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The productivity of tropical grain production

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ABSTRACT
The objective of this manuscript is to understand better the nature of agricultural growth and productivity under a new tropical system of production, safrinha or succession cropping, which results in two large crops per year. The subject provides scholars and policymakers a technical foundation by which to think about the potential for market moving agricultural expansion and greater grain supplies originating from the tropics. Our results show that commercial tropical grain producers continue to rely on input intensification, principally chemicals, and extensification of their land base, and relatively low levels of technology, to increase grain production.

KEYWORDS: extensification; intensification; maize; productivity; safrinha; soybean; tropical

The global rise in demand for grains will increase competition for land, water, and energy, affect the world's ability to produce food, as well as necessitate greater vigilance on reducing food production's impact on the environment (Molden 2007; Lobell *et al.*, 2008; Godfray *et al.*, 2010). This paper focuses on new and emergent structures in grain production occurring in the tropics that sit at the nexus of the food demand-environment issue. Specifically using data from the most productive tropical region in the world Mato Grosso, Brazil (Goldsmith and Hirsch, 2006), we formally measure the level of agricultural productivity of soybean and maize production. We hypothesize and test whether a unique form of soybean and maize production, the ''safrinha system,'' achieves high levels of factor as well as total factor productivity. If true, the findings would indicate new growth and competitiveness opportunities for rural economies in the tropics.

Secondly, we hypothesize as to the source of any positive productivity gains, which has the practical implication of identifying whether the tropical expansion continues to reflect traditional extensive farming systems, which have negative environmental consequences, or whether the expansion might instead involve technology based intensification, which can be both environmentally and economically favorable. Our identification in this research as to the type and level of soybean and maize productivity, across all inputs, provides some of the first evidence as to the nature of modern commercial tropical grain production.

Literature review

Tropical environments contain some of the most valuable and sensitive native biomes (Baudron and Giller, 2014). As a result, land use changes in the tropics from native biomes to agriculture reflect major tradeoffs for policy makers: assuring a low cost and well-distributed food supply and bringing economic development to some of the poorest regions of the world versus reducing the adverse effects of deforestation on climate change; and maintaining the planet's biodiversity. Expanded production in the tropics raises not only land use change questions, but also introduces additional policy dilemmas related to the land sparing debate (see Cohn, *et al.*, 2014). Successful expansion in one area theoretically relieves the pressure to develop land elsewhere. This notion is the common ''postage stamp'' proposition that argues that sufficiently increasing agricultural productivity could, in the limit, allow the production of all the world's food in a very small area, a ''postage stamp.'' Thus some argue that if in fact tropical production can be highly productive, other lands may be deployed for alternative uses, including the preservation of native biomes (Phalan *et al.*, 2011). We are curious as to the level of productivity tropical soybean-maize systems achieve, because if highly productive then we may be witnessing a shift in the locus of global agriculture. Historically superior productivity resulted in the temperate regions in North America and Europe engaged significant land use change by clearing of forests and the plowing of prairies, which in turn released other regions from contributing to global grain stocks (Conway, 2001). Thus high productivity in the ''North'' spared land from development in the ''South.'' Raising tropical agricultural productivity through the development of new soybean-maize systems may change the land sparing equation.

The study of agricultural productivity commonly employs analysis of the relationship between outputs and inputs,

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which has long been a subject of research. We refer readers to Fuglie (2004), Fuglie (2010) Rada and Valdes (2012) for a basic understanding of the approach. The TFP can be extended further to include revenue and cost shares to better match the manager's decision making process (Equation 1). Total output growth is estimated by summing over the output growth rates for each commodity weighted by its revenue and cost share.

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \sum_i R_i \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) - \sum_j S_j \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right) \quad (1)$$

where R_i is the revenue share of the ith output and S_j is the cost-share of the jth input.

Of particular interest is not simply the relationship between inputs and output, but output per unit of land, which is yield, as well as the expansion of land used to raise output, extensification (Equation 2).

$$\underline{A} \qquad \underline{B} \qquad \underline{C}$$

$$\dot{Y} = \dot{X}_1 + T\dot{F}P + \sum_{j=2}^{J} S_j\left(\frac{\dot{X}_j}{X_1}\right) \quad (2)$$

$\dot{X}_1$ reflects the change in the size of the land base. Increasing output by adding land under cultivation reflects extensive growth, while increasing yield per unit of land reflects intensive growth, whether that be through greater productivity or increasing inputs per land unit. Rearranging terms within the TFP framework allows the identification of three elements of output growth; the addition of land, factor productivity and changing inputs. Output growth, $\dot{Y}$ becomes simply the growth in TFP plus the growth rates of land and the inputs multiplied by their respective cost shares. Empirically estimating the three components of growth, which we do, reveals the distribution as to the source of growth.

From 2001–2010, global output of total crop and livestock production increased by an average 2.5% per year (Figure 1). Globally, agriculture total factor productivity during the 2001–2010 period comprises 72% of global agricultural growth while input usage per hectare, expansion of agricultural land, and increased irrigation comprise 13%, 11%, and 4% respectively (Fuglie and Rada, 2013). Thus at the global level, the use of technology, whether physical or managerial, significantly raises agricultural output. The main source of output expansion has not been through the addition of more inputs, say chemicals, per hectare or expanding agriculture's land footprint, extensification. Thus, we hypothesize and analyze the following: Ho1: Tropical soybean and maize production follows the global trend and involves high levels of total factor productivity ($T\dot{F}P$).

