profitability of input use (Meertens et al., 1999). Rice-related extension has also proved to be important in whether improved variety seeds and modern planting methods were adopted by both irrigated and rainfed farmers in Tanzania (Nakano et al., 2011), while experience with rice farming has also proved to be an important indicator in rice yields. Two studies of farmers in upland and lowland ecosystems in Uganda and Côte d'Ivoire found that farmer's experience had a significant impact on rice yields (Kijima et al., 2006; Sakurai, T.; 2006). One study of smallholders in Tanzania observed that younger farmers were more willing to transport manure to distant plots and construct soil conservation structures as part of a project to increase soil fertility. Additionally, the outlier poor farmers who purchased inorganic fertilizer were generally younger (Mowo et al., 2006). Another study found that younger farmers in Nigeria were more likely to adopt New Rice for Africa (NERICA) improved varieties (Tiamiyu, 2009).

Finally, gender is another possible determinant of rice productivity. Peterman (2011), studying farmers in Nigeria and Uganda, suggests than men and women may have different productivity based on different availability and quality of inputs, and that they also may have different production functions. She observes that female-controlled plots of any crop have lower productivity than male-controlled plots in the same household, even when controlling for unobservable household characteristics, which indicates that household bargaining and decision making about input allocation matters. In Sub-Saharan Africa as a whole, female farmers have been less likely to adopt technologies that improve productivity (Cagley, 2009). Women may be constrained by labor availability, education, cultural appropriateness of adopting technology, and inadequate access to resources (Cagley, 2009).

5. Data and Methods

5.1. Survey Design

The Tanzania National Panel Survey (NPS) data were collected over a twelve-month period from October 2008 through September 2009. The sample design was constructed to produce nationally representative estimates, and it consists of 3,265 households from eight administrative zones, each with a rural/urban cluster, for a total of sixteen sampling strata. The resulting data can produce nationally representative estimates, however, sample size limitations preclude reliable statistics at the regional or district level. Agricultural households completed an additional farm questionnaire, resulting in 2,474 respondents who report involvement in any crop, fishing, or livestock cultivation.

5.2. Regression Analysis and Methods

We aim to understand the drivers of rice yields in Tanzania and examine whether and how yield measurement methodology might impact both mean productivity 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 rice (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 planted was replaced with area harvested. The sample furthermore omits a small number of observations where farmer reports regarding crop area losses were found to exceed the farmers' total landholdings (likely reflecting data error). Quantities harvested were collected based on farmer estimations of weight. As discussed above, these estimates are likely an imperfect but empirically accepted measure of quantity.

Based on area values we calculated the rice yield two ways, first, using the weight harvested divided by the area harvested and then using the amount harvested divided by the area planted. As discussed above, area harvested does not account for loss of crop area due to drought, rains, fire, insects, animals, crop theft, diseases and community problems, lack of labor, and other factors. While these area losses may be infrequent in field trials, farmers in the Tanzania NPS frequently report harvesting less area than planted and yields between the two measures differ substantially. Yield observations greater than 12,000 kg/ha were deemed improbable outliers and eliminated from the analysis. Based on the literature review on rice constraints, a variety of variables meant to measure abiotic, biotic, management, and socio-economic constraints were included in the yield regression analysis. We compared two models. Model 1 is an OLS 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. Unless otherwise noted, each variable included in the regression had a minimum number of plot observations (>30). Certain variables found to be important in the literature review were excluded from the regression due to insufficient observations or unavailability of data. These include access to credit, weeds, and input prices.

5.3. Description of the Sample

In the 2007/2008 survey seven percent of all long rainy season plots described in the survey contained rice. Of these 534 rice plots, we had sufficient data on 376 plots from 318 households to include in the analysis. Table 3 shows descriptive statistics for the sample in three groups: (1) for all plots in our sample (N=376), (2) those with losses in area between planting and harvesting (N=78 plots), and (3) those without area losses (N=298 plots). P-values show the statistical significance of differences in characteristics between plots with and without area losses.

