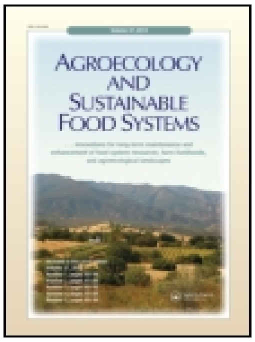

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ABSTRACT
Contemporary society is characterized by faith in the technological paradigm as a solution to economic, social, and environmental challenges. This has led to a lack of critical analysis toward the contradictions inherent to production systems. In the primary sector, this phenomenon is expressed by the creation of a productivist ideology in which "producing more is better." The negative aspects of the production techniques are hidden or classified as necessary evils to be solved with more technology. A case study compared three corn production systems on family farming: a) organic agroecological maize with open-pollinated variety (OAM), b) conventional hybrid maize (CHM), and c) transgenic hybrid maize (THM). The CHM and THM had greater production costs and productivity driven primarily by high dosages of fertilizer and the price of GM seeds. The high doses of nitrogenous fertilizer contaminate water and food with nitrates and nitrites. Economic viability of CHM and THM depends on large-scale production and public subsidies to purchase inputs and outsource risks through crop insurance. This article demonstrates that increasing agricultural productivity through the intensive use of inputs contrasts with the diminishing return on invested capital, and increases the environmental impacts without changing the economic performance of the activity.

KEYWORDS
Added value; family farming; sustainability

Introduction

There is growing concern that failure to increase global food production in step with population growth could be catastrophic (FAO 2011; Foley et al. 2011). Such warnings of imminent famine have recurred for centuries (Malthus 1798; Ehrlich 1968), but have been met by spectacular increases in food production driven by new technologies and the expansion of

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agricultural land. Widespread adoption of crop rotation and heavy plows dramatically increased output between the 11th and 13th centuries (White 1964), with even higher yields obtained during the British agricultural revolution of the 18th and 19th centuries, when forage and livestock were incorporated into the rotation, providing food, animal traction, weed control, and organic fertilizers (Mazoyer and Roudart 2010). In the 1840s, Liebig (1803–1873) demonstrated that plants could be grown in specific chemical solutions containing no organic matter, initiating the widespread use of chemical fertilizers, which accelerated after the development of the Haber–Bosch process for synthesizing nitrogen fertilizer in 1910 (Goodman, Sorj, and Wilkinson 1990; Pollan 2006). The Green Revolution of the 1950s, which combined careful plant breeding with intensive mechanization, irrigation, mineral fertilization, and pesticide use was followed by transgenic hybrid agriculture, which incorporates genetic traits into food plants that theoretically make them more productive and easier to grow (Goodman, Sorj, and Wilkinson 1990). Using these technologies, Brazil has dramatically increased agricultural yields and agricultural area in recent decades, particularly in the Amazon and the Cerrado biomes (Macedo et al. 2012; Rada 2013; Nepstad et al. 2014).

Many of these technologies, however, have caused serious environmental problems (Enserink et al. 2013; Carson 1962), as has the conversion of natural ecosystems to agriculture (Nobre and Borma 2009; Nepstad et al. 2008; Foley et al. 2007). As a result, agriculture now poses one of the greatest threats to global ecosystems and to the life-sustaining services they generate, including ecosystem services essential to agriculture (Millennium Ecosystem Assessment 2005; TEEB 2008; Rockstrom et al. 2009; IPCC 2013). In some ecosystems, so much land has been converted to agriculture that the original ecosystems and the ecosystem services they provide may collapse without extensive restoration (Aronson et al. 2006; Aronson, Milton, and Blignaut 2007), so expansion of agricultural area is no longer viable. This is the case in Brazil's Atlantic Forest (Metzger 2009; Silva et al. 2011; Banks-Leite et al. 2014).

The need to develop agricultural systems that increase food production and protect local and global environments may be the greatest challenge of the 21st century (Godfray et al. 2010; Foley et al. 2011). Two distinct approaches have been proposed to meet this challenge, known as land sharing and land sparing. These differing views have generated major debates among both scientists and policymakers (Wisniewski et al. 2002; Ewers et al. 2009; Azadi and Ho 2010; Godfray 2011; Fischer et al. 2011; Phalan et al. 2011).