Increased yields, rising grain production, and higher incomes may cause farmers to expand their operations, thus increasing their land base (Southgate, 1990). Global trends though demonstrate that farmers don't employ an extensification strategy to meet growing food demand and increase the levels of profitability of their operations. Thus we hypothesize that land expansion (extensification) will play a minor role in the expansion of output by our sample of tropical producers. Ho2: Tropical soybean and maize production follows the global trend and involves low levels of extensification ($\dot{X}_1$).

Finally intensifying production by increasing the level of inputs, especially crop protection, fertilizers, and fuel certainly raises output at the margin. Input intensification, while raising output per hectare and the productivity of land, labor, and physical capital, can have negative local, regional, and global consequences, such as increased erosion, lower soil fertility, reduced biodiversity, ground water pollution, eutrophication of rivers and lakes, and changes to atmospheric constituents and climate (Matson 1997). But positive input productivity can be land sparing worldwide if yield growth outpaces demand growth (Baker *et al.*, 2013). We therefore hypothesize at minimum positive productivity, or consistent with Ho1, high levels of factor productivity resulting from the use of technology across the set of inputs.

Ho3: Tropical soybean and maize production follows the global trend and involves positive levels of factor productivity ($\sum_{(j=2)}^{J} S_j\left(\frac{\dot{X}_j}{X_1}\right)$) across the set of J inputs.

Methods

Researchers employ the number index approach, which holds revenue and cost shares constant over time, when

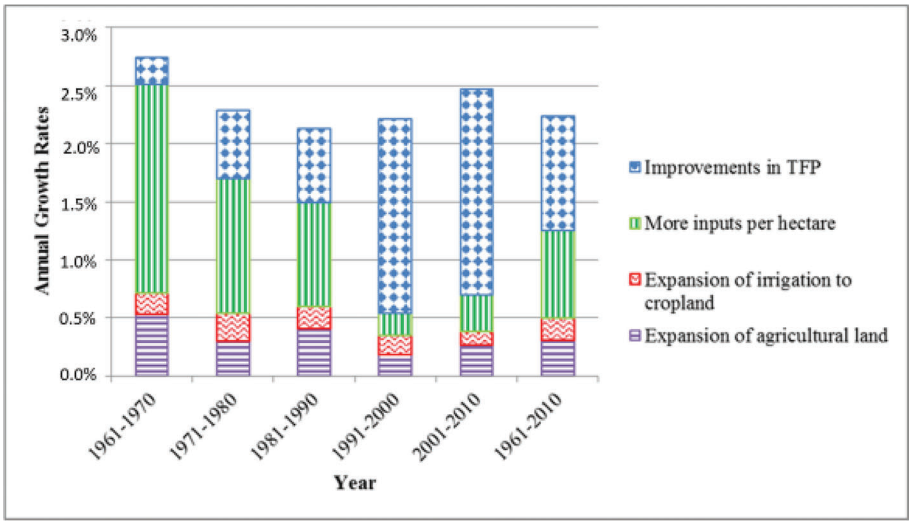

Figure 1: Global sources of growth in agricultural output, 1961–2010
Source: Fuglie, 2010.

prices and costs are not available, (see examples Evenson and Fuglie, 2010; Fuglie, 2010). The number index measure of TFP growth leads to "index number bias" in the measurement of TFP as producers change the combination of inputs and outputs in production in response to price changes.

Most analyses of total factor productivity commonly assume constant returns to scale which is necessary with national or aggregated datasets. Economies of scale is a firm-level assumption that does not apply to nations, and requires comparisons among firms to test (Evenson and Fuglie, 2010). Thus misspecification may take place because there may exist economies of scale among farm businesses (Kislev and Peterson, 1991). Additionally, input costs, prices, and revenue shares are assumed to be invariant and constant because data are aggregated at the national or regional level, when using such datasets (Fuglie 2010). The cost share weights often become fixed elements in the analysis of factor productivity. Homogeneous and time invariant prices and costs preclude a model specification that assumes that managers dynamically respond to changes in prices and costs, and thus shift both their input and output decisions.

We address these limitations by conducting our analysis using firm level data involving a cross section of dynamic cost shares and prices. Therefore, firm level analysis of total factor productivity becomes richer as it does not require a simplifying assumption with respect to returns to scale, revenue shares, and cost shares. Additionally, technological change may redefine the value proposition for input buyers, making price and cost determinations over time difficult, which has been a limitation in previous studies (Avila and Evenson 2010). For example, seed costs rise as maize seed containing transgenic technology substitutes for chemical inputs when fighting insect pests (Goldsmith 2001). Thus firm level data might reflect the dynamic switching by managers between chemicals and seed, depending on relative costs and perceived benefits.