[TABLE 3 HERE]

The average household in the sample had 5.4 members and 2.31 hectares of land. Twenty-six percent of households were headed by females. The average head of household was 48 years old and had just over 5 years of education (though 96 household heads reported no formal education). Mean plot yields of area harvested for the sample were 1557.049 kg/ha (median: 1129.3kg/ha), while mean yield for area planted was 1306.1 kg/ha (median: 926.6 kg/ha). Both yield measures are substantially less than FAOSTAT's yield estimate for the year 2008 of 2000 kg/ha.

A minority of plots in the sample had fertilizers or pesticides applied, with 10% using inorganic fertilizer, 5% using organic fertilizer and 12% using a pesticide, herbicide or fungicide. Use of improved variety (IV) seeds was also low, with only 5% of plots in the sample planted with IV seeds. Eighteen percent of the plots were intercropped, although we do not have information on the planting density of any of the plots. Irrigation was also infrequently reported; only 5% of plots were irrigated. We found significant differences between plots with area loss and those without for yield by area planted, proportion irrigated, and number of years the plot was last left fallow.

The most common reason reported by farmers for a loss in area between planting and harvesting was drought (see Figure 3).

[FIGURE 3 HERE]

6. Regression Results

Table 4 provides the results from two OLS regressions on the yield of rice plots. The overall explanatory power of the regressions is slightly higher for the yield measurement by area planted (Model 2) with an R-squared of 0.497, compared to 0.412 for yield by area harvested (Model 1). Comparing the models suggests very different policy recommendations arising from an examination of yields as defined by area planted as opposed to by area harvested. For yield by area harvested, rainfall, soil nutrient availability, historical temperatures, plot size, household head education level, labor, and access to ox labor are significantly associated with yield variation. Based on the results of the analysis of yield by area harvested, interventions that address abiotic constraints (for example targeting rice interventions in areas that reliably receive sufficient rainfall) and increasing access to labor saving technology, such as ox plows are most likely (of the drivers) to be associated with higher yields.

Analysis of the alternate yield measure, which replaces area harvested with area planted in the yield calculation, reveals four additional significant variables: higher than average rainfall, female head of household, extension advice received by the household, and marketing of rice by the household. The number of years the plot was left fallow is not significant in this regression. The other eight significant variables from the area harvested regression are also significant in the area planted analysis (signs are the same, but levels of significance and size of coefficients differ).

[TABLE 4 HERE]

As expected, rainfall lower than a nine year average was associated with lower yields in both models. The effect was stronger in Model 1, where rainfall less than 50 mm below the average was associated with harvesting an average of 372 kg of rice less than normal rainfall plots. Rainfall in 2007-2008 was low for many Tanzanian households, 260 of the 376 plots were in areas that received lower than average rainfall. Alternate models incorporated overall rainfall for the year, but this variable was not significant, indicating that deviation from expected rainfall may be more important than amount of rain in areas growing rice. Interventions that decrease water requirements, improve water efficiency, or provide irrigation may mitigate low rainfall constraints.

While data from the Harmonized World Soil Data on soil nutrient availability shows that having no or slight constraints to soil nutrient availability was positively associated with yield in both models, the coefficient is more than twice as large in Model 1 compared to Model 2. Using the common yield metric wherein area losses are not included, having no or few soil nutrient constraints is associated with a 726 kg increase in per-hectare yield, while in Model 2 (accounting for area losses) the association is only 315 kg/ha. This suggests that measuring yield by area harvested may overestimate the importance of soil nutrient availability relative to other factors in determining Tanzanian rice yields.