Proponents of the land sparing approach, which is basically a continuation of current trends, generally advocate more intensive chemical inputs, improved hybrids and transgenic crops to increase yields per hectare, thus, allowing more land to be set aside for conservation (Phalan et al. 2011; Uzogara 2000; Dibden, Gibbs, and Cocklin 2013; Proponents of land sparing claim that agroecological and organic systems are either incapable of feeding the world, or else could cause more environmental harm because they demand more land conversion (Seufert, Ramankutty, and Foley 2012; Connor 2013; de Ponti, Rijk, and van Ittersum 2012). Agriculture should focus on maximizing yield per hectare.

In contrast, agroecology and other land sharing approaches seek to design agricultural systems that mimic the closed cycles of ecological processes with a focus on productivity, stability, sustainability, and equity (Altieri 2002; Gliessman 2007). Many proponents of agroecology and land sharing claim that conventional agriculture is based on NPK or "productivist" mentality, in which the goal is greater yields, environmental problems are largely ignored, and soil is seen simply as a substrate to which farmers apply industrially synthesized fertilizers to produce food and raw materials. This reductionist approach is only capable of considering one or two variables simultaneously, and, thus, proposes simplistic solutions to complex problems, which frequently cause new problems (Perfecto and Vandermeer 2015; Howard 1943; Pollan 2006). Furthermore, modern, input-intensive agriculture has low socioecological resilience: fossil fuels (the feed stock for most fertilizers and pesticides) and other nonrenewable resources, including mined phosphates, which must eventually run out (Cordell, Drangert, and White 2009; Dawson and Hilton 2011; reliance on a limited variety of hybrid seeds increases the threat of major crop failure in the face of a new disease or pest (Gliessman 2007); and fertilizers and pesticides degrade the ecosystem services they are intended to replace, thus, increasing our reliance on technologies that resource depletion or waste emissions may force us to abandon (Power 2010). Agroecology is designed to replace nonrenewable off-farm inputs controlled by profit-driven, agro-industries with renewable on-farm inputs generated by natural ecological processes and the farmers' local knowledge of the same (Altieri and Nicholls 2012). Land sharing proponents claim that agroecology can reverse ecological damage while producing nearly as much or even more food per hectare than conventional food systems (De Schutter 2010; Pretty et al. 2005; Badgley et al. 2007; IAASTD 2008; Ponisio et al. 2014).

Another important issue is which of these production systems is most viable to farmers, the agro-industrial sector, and to society as a whole. Net income is the difference between total revenue and total costs, including ecological costs, and is maximized when rising marginal costs equal diminishing marginal benefits. There is widespread concern that the mono-cropping, chemical use, and mechanization associated with both the Green Revolution and transgenic hybrids degrades soil quality and structure and wipes out native populations of pest predators even as pest insects develop immunity, forcing farmers to apply ever greater quantities of expensive and environmentally harmful pesticides and fertilizers (Pimentel and Pimentel

1990; Pingali 2012; Fox et al. 2007). These expenditures reduce net incomes to farmers, but increase profits for agro-industrial corporations. Driven primarily by profit, private corporations have little incentive to protect the environment or meet the needs of the underfed, who are invariably poor with minimal purchasing power (Spielman 2007; Byerlee and Fischer 2002; Pingali and Traxler 2002). Governments rarely force farmers or agroindustry to pay the ecological costs of their activities, and often provide direct subsidies as well, which increase farmer net incomes but reduce net social gain (Myers and Kent 2001; Weiss and Bonvillian 2013). Government enforced patents on hybrid seeds and other inputs allow agroindustry to charge monopoly prices far exceeding the marginal cost of production, which reduces economic benefits for farmers and society while allowing agroindustry to extract most of the economic surplus that these technologies generate (Farley and Perkins 2013; Wright and Pardey 2006).

The ratio of marginal social costs to benefits for conventional agriculture in Brazil may be worsening. According to data gathered by IBGE (2012), the quantity of fertilizers sold per unit of cultivated area doubled between 1992 and 2004. Brazil has also become the world leader in the use of pesticides, with average applications exceeding 3.5 kg of active ingredient per hectare in 2009 (IBGE 2012; Londres 2011). The intensive use of inputs increases both ecological and economic costs and risks (Altieri and Nicholls 2012; FAO 2013; Espíndola and Nodari 2013).