Our model follows the Tornqvist index approach (Fuglie, 2004) and employs dynamic costs and prices, thus is more realistic. The Tornqvist index minimizes the effect of changes in price weights on output and input aggregation because weights are able to adjust over time as prices change. The Tornqvist index is more intuitive as managers will adjust input quantities based on both input cost and output price changes. We refine the components of Equation 2 above employing the Tornqvist index of simplified output (Equation 3), input (Equation 4), and total factor productivity growth (Equation 5), respectively, for year t:

$$\dot{Y} = \ln\left(Y_t / Y_{t-1}\right) = \sum_{i=1}^{n} \frac{\left(R_{i,t} + R_{i,t-1}\right)}{2} \ln\left(\frac{Y_{i,t}}{Y_{i,t-1}}\right) \quad (3)$$

$$\dot{X}_1 = \ln\left(X_t / X_{t-1}\right) = \sum_{j=1}^{m} \frac{\left(S_{j,t} + S_{j,t-1}\right)}{2} \ln\left(\frac{X_{j,t}}{X_{j,t-1}}\right) \quad (4)$$

$$T\dot{F}P = \ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \ln\left(\frac{Y_t}{Y_{t-1}}\right) - \ln\left(\frac{X_t}{X_{t-1}}\right) \quad (5)$$

Research setting

Intensification ratios reflect the number of crops per year average, which globally average less than 1.0 [per year (.82) (Siebert *et al.*, 2010). Within the last 15 years succession cropping (without irrigation), called "safrinha" in Portuguese, with an intensification ratio of 2.0 has emerged as a new farming system viable only in tropical settings. Succession cropping involves planting and harvesting two full crops per year on the same parcel of land. The safrinha system therefore involves "benign" extensification because while more hectares are planted, the land footprint remains unchanged. Successful development of these tropical grain systems provides the global community with a new land resource to meet rising food demand that is expected to double by 2050.

The planting and harvesting calendar in Mato Grosso differs from mid-latitude countries, such as the U.S. Tropical farmers plant soybean in the southern hemisphere anywhere from late September until late December and then harvest in mid-January until late April. But those who wish to produce two crops, plant prior to November 15 so that they are able to harvest the soybean, and then plant the maize crop in January and February (Goldsmith *et al.*, 2015).

Mato Grosso was a global deforestation hotspot in the early 2000's where active land clearing for agricultural expansion took place (DeFries *et al.*, 2013; Neill *et al.*, 2013). Deforestation though declined towards the end of the first decade of the 21st century through the combined effects of third party monitoring, government policies, and private sector initiatives that resulted in enhanced transparency and effective monitoring and enforcement (Fearnside, 2003). More importantly, these initiatives constrained land-clearing strategies (extensification) that traditionally had supported agricultural output growth.

Succession cropping represents, in part, a response to curtailed land availability that resulted from better deforestation control. Succession cropping differs from lower intensity single cropping, commonly practiced in temperate and sub-tropical settings, where farmers produce only one crop per year. Statewide maize follows soybean on 35% of the soybean hectares, almost doubling between 2008 and 2012 (Figure 2). Total safrinha maize production totals 19 million metric tons, which is about 2% of global supply.

Data

Previous studies on productivity growth in developing countries have limited access to reliable firm level data (Fuglie 2004; Fuglie 2008; Avila and Evenson 2010). Additionally, the lack of input and output quantities and prices limits productivity analysis. But the managerial decision making behind production decisions involves varying input usage and outputs based on the marginal productivity of an input and its relative cost, and relative output prices. So granular production, price, and cost data support the analysis of productivity, but often are difficult to obtain. As a result, there historically has been a lack of firm level agricultural data in Brazil, which constrains the detailed analysis of the TFP question (Gasgues and Conceição 2000; Gasgues *et al.*, 2004; Goldsmith, 2008; Avila *et al.*, 2010).

Two public agencies do compile statistics on the costs of production for the state of Mato Grosso, CONAB (Companhia Nacional de Abastecimento) and IMEA (Instituto Mato Grossense de Economia Agropecuária). But we only use these data for validation purposes

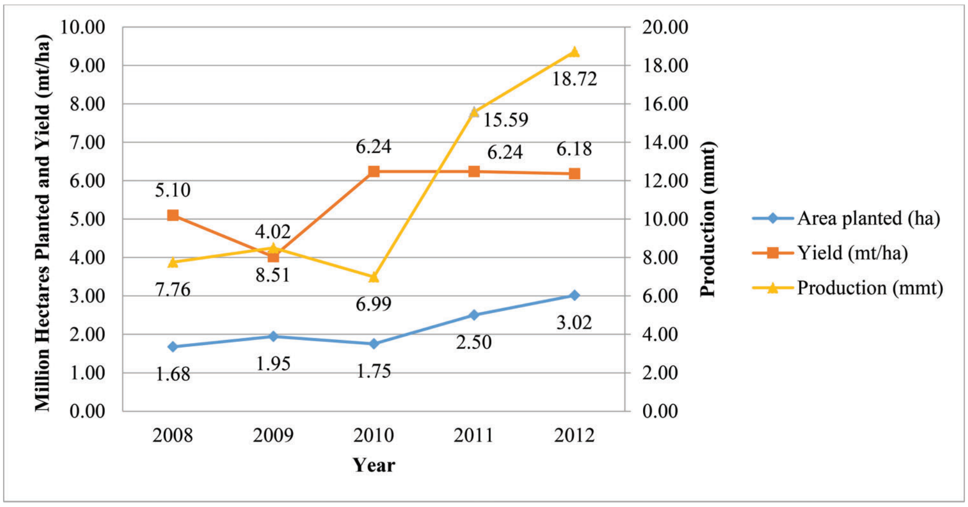

Figure 2: Mato Grosso safrinha maize production, 2008–2012
Source: IMEA and author's calculations.