Higher historical temperatures were also associated with lower yields in both models, as predicted by the literature. Each 0.1 degree Celsius increase in average temperatures was associated with a decrease of 17.5 kg and 10.9 kg for Model 1 and Model 2, respectively, with a higher level of significance in Model 1. (Note that seed varieties that perform better in warmer temperatures may improve yields in warmer areas, however our data do not allow differentiation based on such variety-specific traits). As expected by theory, larger plot sizes were associated with lower yields in both models. Each additional hectare of land ownership was associated with a decrease in yields of 317 kg and 271 kg, respectively for Models 1 and Model 2. Though our results indicate associations, not causality, interventions that encourage better management of smaller plots may prove more effective in increasing small scale farmer productivity than interventions that encourage farmers to expand the area under production.

As for demographic variables, each year of formal education received by the household head is associated with a slightly higher but significant yield (56 kg/ha harvested; 31 kg/ha planted). (For reference, about one third of farmers reported no formal education (96 out of 318 household heads); and the average was 5.2 years.) The number of days of household and hired labor was positive and significant for both models. Each additional day of household labor was associated with higher yields of about 1 kg/ha in both models. The coefficient for hired labor was roughly nine times larger than that of household labor. This is consistent with the literature and implies the importance of additional labor during times when household labor is scarce. Finally, while the survey did not ask farmers directly whether ox plows were used on rice plots, we used information about whether households owned or rented oxen or ox implements as a proxy for animal labor. Plots cultivated by households with access to animal labor had significantly higher yields than households without oxen or ox implements. While the association was highly significant in both models, the coefficient was twice the size in Model 1, suggesting measuring yield by area harvested may overestimate the effect of animal labor. In both models, the coefficient was large: access to oxen was associated with an increase of 1196 kg/ha harvested and 643 kg/ ha planted.

6.1 Additional explanatory factors when evaluating yield by area planted:

While the above factors explaining variability in yield are similar in both models, Model 2 (area planted) reveals additional significant variables. Rainfall above 50mm higher than average is associated with smaller yields by 652 kg/ha. The rainfall results suggest (again extrapolating generously) that interventions that improve outcomes under high rainfall situations may be as important as those that mitigate consequences of low rainfall. The coefficient for high rainfall was larger and more significantly associated with lower yields than low rainfall, though high rainfall was much less common in 2007-08 (29 out of 376 plots) than low rainfall (260 out of 376 plots). Evaluating yields by area harvested underestimates the detrimental effects of high rainfall, perhaps because flooding can wash away entire areas of the plot, which would then not be considered in area harvested.

Measures of yield by area planted also have implications for female-headed households: female-headed households were associated with yields 212 kg/ha lower than male headed households in Model 2 (while the coefficient was insignificant in Model 1). The negative association between female heads of household and lower rice yields may indicate constraints faced by female-headed households not accounted for elsewhere in the model. Gender sensitive interventions and additional research into the constraints faced by female headed households could improve yields for these households.

Unexpectedly, households that received extension advice produced yields 251 kg/ha lower than other households. While this analysis does not provide an explanation for that finding, it is possible that farmers are incompletely implementing advice, for example using fertilizers without adequate irrigation, leading to poor outcomes. Alternatively, the farmers receiving extension services may have less experience or exhibit other characteristics (such as low production that is being deliberately targeted by extension agents) that affect their productivity. Finally, the effect of market access is amplified when yield by area planted is considered. Households that sold rice produced yields 572 kg/ha higher than households that did not market their harvest. The large and highly significant coefficient for selling rice suggests two possibilities. Farmers may be more likely to choose to sell rice when they harvest the amount they expected to harvest at planting (i.e., they have no area losses). Alternatively, market oriented farmers may be less likely to experience area losses, due to better land or management practices.

7. Conclusions

Small scale rice farmers in Tanzania regularly harvest yields far below the world average. To increase production, yield constraints must be accurately identified and remedied. But to increase productivity there is an additional need to recognize differences in farming practices and growing conditions that vary widely across farming systems, across agro-ecological zones, and across levels of poverty (Waddington et al., 2010). The latest Tanzanian NPS data show smallholder yields continue to differ drastically from national trends not only for rice, but also for maize and millet (where yields of the most productive 5% of farmers are up to four times greater than the median). Such disconnects may well imply “yield gaps” yet to be overcome, but they may also imply that the simple kg/ha measures used to track national production in the past are not working to track smallholder progress today.