Brazil's public policies may exacerbate the problem. The National Program to Strengthen Family Agriculture (PRONAF) offers subsidized loans for off-farm inputs to agriculture. The family farmer insurance program (SEAF) provides subsidized crop insurance to family farmers who rely on PRONAF credit. Both public policies stimulate the adoption of input intensive "modern" farming practices in pursuit of greater productivity (Tonneau and Sabourin 2007; Grisa 2012).

Family farmers in Santa Catarina, Brazil, practice three different production systems for maize: organic agroecological maize (OAM), conventional hybrid maize (CHM), and transgenic hybrid maize (THM). The Brazilian government currently provides subsidized crop insurance for CHM and THM, but not for OAM (Capellesso, Rover, and Cazella 2014). Furthermore, farmers are rarely penalized for the ecological damage caused by agrochemical inputs. These policies are likely to increase the net income of CHM and THM to farmers relative to OAM, but are also likely to induce both types of HM farmers to take more risks and cause more ecological degradation than is socially desirable.

The goal of this research is to conduct a comparative analysis of these three production systems to help understand which approach is best able to maintain or improve food production and farmer livelihoods while reducing ecological costs. We also examine the impact of policies on farmers' production choices.

Patents allow agroindustry to extract monopoly rent for hybrid seeds and other patented inputs. We therefore expect that input prices will be greatest for THM, followed by CHM then OAM, and these higher prices will cancel out potentially higher revenue, equalizing individual farmer net income across practices, as predicted by economic theory. Negative ecological impacts of fertilizers and pesticides will reduce the social economic gain of THM and CHM, although we will not attempt to quantify ecological costs. We also expect that lower input costs for OAM will make it less risky than CHM or THM, especially in regions where climate variability has a large impact on yields.

Rational farmers would likely choose the least risky option when expected net incomes are approximately equal. However, government policies, particularly crop insurance, can change both the riskiness and net income of different practices for farmers. Subsidized crop insurance is currently only available to CHM and THM farmers. Numerous authors have found that subsidized insurance allows them to pass their risks on to society, thus encouraging them to engage in riskier behavior than they otherwise would (Capellesso, Rover, and Cazella 2014; Vasconcelos 2012; Petersen 2013), and we expect our study to support these results.

Methods

Following methods outlined by Yin (2005), we performed a case study of family farms in Far Western Santa Catarina, in the municipalities of Bandeirante, Barra Bonita, Descanso, Guaraciaba, and São Miguel do Oeste. The study area is characterized by small farms dominated by dairy production and maize production that is often intended exclusively for animal feed. During the harvest of 2011–2012, we surveyed 14 randomly selected family farmers using each of the three maize production systems common in the area: transgenic hybrid maize Bt[1] (THM), conventional hybrid maize (CHM), and organic agroecological maize with improved varieties (OAM). We chose maize for our study because it is widely planted on family farms and receives more resources from PRONAF than any other crop. Our study includes seven farms in THM, four in CHM and three in OAM, roughly reflecting the prevalence of these cropping systems in the region. Crops were sown between September 10 and 31 October 2011, which is appropriate for the agroclimatic zone (Brasil 2011).

We must emphasize that given our small sample size, our study must be interpreted as exploratory, with the goal of helping to formulate clear hypotheses that can be scientifically tested with larger and more detailed studies. In the case of THM farmers, the high level of technological standardization suggests that our sample is likely to be reasonably representative across farms, but we still face the limitation of data from only one year of drought and one year of optimal rainfall. In the case of CHM and OAM farms, there are simply too few farmers using the methods, and it was difficult to obtain even these limited samples. Driven by the productivist mentality, most CHM farmers have converted to THM; it is currently difficult to even obtain nontransgenic hybrid seeds. Most organic farmers in the region produce vegetables, not corn.

Data collection occurred in three stages: 1) a soil sample collected prior to seeding; 2) surveys of the cultivated areas using global positioning system equipment during the growing season; and 3) production and marketing data collected postharvest. In each stage, we performed semistructured interviews with the farm families to gather additional data on the three systems. To compare means between treatments, we used the Duncan test (5%) in the statistical program Sanest (Zonta and Machado 1984), which allows comparison between treatments with different sample sizes.