Table 1: Comparison among the Reference Project, IMEA, and CONAB: soybean production averages – 2007–2012

Variables	Unit	Reference Project	IMEA	CONAB	IMEA difference
Land	(US$/ha)	77.83	142.93	131.79	–46%
Labor	(US$/ha)	48.32	15.87	34.69	204%
Fertilizer	(US$/ha)	221.36	264.32	261.07	–16%
Seed	(US$/ha)	56.37	50.2	46.02	12%
Pesticide	(US$/ha)	159.24	168.8	104.2	–6%
Diesel	(US$/ha)	43.99	–	–	–
Machine	(US$/ha)	53.36	24.06	52.67	122%
Aggregate inputs	(US$/ha)	675.96	666.17	630.44	1%
Gross revenue	(US$/ha)	1,077.18	1,146.43	492.92	–6%
Net return	(US$/ha)	401.21	480.26	–137.52	–16%
Grain price	(US$/mt)	331.26	367.45	164.31	–10%
Grain yield	(mt/ha)	3.25	3.12	3.00	4%

because price and cost estimates result from only a small phone survey of industry representatives; 10–15 participants along the entire value chain. The CONAB and IMEA data sets result from no direct interviews of, and data collection from, actual farmers to obtain actual prices received, costs incurred, or production decisions made (Anonymous 2010; Anonymous 2014).

This research addresses the data problem by using a unique firm level dataset derived from the Reference Project farms of the Maize and Soybean Association of Mato Grosso (Aprosoja, 2009). The data set provides the only detailed farm level income, expense, input, and output data available in tropical Brazil. The Reference Project began in 2007 to establish performance benchmarks for farmers in the state and provide the basis for a farm management training curriculum. The EPAGRI (Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina) program offered in the southern state of Santa Catarina serves as the model for the Reference Project (Spies, 2007). Aprosoja's team of regional technicians; train farmers how to use the data entry software, assist the farmers uploading their annual data, provide support in the form of data cleaning, summarize, analyze, and report the data for the benchmarking reports, and deliver farm management workshops (Aprosoja, 2015). Volunteer farmers apply, and about 40 are selected to be representative of the membership in terms of farming operation type, size, and geography (Aprosoja, 2010).

The database for this research comprises 43 farms producing soybean and maize between 2007 and 2012. The data include detailed costs, revenues, input quantities, and inventory values. Agronomic data and farm characteristics are also included such as farm size, share of different enterprises within the farm, percentage rented, etc. Estimates of the value of farm assets owned are made at the time farmers join the Reference Project. Depreciation plans are also part of the data collection process. The farmers upload their data into a central database using software provided by Aprosoja. Farmers have access to all the data online and so are able to see and correct data as needed.

From 2007–2012, the sample Reference Project farmers plant on average 1,632 ha of soybean, which is slightly smaller than the average of 2,000 for the state (Goldsmith, 2015). The Reference farmers produce 732 ha of second crop, safrinha maize. Thus 46% of total soybean land in the sample is followed by a maize succession crop. The level of succession is 21% higher than the 38% average level for the state. Aggregate input costs, including an annual land charge, are 1% higher at $676 compared with the state's statistical bureau, IMEA, estimates (Table 1). Soybean yields are about 4% higher, while prices received are about 10% lower. Thus overall the Reference farmer operational characteristics, costs, and prices, while not perfectly matched to the official state estimates, compare well to the official statistical averages for the state.

Clearly though caution should be employed as to the generalizability of the Reference data. Our challenge is that we need to understand the phenomenon of tropical intensification, and data are limited. The Reference data provide, to our knowledge, the best data available to date on the new fast growing class, the tropical commercial-scale grain farmer.

The data collected in Mato Grosso are recorded in the local currency. We convert all costs and prices to U.S. dollars based on the U.S. Federal Reserve Bank's daily average exchange rate for the years 2007–2012. Cropland harvested is the area planted for soybean and maize by each farmer. Cropland prices are the cost of land, reported by farm owners to the Reference Project, and measured in Brazilian Reals per hectares. By definition farmers' second crop maize (safrinha) land use is always less than or equal to the soybean cropland harvested. The Reference Project allocates total annual land costs across soybean and maize budgets based on the percentage of total cropped hectares each comprises.

Labor and wages include expenses related to annual hired labor. Farmers do not report unpaid labor costs. To calculate the number of workers per farm, the labor cost per farm was divided by the annual labor wage per worker for the state of Mato Grosso provided by IBGE (Instituto Brasileiro de Geografia e Estatística) for the years 2007–2012. The Reference Project allocates total annual labor costs across soybean and maize budgets based on the percentage of total cropped hectares each comprises.