The continued reliance on harvested yield as the primary indicator of agricultural productivity is all the more troubling because over time the sources of yield data have, in many ways, become even more suspect (Jerven, 2014) with both national and industry reports of yield data coming under increasing scrutiny (Sandefur & Glassman, 2015). The results of this analysis suggest the choice to measure rice yields using area harvested rather than area planted provides very different estimates of mean agricultural productivity and, moreover, analyses based on those different results will lead to different conclusions regarding factors that explain yield variability. In our sample of Tanzanian rice farmers, smallholders harvested less than the area they planted on 23% of the sample plots. Farmers reported area losses even more frequently for other crops in the Tanzania NPS (e.g., maize, sorghum, or wheat), suggesting discrepancies between alternative yield calculations may be even larger. Findings suggest a need to better specify yield measures in published findings, with yield by area planted offering a more accurate indication of where investments are most needed to improve smallholder productivity.

Such measurement inconsistencies alone should make us question the common yield metric. But perhaps even more fundamental are the missing pieces of a simple “kg/ha” proxy relative to the more complex smallholder farm productivity we intend to track. Common crop yield has been increasingly criticized in social and environmental segments of the research community (Cassidy et al., 2013), in large part because the numerator and denominator of yield (kilograms and hectares) don't allow for direct consideration of benefits outside of weight harvested, or costs outside the (implicit) cost of land. The specific example of intercropping – especially common among smallholder subsistence and women farmers – is an important example. Intercropping involves growing multiple crops interwoven on a single piece of land. But common yield’s "kilograms of crop X per hectare harvested" precludes the possibility of incorporating intercrops into productivity estimates, despite the potential dietary diversity, soil nutrient, and risk management benefits afforded by multiple crops (Khan et al., 2014).

Similarly the costs of household labor, hired labor, purchased fertilizer, and environmental damages from different farm practices are all excluded from the common yield measure – as, therefore, are changes in the relative value of these inputs year-to-year. From a farm income perspective this is a potential concern, since there is no guarantee that the highest-yielding management strategy (in total kg/ha) is also the highest profit-generating strategy (in net kg/$). From a societal perspective, defining "success" in terms of common crop yield similarly means that project evaluations can only consider labor, social and environmental costs secondarily (Tittonell & Giller, 2013). These are not caveats to an otherwise fine measure – they are fundamental flaws with real repercussions.

There is an urgent need to better specify productivity measures in agricultural initiatives and scientific studies purporting to target smallholder productivity. Calculating yield by area planted is a first step towards a more accurate accounting of agricultural productivity to help prioritize investments for the most marginal farmers. But if the goal is more than crop output alone – if it includes improved nutrition, higher incomes, and lower risk among all rural poor – then the agricultural development community requires an even broader set of measures that better reflect that goal.

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Tables and Figures

Table 1. Sources of yield data and inconsistent reporting of yield calculations in published scholarship

Citation	Yield Data Source	Yield Calculation
Ahmed, S., Diffenbaugh, N., Hertel, T., Lobell, D., Ramankutty, N., Rios, A., Rowhani, P. (2011).	farmers' fields	area harvested
Becker, M., Johnson, D. E., Wopereis, M., Sow, A. (2003).	farmers' fields	not specified
Adigun, J., Lagoke, S., Adekpe, I. (2005).	research station experiment	not specified
Agboh-Noameshie, A., Kinkingninhoun-Medagbe, F., Diagne, A. (2007).	farmers' fields	not specified
Kafiriti, E. M., Dondeyne, S., Msomba, S., Deckers, J., Raes, D. (2003).	farmers' fields	not specified
Kanyeka, Z. L., Kibanda, J. M., Msomba, S. W. (2004).	on-farm trials	not specified
Becker, M., Johnson, D. E. (1999).	farmers' fields and a research farm	not specified
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Buah, S., Nutsugah, S., Kanton, R., Atokple, D., Dogbe, W., Karikari, A., Wiredu, A., et al. (2011).	farmers' fields	not specified
Bucheyeki, T. L., Shennkalwa, E., Kadadi, D., Lobulu, J. (2011).	farmer interviews	not specified
Ceesay, M., Uphoff, N. (2006).	research station experiment	not specified
Lobell, D. B., Cassman, K. G., Field, C. B. (2009).	N/A	not specified
Meertens, H. C. C. (2003).	literature review	not specified