We adapted our economic analysis from the methods used by the National Supply Company (Conab), which differentiates between fixed and variable costs. Variable costs in our 2011–2012 survey included the operation of machinery and equipment, labor, seeds, pesticides, fertilizers, and soil amendments, transportation, and drying. For fixed costs, Conab includes "depreciation, periodic maintenance of machines, social charges,[2] fixed capital insurance, and expected returns to fixed capital and land" (Conab 2010: 20 [translated by authors]). Since we are conducting a comparative economic study between production systems, we focused only on the fixed costs that were relevant to the different technologies used. We standardized the costs of operating machinery and equipment in relation to market prices and used equal per diem costs for all the family farms.[3] Differences in land prices were primarily due to the proximity to the city or to paved roads, so we did not include land rent. We did not include capital depreciation, fixed capital insurance and returns to fixed capital.

None of the farmers used hired labor, so we valued the farmers estimates of their own labor inputs at the going wage (as reported by farmers in Brazilian real) of R$50.00 per eight-hour working day (R$6.25 per hour). Although we treated the farmer's own labor as a cost, we did not count it as an expenditure because no monetary payment was involved. The labor costs for mechanized services, animal traction or pesticide spraying are not added to other labor costs, but rather included in the cost of these services, which were often hired out.

Cover cropping is part of the production system, so we included establishment cost, which is zero in cases of natural reseeding of *Lolium multiflorum*. For poultry bedding and granulated organic fertilizer, we used the prices paid by the farmers. For soil amendments (calcareous), we used the average application cost over the last three years to account for residual effects. Farmers provided transportation and drying costs of maize production in R$/bag.

We used gross margins (Equation (1)) and value added (Equation (2)) to compare economic efficiency across different systems of maize production. Gross margin is equal to gross revenue minus all variable costs[4]; when fixed costs are included, gross margin is equivalent to economic net income as defined in microeconomic textbooks. A rational, profit-maximizing farmer should shut down when gross margins are negative. Value added is equal to gross revenue minus variable costs purchased in the market (expenditures). Value added includes the return to both the farmer's labor and capital, and is equivalent to accounting profits as defined in microeconomic textbooks. It has long been recognized that small family farmers with negative gross margins but positive value added often do not shut down, and instead engage in self-exploitation, which means they could work less or earn more as hired labor. Farmers may do this because they undervalue family labor, crop prices are temporarily low or they have other reasons for farming than net income maximization (Galt 2013; Mann and Dickinson 1978; Pratt 2009). When calculating value added, expenditures on animal services, family manpower, and organic fertilizer produced on the property were not considered because they are not purchased in the market. Since some farmers use some of their production for home consumption, the Gross Income was calculated using the sales price of products consumed on-farm provided by the farmers, R$25.00 per bag for the CHM and THM, and a 30% higher R$32.50 per bag for the OAM.

$$\text{gross margin} = [\text{gross income}] - [\text{variable costs}] \tag{1}$$

$$\text{added value} = [\text{gross income}] - [\text{expenditures}]. \tag{2}$$

Drought is a serious problem in Western Santa Catarina, with 7–12 periods of drought registered between 1991 and 2010 in the case study municipalities (Espíndola and Nodari 2013). Good rainfall for the 2010–2011harvest was followed by new droughts in 2011–2012 and 2012–2013. In order to compare years of drought with years of good rainfall, we obtained from farmers the crop yields from 2010–2011, which they identified as a year of optimal rainfall during which they applied approximately the same inputs to the same land areas as in 2011–2012. We adjusted transportation and drying costs according to the volume of grains from each harvest. These data allowed us to estimate gross margin and value added for a year with optimal rainfall,[5] although we acknowledge that our resulting comparison of good and poor rainfall years is essentially anecdotal owing to the sample size.

Our analysis of technical efficiency follows the guidelines of The Brazilian Society of Soil Science (BSSS; Tedesco et al. 2004), which allow farmers to determine the applications of specific quantities of fertilizers (NPK) and correctives (calcareous) required to achieve a given expected yield (EY) based on the soil nutrient profile. We modified this approach by using data from our soil analysis and reported fertilizer applications to calculate EY for each of the farms for each of the macronutrients, as if the macronutrient were the limiting factor of production. Recommendations for the application of macronutrients are based on a minimum EY for maize of 4,000 kg ha^{-1}. When actual applications fell below the minimum recommended, EY was less than 4,000 kg ha^{-1}.