Fertilizer is the amount of major inorganic nutrients annually applied to production, measured in metric tons per hectare. The fertilizer expense includes nitrogen, phosphorous, and potash. Farmers report the unit price per metric ton, application rate per hectare, and cost per hectare. These are then converted to fertilizer cost per farm for the TFP analysis.

Only 14% of the farmers report soil correctives (limestone) and pricing data were highly variable. Limestone accounts for less than 1% of the cost of production on those farms. It is an inexpensive input and it is applied every four to five years, thus there are a high number of missing values. Soil correctives were dropped from the cost of production.

Seed is measured in metric tons. Farmers report the seed cost per hectare, which is then converted to seed cost per farm for the TFP analysis. Aprosoja provided fixed seeding rates for soybean (0.05 mt/ha) and maize (0.04 mt/ha) production, which were used to calculate the price per metric ton of seed using the seed cost per hectare.

Pesticide is measured in liters. Farmers report the pesticide costs per hectare, which is then converted to cost per farm for the TFP analysis. To determine the amount of pesticide used per farm, the pesticide cost per farm was divided by the annual pesticide price per liter for the state of Mato Grosso provided by CONAB (2007–2012).

Across the entire panel, and across both crops, 13% of purchases involve complete input packages, where farmers pay one price per hectare for seed, fertilizer and pesticides. The cost was allocated to seed, fertilizer, and pesticide cost categories based on the average share costs from the other Reference Project farms.

Diesel is measured in liters. Diesel costs were provided on a per hectare basis. The diesel cost per farm was divided by the annual diesel price per liter for the state of Mato Grosso reported by ANP (Agência Nacional do Petróleo), for the years 2007–2012.

The quantity of machinery is the number of tractors, seeders, sprayers, and combines per farm. Machine expenses include only depreciation expenses in order to more accurately estimate the changes in machinery capital utilization in the TFP analysis. Reference Project farmers provide total depreciation costs on a per hectare basis. The machinery depreciation cost for each soybean and maize farm was estimated based on the value of equipment when farmers first joined the project and then follow the farmer's own depreciation schedule. The number of machines was distributed to each crop based on the cropland share percentage. Publically available pricing data on equipment types are nonexistent in Mato Grosso. For validation purposes, we compared the machinery expenses per hectare to FGV/IBRE (Fundação Getulio Vargas – Instituto Brasileiro de Economia) tractor prices per hectare for the years 2007–2012.

Results and Discussion

Descriptive statistics

Between 2007 and 2012, total production of soybean increased from 4,776 tons to 5,258 tons, averaging a 1% growth rate per year for the Reference Project farms. Total maize production increased from 2,811 tons to 4,140 tons, with an average annual growth rate of 13% (Table 2). This rapid increase in maize production results from the maize planted area growing at an annual rate of 8% per year from 2007–2012. The average soybean price growth rate equals 7% compared to maize at – 3% for the 2007–2012 period. Gross revenue per farm increased at an average annual growth rate of 8%.

Table 2: Soybean, maize, and succession crop production – average annual growth rates, 2007–2012

Variables	Unit	Average growth rates		
		Soybean	Maize	Succession
Grain yield	(mt/ha)	– 0.02	0.04	0.02
Area planted	(ha)	0.03	0.08*	0.03
Grain production per farm	(mt)	0.01	0.13	0.06
Price per mt	(US$)	0.07	– 0.03	0.05
Gross revenue per farm	(US$)	0.08	0.09	0.08
Maize land share	(%)	–	–	0.10

*Note: Maize extensification growth rate is 8% however under the succession system maize production involves no additional hectares.

Brazil's tropical soils require high input rates and active input management, especially for fertilizers, pesticides, and machinery (Schenpf, *et al*., 2001; Goldsmith, 2008; Rada and Valdes 2012). Additionally, tropical environments, have no freeze period, and have extended periods of high moisture and constantly high temperatures. High temperatures allow for significant pest pressure and therefore require aggressive management of harmful insects, weeds, and fungi. High yield outcomes in tropical settings rarely result from fertile soils and but rather from effective input management and the use of adapted seed varieties. As a result, fertilizer and pesticide cost per hectare are higher in soybean production in the tropics compared to higher latitude regions. Reference farmer soybean fertilizer and pesticide costs average US$221 and US$159 per hectare respectively, and US$183 and US$69, respectively, for second crop maize (Table 3). Combined average expenditures on fertilizer and pesticide for both crops equals US$404 and US$228 per hectare, respectively, and together comprise 53% of the total cost of production.

The average cost per hectare of maize seed is US$115; almost double the cost of soybean seed. It is important to note that soybean is a self-pollinated crop, thus producers can save and process some of their own grain for seed, which can directly lower the cost of soybean seed, and indirectly discipline the market price for soybean seed. Labor, diesel, and machinery costs per hectares are almost 1.50 times higher for soybean production compared to maize production, but are the lowest input cost categories on a per hectare basis.

The average cost difference of inputs per soybean hectare is US$130, or 19%, more in soybean production, than for maize, but gross revenue per hectare is about 1.50 times greater for soybean. Thus producers correctly focus greater input resources on the soybean crop, and limit inputs to the maize crop. This relationship differs from the Midwest U.S. where producers expend 28% more on the maize crop than soybean (Montesdeoca and Goldsmith, 2013).