Table 2. Comparison of reported 2008 Tanzanian rice yields

Source/Year	Method of Yield Measurement	Rice Yield (kg/hectare)	Measurement notes
FAOSTAT 2008	Quantity harvested / area harvested	1726.322	
TPNS 2007/2008	Quantity harvested / area harvested	1290 kg/ha	Long Rainy Season; includes some observations excluded from our analysis
TPNS 2007/2008	Quantity harvested / area planted	1040 kg/ha	Long Rainy Season; includes some observations excluded from our analysis
NBS Agricultural Census 2007/2008	Quantity harvested / area planted	1600 kg/ha	Long Rainy Season; excludes commercial farms

Table 3. Characteristics of long rainy season rice cultivators in Tanzania

Variable	**All plots N=376**	**Plots with no area loss N=298**	**Plots with less area harvested than planted N=78**	**P-value**
Household Characteristics (N=318)				
Average Household Landholding Size (ha)	2.31	2.13	2.93	0.201
	(0.196)	(0.180)	(0.606)	
Proportion of Female-Headed Households	0.26	0.27	0.20	0.328
	(0.027)	(0.033)	(0.057)	
Average Age of Household Head (years)	48.05	47.61	49.53	0.482
	(1.229)	(1.261)	(2.663)	
Average Education of Household Head (years)	5.19	5.21	5.12	0.862
	(0.225)	(0.256)	(0.474)	
Average Daily Consumption (USD /adult equivalent)	1.24	1.25	1.20	0.588
	(0.044)	(0.048)	(0.086)	
Proportion Received Extension Advice	0.17	0.15	0.24	0.189
	(0.027)	(0.031)	(0.061)	
Plot Characteristics (N=376)				
Mean Yields (kg/ha planted)	1306.13	1473.06***	731.25	0.000
	(103.3)	(0.119)	(0.148)	
Mean Yields (kg/ha harvested)	1557.05	1473.06	1846.30	0.287
	(132.9)	(119.5)	(344.5)	
Median Yields (kg/ha planted)	926.65	1186.11	370.66	
Median Yields (kg/ha harvested)	1129.27	1186.11	1037.84	
Mean Plot Size (includes entire plot)	1.79	1.58*	2.54	0.055
	(0.132)	(0.101)	(0.492)	
Mean # years fallow	0.17	0.12*	0.37	0.068
	(0.044)	(0.043)	(0.123)	
Proportion of Plots				
Using Improved Variety Seed	0.05	0.06	0.02	0.104
	(0.016)	(0.020)	(0.013)	
Using Organic Fertilizer	0.05	0.05	0.03	0.591
	(0.019)	(0.019)	(0.023)	
Using Inorganic Fertilizer	0.10	0.11	0.07	0.395
	(0.027)	(0.030)	(0.033)	
Using Pesticides, Herbicides, Fungicides	0.12	0.12	0.11	0.896
	(0.047)	(0.057)	(0.053)	
No or Few Soil Nutrient Availability Constraints	0.33	0.32	0.35	0.809
	(0.066)	(0.066)	(0.108)	
No or Few Soil Workability Constraints	0.65	0.63	0.70	0.458
	(0.065)	(0.068)	(0.089)	
Intercropped Rice	0.18	0.16	0.22	0.396
	(0.032)	(0.030)	(0.076)	
Irrigated	0.05	0.06*	0.02	0.073
	(0.018)	(0.019)	(0.021)	
Geospatial Variables				
Mean 12-month Rainfall July-June for 9 yr period (mm)	802.24	814.36	760.50	0.254
	(36.78)	(35.37)	(55.456)	
Mean Historical Temperature (Celsius)	24.28	24.32	24.15	0.481
	(0.159)	(0.185)	(0.191)	
Mean 12-month Rainfall July 07-June 08 (mm)	750.64	766.78	695.08	0.148
	(39.679)	(40.098)	(53.476)	