Results and discussion

OAM farms used solar drying and ground their corn into flour. CHM farms also used solar drying; three quarters of farms used their corn for their own cattle, while one farm produced for commercial markets. All THM farms produced for commercial markets, and used artificial drying to hasten harvest and allow planting of a second, smaller crop before winter frosts. Solar drying and on-property storage on OAM and CHM family farms reduced average spending for transport and drying, as seen in Table 1.

Costs of manpower, animal services, and mechanization varied far more between the family farms than the averages reveal. Some properties were fully mechanized (1/4 in CHM; 1/3 in OAM; and 7/7 in THM), while in others mechanization is limited to old threshers (2/4 in CHM, and 1/3 in OAM) combined with human and animal labor, although cost differences between animal traction and mechanization were not statistically significant across

Table 1. Variable costs of maize production in the three systems adopted by the farmers in the harvest of 2011–2012, in the far western region of Santa Catarina.

	OAM			CHM			THM		
	1 ha^{-1}	R$ ha^{-1}		1 ha^{-1}	R$ ha^{-1}		1 ha^{-1}	R$ ha^{-1}	
Labor (h)	47.9	299.58	a	17.6	157.18	ab	—	—	b
Animal services (h)	19.7	236.00	a	21.2	230.07	a	—	—	a
Mechanization (h)	2.7	246.83	a	1.5	176.31	a	5.0	482.69	a
Covering seeds (kg)	26.7	10.67	a	23.8	11.90	a	29.2	23.17	a
Maize seeds (kg)	29.8	45.42	a	22.2	305.52	b	20.0	465.51	c
Pesticides (l, kg)	—	—	a	5.1	106.47	b	7.2	92.80	b
Fertilizers, correctives*		261.88	a		952.77	b		825.16	b
Drying, transportation		—	a		66.63	ab		197.12	b
Average variable cost	1,100.38		a	2,006.85		b	2,118.08		b
Average expenditure	564.80		a	1,696.46		b	2,118.08		b

Note: Differences between variables (R$ ha^{-1}) in each line followed by the same letter are not statistically significant according to the Duncan test: $p < 0.05$. OAM: organic agroecological maize with open-pollinated variety; CHM: conventional hybrid maize; THM: transgenic hybrid maize.
*Volume data is available in a specific Table 2.

treatments. The fact that operator labor was incorporated into the mechanization costs explains why THM had no labor costs (Table 1).

Costs for maize seeds, pesticides, fertilizers, and correctives deserve more attention. The data clearly show the higher cost of the transgenic hybrid seeds, which exceeded those of conventional hybrids by 52.4% and of open-pollinated varieties by 1,024.9%. While data on the actual marginal costs of production is proprietary, the much higher costs for transgenic and conventional hybrid seeds suggests that agroindustry is able to capture monopoly rent, as economic theory predicts. The Bt technology was developed to control the *Spodoptera frugiperda* and the *Helicoverpa zea* (Carneiro et al. 2009), but pesticide applications were not statistically different for transgenic and conventional hybrid maize. This contradicts Silveira et al.'s (2005) claims of decreased pesticide use, but supports the Brazilian farm lobby Agrosoja claims that the Bt technology no longer functions for *S. frugiperda*, and farmers must apply pesticides (Stauffer 2014). Furthermore, intensive use of soluble fertilizers and direct seeding systems has contributed to the emergence of secondary pests such as *Diloboderus abderus, Liogenys suturalis, Phyllophaga* spp., and *Cyclocephala* spp. not controlled by Bt, which now require chemical control (Barros 2012).

In 2013, Brazil's Ministry of Agriculture, Livestock and Supply responded to the emergence of another worrisome pest, *Helicoverpa armigera*, by authorizing imports of pesticides containing Emamectin Benzoate, which had been banned in Brazil since 2005 (Brasil 2013). The use of broad-spectrum insecticides on the 2013–2014 crop decimated populations of pest predator insects, contributing to a surge in *Bemisia tabaci* populations. *B. tabaci* is a vector for plant viruses, and required additional insecticide applications to control (Pitta 2014.).The evidence that Bt technology does not result in reduced pesticide use, and that pesticides used to solve one problem may cause new ones, supports the argument that the reductionist, NPK mentality is ill suited to agricultural production (Pollan 2006). Instead, transgenic Bt technology could be replaced with biological controls, such as *Bacillus thuringiensis* itself or the *Trichogramma* spp. The latter is a parasitoid wasp produced in bio-factories that attacks the caterpillars' eggs (Almeida, Silva, and Medeiros 1998; Cruz and Monteiro 2004) and also helps to control *H. armigera* (El-Wakeil 2007).