On average the net return per hectare for soybean is US$401, an estimated 2.50 greater net return than maize, which averages US$160 per hectare. Maize as a lower-valued crop receives a grain price of US$127 per metric ton, almost 40% of the soybean price, which averages US $331 per metric ton for the Reference farmers. Maize yields relatively poorly in the tropical setting of Mato Grosso. Average maize yield for the Reference farmers is 40% more than soybean yields; a ratio of 1.69:1. But the ratio in Midwest U.S. (Illinois) is 3.03:1. So Reference Project farmers face not only 35% lower maize prices, but also 50% lower maize yields compared with the United States.

Factor productivity: output growth

Soybean output increases 51% across the Reference Project farms between 2007 and 2012, or 8% per year (Table 4). Rising prices account for about 2/3rds of the increase and expanding soybean cultivation about 1/3rd, and together they compensate for a slight fall in yield.

The maize output growth exceeds soybean yield growth by increasing 66% per farm from 2007 and 2012, or 9% per year. Maize's output increase reflects a different story from soybean. Maize area planted comprises approximately

Table 3: Soybean, maize, and succession crop production average costs per hectare, 2007–2012

Variables	Unit	Average cost per hectare		
		Soybean	Maize	Succession
Land	(US$/ha)	77.83	47.29	125.12
Labor	(US$/ha)	48.32	29.73	78.04
Fertilizer	(US$/ha)	221.36	182.55	403.90
Seed	(US$/ha)	56.37	115.17	171.53
Pesticide	(US$/ha)	159.24	68.90	228.14
Diesel	(US$/ha)	43.99	28.21	72.19
Machine	(US$/ha)	53.36	34.26	87.62
Aggregate inputs	(US$/ha)	675.96	545.70	927.15
Gross revenue	(US$/ha)	1,077.18	705.70	1,414.37
Net return	(US$/ha)	401.21	160.00	487.22
Grain price	(US$/mt)	331.26	127.54	458.80
Grain yield	(mt/ha)	3.25	5.50	8.75
Area planted	(ha)	1,632.11	731.63	1,632.11

Table 4: Soybean, saize, and succession output and input usage: average annual growth rates (%), 2007–2012

Variables	Unit	Average growth rates (%)		
		Soybean	Maize	Succession
Output growth	(%)	8.00	9.00	8.00
Area planted	(ha)	3.00	8.00	3.00
No. of workers	(person)	–5.00	–4.00	–5.00
Fertilizer	(mt)	4.00	13.00	5.00
Seed	(mt)	3.00	8.00	4.00
Pesticide	(liter)	16.00	16.00	16.00
Diesel	(liter)	4.00	6.00	4.00
Machine	(machine)	10.00	15.00	11.00

2/3rds of the increase, and yield 1/3rd, while price actually fell 3%.

Output increased 53% from 2007 and 2012, or on average 8% per year when combining both crops as a succession crop production system. Producers incur negative yield growth in soybean and positive yield growth in maize. There is an interesting interplay among expanding hectares planted, yield improvement, and price across the two crop system as farmers strive to achieve overall business (output) growth. Reference Project farmers expand crop production output by increasing hectares planted of both soybean and maize. But this expansion is minimally extensive as the expanded maize hectares occur on the same land has the soybeans. This uniquely tropical form of output growth plays a major role for Brazilian farmers seeking to expand gross revenue, without opening new lands for agricultural production. Thus succession cropping and higher maize yields leads to most of the increase in output per hectare, not increased soybean yields or rising prices.

Factor productivity: input growth

Farm labor for soybean production mostly decreases over the six-year period with an average 5% decrease from 2007–2012. The number of workers for maize averages a – 4% growth rate per year. A rising annual labor wage serves as the likely cause for the slowdown in labor use on the Mato Grosso farms. Over the six-year period, the annual labor wage doubles from US$4,969 in 2007 to US$10,055 in 2012, growing at an annual rate of 14% per year.

The substitution of labor inputs occurs with the intensification of industrial inputs such as fertilizer, seed, pesticide, diesel, and machinery. Pesticide and machinery inputs have the highest overall growth rates from 2007–2012, within the safrinha cropping system, growing at 16% and 11% per year, respectively. The price for all inputs, except pesticides, has risen over the study period amplifying input intensification as a source of growth (Table 5). The average fertilizer price per metric ton for soybean production from 2007–2012 is 76% (US$513) that of the fertilizer price of maize at US$684. From 2007–2012 the average price of maize seed was 2.5 times greater, US$2,880 per metric ton, than that of soybean seed at US$1,127 per metric ton. In sum Reference farmers face relatively higher input costs and lower grain prices for maize, compared with soybean, which is only partially compensated for by maize's moderately higher yields compared with soybean.

The Tornqvist index is based on actual factor (cost) shares paid for inputs and input quantities per year. The Tornqvist index measures a 40% increase in total input use in soybean production between 2007 and 2012, while input use growth is almost twice as high in maize at 76%. High maize total input use growth results from the growth in area planted, and fertilizer, and pesticide application. The Tornqvist index for the safrinha system as a whole shows a 44% increase in inputs from 2007–2012.