Standard errors in parenthesis.

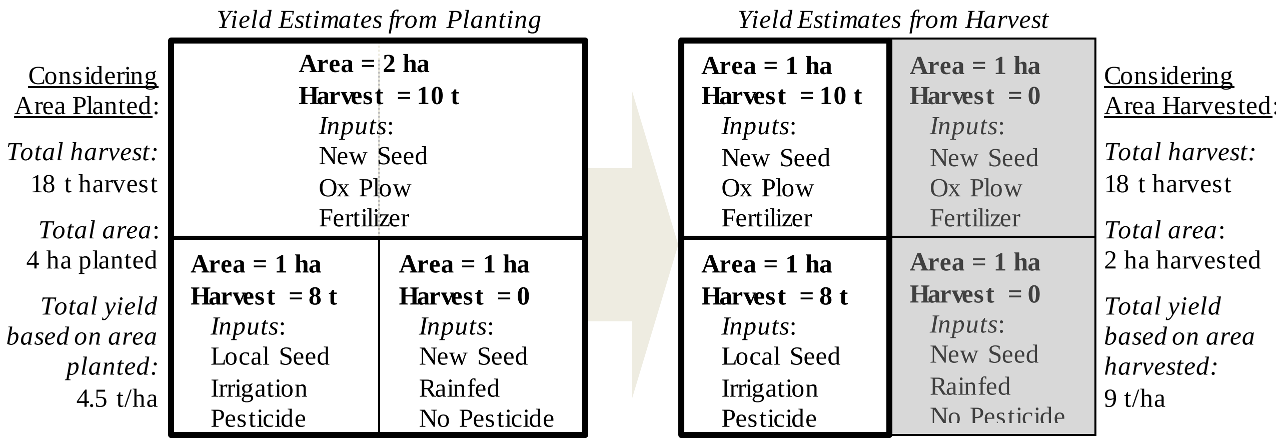
*** p<0.01, ** p<0.05, * p<0.1 (difference between plots with and without area losses)

Table 4. OLS regression results for yield by area harvested versus yield by area planted