Fertilizers are the major cost for transgenic and conventional hybrid maize, with correctives playing a lesser role (R\$43.88 ha^{-1}in the CHM, and R\$31.64 ha^{-1} in the THM). Applications of soluble fertilizers averaged 724.5 kg ha^{-1}with CHM and 709.7 kg ha^{-1} with THM, and no fields had low application rates. Given the economic importance of fertilizer applications, we compared actual applications with those recommended by the BSSS for the soil structure and levels of soil fertility found in our study site (Table 2) as explained in our methods.

Table 2. Corrective analyses of pH and expected yield (EY) of maize grain according to the application of fertilizers (N, P, K), in three systems of maize production —family farms (FF) productive units in the far west of Santa Catarina, in the crop of 2011–2012.

		THM (kg ha^{-1})										
		1PD		2PD	3PD	4PD		5PD		6PD	7PD	
Organic fertilizer		—		16,667[f]	—	—		—		—	7,050[f]	
Urea fertilizer		512.8		416.7	344.8	348.2	253.3			481.8	296.2	
NPK fertilizer		416.7		416.7	344.8	348.2	283.5			272.7	296.2	
Liming[a]		—		1,600	—	—		—		—	1,600[c]	
N	EY of corn	15.839	18.506	14.720	11.747	11.869	10.136	10.136	10.136	16.576	11.246	11.246
P_2O_5	EY of corn	8,143	8,143	5,187	5,920	6,661	<4,000	<4,000	<4,000	<4,000	7,939	7,939
K_2O	EY of corn	5,987	5,987	10,160	5,138	8,179	5,252	8,252	5,252	9,455	8,020	8,020
Liming needed[b]		1,200	1,350	0	1,200	0	675	0	0	0	0	1,050
Harvest 2010–2011		10,742		10,200	8,571	10,345	6,514			9,818	10,903	
Harvest 2011–2012		3,453		8,517	6,360	2,974	2,888			7,004	4,350	
				CHM (kg ha^{-1})						OAM (kg ha^{-1})		
		8PD		9PD	10		11[e]	12			13	14
Organic fertilizer		—		—	—		—	10,769[d] + 308			578	280
Urea fertilizer		298.0		371.7	365.9		469.8	—			—	—
NPK fertilizer		397.4		334.6	365.9		293.7	—			—	—
Liming[a]		2,000		—	—		1,770	—			—	—
N	EY of corn	10,658		12,493	11,171				<4,000		<4,000	<4,000
P_2O_5	EY of corn	7,742		5,694	< 4,000		[e]		<4,000		<4,000	<4,000
K_2O	EY of corn	5,768		8,015	5,390			4,000			4,000	<4,000
Liming needed[b]		0		1,800	4,200			2,200			2,700	1,800
Harvest 2010–2011		6,755		8,922	8,780		7,143	5,692			6,067	4,200
Harvest 2011–2012		3,576		6,702	5,268		6,600	3,846			5,393	720

[a]kg ha^{-1} of limestone powder applied in effective calcium carbonate equivalent 100%.
[b]kg ha^{-1} of limestone powder necessary to achieve ideal soil PH in effective calcium carbonate equivalent 100%.
[c]Analysis collected after the use of limestone powder.
[d]Soil sample collected after the use of aviary litter.
[e]Area with no sample collection of soil.
[f]Liquid with low concentration.
THM: transgenic hybrid maize; CHM: conventional hybrid maize; OAM: organic agroecological maize with open-pollinated variety; PD: Direct seeding; NPK: soluble fertilizers with different compositions of N, P_2O_5 and K_2O.