Factor productivity: land use growth

Soybean area planted grew from 1,429 hectares planted in 2007 to 1,710 hectares in 2012, averaging 1,632 hectares planted per farm over the six-year period. Soybean cropland expands about 3% per year throughout the entire period (Table 4). On that same cropland, maize planted increases an average 8% per year. In general, the area of cropland planted continues to grow, driven by the increase in price of land and the need to achieve commensurate returns for the added land cost. From 2007–2012, the price of land per hectare increases at a rate of 16% per year.

Total and partial factor productivity: soybean

The growth in total soybean output is due almost entirely to increases in land under cultivation and price, as yield decreases. Soybean shows positive total factor productivity, even though land factor productivity is negative, as are pesticides and machinery (Table 6). Labor productivity dramatically rises as a reduction in labor occurs while output expands. Small amounts of soybean land expansion under cultivation and price increases compensate for the decline in yield and weak individual factor productivity.

Specifically, soybean productivity per worker increases by an average 13% per year from 2007–2012, as labor inputs decline 5% per year while output grows. Also land per soybean worker increases by about 8% per year, as land under cultivation to expands while labor declines. Output growth per metric ton of fertilizer increases by approximately 5% per year. Fertilizer productivity is dampened as the sharp rise in costs offsets the relatively low levels of fertilizer usage growth. Similarly, soybean seed factor productivity grows 5% per year, as its change in quantity used rises only 3%. Interestingly the price of seed rose 15% but its cost share changes little due to seed being a relatively small component of the soybean input bundle. There also is significant inflation among a number of the other more important inputs, such as land,

Table 5: Soybean, maize, and succession crop input prices & average annual growth rates, 2007–2012

Variables	Average growth rates			Unit	Average prices			Cost
	Soybean	Maize	Succession		Soybean	Maize	Succession	Share
	%				US$			%
Grain	7.00	–3.00	5.00	(/mt)	331	127	484	–
Land	17.00	16.00	16.00	(/ha)	78	47	124	13.00
Annual Wages*	14.00	14.00	14.00	(/person)	7,724	7,724	7,724	7.00
Fertilizer	9.00	7.00	8.00	(/mt)	513	683	1,197	33.00
Seed	15.00	11.00	12.00	(/mt)	1,127	2,879	4,006	8.00
Pesticide**	–3.00	–3.00	–3.00	(/liter)	26	26	52	24.00
Diesel***	2.00	2.00	2.00	(/liter)	1	1	72	7.00
Machine****	1.00	7.00	3.00	(/tractor/ha)	47	20	67	8.00

Note: The sources of prices are *IBGE, **CONAB, ***ANP, and ****FGV/IBRE.

labor, and fertilizer. Productivity per machine decreases by an average of 2% per year from 2007–2012. Weak machinery productivity among the sample of farmers from Mato Grosso occurs as machinery use grows faster than output. This may reflect rapid expansion of conventional machinery capital in the face of the rise in total hectares cultivated combined with a need to reduce labor costs due to rapidly rising wages. Pesticide is the second largest component of the farmer's input bundle (24%) and also achieves negative (–7%) factor productivity because the quantity used dramatically rises 16% per year on average, far outstripping soybean output growth. The decline in factor productivity occurs even as prices per liter fall (–3%). Finally, diesel, a fairly minor soybean input at 8% of total costs, saw only a 2% annual increase in price, a moderate 4% increase in quantity used, and little change in its cost share. As a result, diesel usage reflects a positive factor productivity of 4% per year.

Total and partial factor productivity: maize

The decline in maize total factor productivity over the study period results from the rapid rise in fertilizer, pesticide, and machinery input usage per farm, which outstrip yield increases that are muted by falling grain prices. Productivity per maize worker increases by 13% per year over the six-year period, as labor inputs decline 4% per year and output increases. In addition, land per worker increases by 12% per year, as land expands and labor declines. Productivity per machine decreases by an average 5% per year from 2007–2012 as maize land expands 8% per year over the period while machinery input use grows at 15% per year. Productivity per metric ton of fertilizer decreases by about 3% per year. This is due to the high annual fertilizer usage growth rate of 13% compared with the output growth of 9% per year. Maize seed factor productivity increases by 1% per year, as its input usage rises at 8% per year. The price of seed grows 11% per year but its cost share changes little because seed is a relatively smaller component among the input bundle, and there is a significant increase among a number of other important inputs, such as land, labor, and fertilizer. Pesticide productivity decreases at 10% per year because input usage increases on average 19% per year, far outstripping maize output growth. Lastly diesel, one of the smallest input categories, with a 5% cost share, sees only a 2% increase in price, a 6% increase in quantity used, and little change in its cost share. As a result, its productivity is positive by improving by 3% per year.

It is important to note the stark management differences between the soybean and maize units within the safrinha system. Higher input usage and factor productivity demonstrate the primacy of soybean production as a business unit within the safrinha system. Maize input usage, especially when removing the high cost seed (hybrid) category, is much lower in tropical settings compared with soybean. The nominally, as well as relatively high, input usage by tropical soybean managers stands in sharp contrast to soybean practices in temperate production zones. Tropical maize factor productivity is poor, showing weak management controls, at the same time maize hectares rapidly expand. Thus it appears that maize within the safrinha system is a secondary crop, and justifies the diminutive Portuguese term "safrinha." Importantly, expanded planted hectares, an extensive approach, dominates over input intensification and total factor productivity in the short run.