		Model 1: *Yield by area harvested*		**Model 2:** *Yield by area planted*	
Constraint type	Description	N: 376 R^2: 0.4121		N: 376 R^2: 0.4973	
		Coefficient	**p-value**	**Coefficient**	**p-value**
Abiotic	No or slight constraints to soil nutrient availability	**726.45***	**0.006**	**315.11***	**0.069**
	No or slight constraints to soil workability=1	204.36	0.244	120.76	0.398
	Annual mean temperature 1960-1990 (10 degrees C)	**-17.46***	**0.009**	**-10.88***	**0.061**
	Rainfall more than 50 mm higher than 9 year average=1	-185.49	0.499	**-651.80****	**0.034**
	Rainfall less than 50 mm higher than 9 year average=1	**-371.68****	**0.029**	**-297.95***	**0.064**
Biotic	Improved variety seed=1	-214.38	0.242	-32.40	0.844
	Farmer reported losses due to birds=1	36.63	0.814	6.86	0.959
	Farmer reported losses due to other causes=1	53.72	0.750	-117.30	0.367
	Pesticide, herbicide, or fungicide use on plot=1	452.68	0.160	279.54	0.157
Management	Inorganic fertilizer use on plot=1	305.66	0.188	347.78	0.117
	Rice intercropped on plot=1	-220.97	0.182	-176.39	0.232
	Number of years the plot was left fallow	**214.37***	**0.056**	94.82	0.121
	Plot size in hectares	**-317.11****	**0.022**	**-271.03*****	**0.005**
	Number of plots owned by the household	-45.90	0.573	-88.34	0.170
Socioeconomic	Zanzibar=1	32.57	0.889	74.99	0.730
	Female head of household=1	-102.04	0.630	**-211.85****	**0.042**
	Age of head of household	-8.20	0.168	-4.64	0.300
	Years of education of head of household	**56.34****	**0.031**	**31.22****	**0.049**
	Household labor days per hectare	**1.16*****	**0.000**	**0.92*****	**0.000**
	Hired labor days per hectare	**8.62*****	**0.000**	**9.08*****	**0.000**
	Household owned/rented ox, ox plough, ox planter, or ox cart=1	**1,195.55*****	**0.000**	**642.72*****	**0.000**
	Household received advice from any source=1	-224.41	0.181	**-250.60***	**0.061**
	Household sold rice=1	187.79	0.522	**571.53*****	**0.000**
	Constant	**767.20***	**0.106**	**896.56****	**0.021**

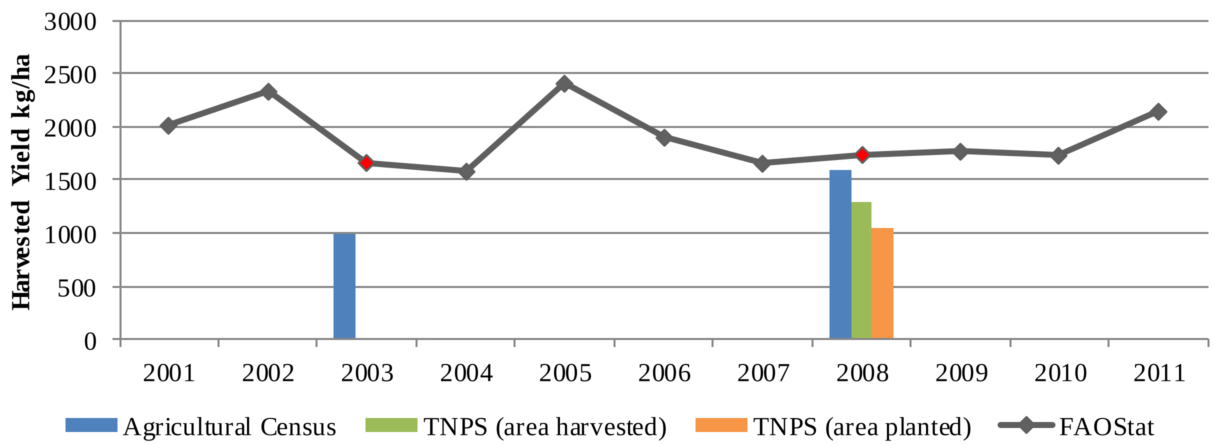
*** p<0.01, ** p<0.05, * p<0.1 | Values in bold represent significant variables. Shading indicates significance in one model but not in the other.

Figure 1. How common yield measures may overestimate 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: *In this hypothetical example, when considering production per area planted (on left) the "best combination" is local seed/irrigation/pesticides, which offers a mean yield of 8 t/ha[planted] which is better than 5 t/ha[planted] from the new seed/ox plow/fertilizer combination. However, when considering production per area harvested (common yield, on right) the "best combination" appears to be new seed/ox plow/ fertilizer, offering 10 t/ha[harvested]. Ignoring the failed crop plots results in biased estimates of management-based yield gains.*

Figure 2: Rice yield estimates 2001 to 2011



Sources: FAOSTAT; Bergh et al., 2012; NBS, 2006; NBS, 2012

Figure 3: Farmer reported reasons for a loss in area between planting and harvesting.