Decomposed output growth

The smallest source of growth in the safrinha system is from total factor productivity, with a growth rate of only 1% per year (Table 7). Thus we reject Hypothesis 1.

Table 6: Soybean and maize productivity growth rate (%) overview 2007–2012

Variables	Cost share		Input use growth rate		Input price growth rate		Productivity growth rate	
	S	M	S	M	S	M	S	M
Land	13	16	3	8	17	16	–2*	4*
Labor	7	5	–5	–4	14	14	13	13
Fertilizer	33	33	4	13	9	7	5	–3
Seed	8	13	3	8	15	11	5	1
Pesticide	24	21	16	19	–3	–3	–7	–10
Diesel	7	5	4	6	2	2	4	3
Machine	8	6	10	15	1	7	–2	–5

Note: Where S = soybean and M = maize; all values expressed as %.
*Input productivity is the ratio of output per unit of input. One unit of land is one hectare therefore its productivity is yield growth per hectare.

Table 7: Soybean, maize, and succession crop decomposed output growth, 2007–2012

Variables	Unit	Soybean	Maize	Maize*	Succession
TFP growth rate	(%)	2.00	–2.00	–2.00	1.00
Extensification growth rate	(%)	3.00	8.00	0.00*	3.00
Input intensification growth rate	(%)	6.00	10.00	18.00	7.00
Decomposed output growth rate	(%)	11.00	16.00	16.00	11.00
Extensification percentage	(%)	27.00	44.00	0.00	27.00
Input intensification percentage	(%)	73.00	56.00	100.00	64.00
TFP Percentage	(%)	18.00	ND	ND	9.00

Note: ND = not determined.
*Extensification percentage for maize is 0% even though maize extensification growth rate is 8%. Under the succession system maize production involves no additional hectares.

Maize has negative rates of growth of TFP at –2%, while soybean shows positive TFP growth at +2%. Only 9% of output growth is due to TFP. Thus the succession system diverges from global trends and employs relatively lower levels of technology, which results in little productivity improvement of the key factors of production. The low TFP growth rate though makes sense when farmers manage the second crop somewhat like a ''free good.'' They are able to expand output through a unique extensification approach where they already own or control the land on which they can expand. This relieves tropical farmers at this point in time of having to make significant capital investments in advanced agricultural technologies to achieve growth.

Farm managers continue to take the traditional approaches to grow their farm businesses, expanding land and non-land input utilization at this stage of the development of tropical agriculture and the safrinha system. Combining soybean and maize into a succession system, presents an extensification annual growth rate of 3% a year, which occurs on the soybean land. The much larger expansion (8% per year) of land for maize cultivation occurs on soybean land so is not extensive, but actually intensive, more output per unit of land. Modern commercial tropical grain farmers continue to utilize the extensification strategy as 27% of growth results from expanding the land base. Thus we reject Hypothesis 2 as tropical producers diverge from global trends where only 11% of growth results from land expansion, less than half the level from the sample.

Finally, safrinha non-land input intensification grows at 7% per year; 10% per year on the maize hectares and 6% on the soybean. So most of soybean output growth (73%) results from increased input usage, while 56% of maize growth results from intensification of inputs. As a system, 64% of succession output growth results from intensification of inputs. Thus we also reject Hypothesis 3 as intensification of inputs as a source of growth among tropical grain producers is almost five times higher than the global level of 13%.

Conclusion

The objective of this manuscript is to better understand the nature of agricultural productivity under a new tropical system of production, safrinha or succession cropping, which results in two grain crops per year. The subject provides scholars and policymakers a technical foundation by which to think about agricultural expansion in the tropics. We are able to isolate how managers utilize the various inputs comprising farm production to produce both soybean and maize. Our sample of tropical farmers shows that 64% of growth involves input intensification strategies through greater chemical input application. This makes sense as pest pressures in tropical environments are high, soil fertility is low, soil quality is poor, and substitution with biotechnology provides only limited benefits. But the environmental tradeoffs from widespread chemical use when expanding production in the tropics requires attention. Alternatively, from an agribusiness perspective the primacy of inputs when increasing output portends a strong business environment for input suppliers, especially when farmed hectares continues to increase through deployment of the safrinha technology. Technologies that can help manage the high pest loads of tropical environments while stewarding the environment will hold great value going forward.

Correspondingly our results show low levels (9%) of total factor productivity driving growth, which can be interpreted as managers preferring traditional inputs and extensification over the use of advanced technologies. For agribusiness technology suppliers the implications from such behavior are a weak demand for the newest technologies among some of the fastest growing markets in the world. Currently, tropical managers can conventionally grow their businesses through succession crop extensification and intensification using traditional chemical inputs rather than expand output employing new technology. Policy makers too should note that technology adoption among tropical farmers, some of whom are some of the largest producers in the world, appears to significantly lag temperate region farmers. But doing so does not appear to constrain their growth.

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