Liebig's law of the minimum states that the growth of an organism is determined by the essential element that is most scarce, or limiting. Formulated in the 19th century, this law remains an integral part of the agronomy curriculum. While we recognize that Liebig's law is overly reductionist, as noted by Sena (2004), it is, nonetheless, relevant that CHM and THM farmers failed to acknowledge the law in two important ways. First, these farmers applied too much nitrogen when potassium and phosphate were limiting. For example, one plot on farm 1 had enough N to produce 18,506 kg ha^{-1}, but only enough K to produce 5,987 kg ha^{-1}. It follows that for the same total expenditures on fertilizers, farmers could increase EY by reducing N applications and increasing P and K until EY is equal for all three. Plots 1, 3, 5, 7, 9, and 10 would also need to apply more soil correctives. Furthermore, farmers of plots 1, 5, and 7 applied the same quantities of fertilizers and correctives to fields with different soil conditions, and could improve their technical efficiency by subdividing fields into homogenous plots (Tedesco et al. 2004). Second, CHM and THM farmers applied some nutrients at levels consistent with higher yields than could be attained by non-nutrient limiting factors, such as water availability. Given the frequency of droughts in the region, water availability will frequently constrain production, and large expenditures on fertilizers are particularly risky (Espíndola and Nodari 2013). It is also important to point out that actual yields generally exceeded estimated yields for the most limiting nutrient, a shortcoming recognized by the BSSS.

In contrast, OAM farmers used organic fertilizers, with small annual quantities of pelletized turkey manure when planting and larger volumes of poultry litter in alternate years. In all cases, their application rates were less than required to achieve an expected yield of 4,000 kg ha^{-1}. None of the OAM farmers applied lime, even though their lime requirements were almost always greater than for the hybrid farmers. Lime deficiencies were not surprising, since OAM farmers manage weeds with tillage, which leads to recommendation for greater use of correctives in comparison to the direct seeding used by THM and CHM farmers. Although water availability was also a problem for OAM farms, it was likely to be the limiting constraint on production since macronutrient levels were lower. Drought also posed less risk to OAM farms, which used their own manpower and animal traction so that expenditures accounted for just half of their variable costs.

No farmer used leguminous cover crops, which can fix nitrogen and provide straw that helps hold water in the soil. This is particularly surprising for OAM farmers, who by law are prohibited from using synthetic nitrogen. Studies suggest that the use of vetch (*Vicia sp.*) as a cover crop can provide up to 50% of the nitrogen requirements for maize cultivation (Beutler et al. 1997). When other farmers did use cover crops, they used grasses or *Brassica* sp., which do not fix nitrogen. Farms 13 and 14 opted to fallow. One reason that OAM farmers do not use cover crops is that they cannot use herbicides to kill the crop. Instead, they till the soil then sow immediately. In the presence of straw from a cover crop, it is only possible to sow seeds after awaiting the release of gases from the fermentation, a period in which weeds can emerge. The farmers were also concerned that plowing promotes soil erosion. Some farmers are testing the control of weeds with electricity as an alternative to plowing and harrowing (Brighenti and Brighenti 2009), but this approach requires a detailed analysis of economic viability.

Excessive nitrogen applications are not only economically inefficient, but are also associated with four environmental problems. First, excess nitrogen increases the susceptibility of plants to pests and diseases, requiring more applications of environmentally harmful pesticides (Chaboussou 2006). Second, nitrate and nitrite leaching contaminates surface and ground water (FAO 2013), negatively affecting human health, since levels greater than 10 mg L^{-1} can cause cancer and methemoglobinemia (Varnier and Hirata 2002; Kreutz et al. 2012). Furthermore, soluble fertilizers (especially nitrogen) have an adverse impact on health (Howard 1943), producing foods with high levels of nitrates and nitrites (Kreutz et al. 2012), and low levels of beneficial phytochemicals (Reganold et al. 2010). Third, nitrogen fertilizers are produced at high temperature and pressure, using large amounts of energy and emitting large amounts of carbon dioxide. Synthetic nitrogen is the main energy expenditure in intensive maize production (Pimentel et al. 2005), accounting for 48.9% of total energy inputs in CHM, 57.8% in THM, and less than one tenth that amount in OAM (Capellesso and Cazella 2013). Fourth, most nitrogen fertilizer is released to the environment (Erisman et al. 2007). When released as ammonia, it threatens eutrophication of water bodies, and when converted to nitrous oxides, threatens both climate stability and the ozone layer (FAO 2013; IBGE 2012). Currently, excessive nitrogen emissions constitute one of the most serious threats to planetary boundaries.

Economic bases of intensification: scale and externalization of risks

The gross margin of an activity—the difference between gross revenue and variable costs—determines whether or not it generates economic net incomes and is worth continuing for net income seeking individuals. Value added is the difference between gross income and off farm expenditures of the production system, and will be greater than or equal to gross margin. Our analysis of the harvest of 2011–2012 shows that both variable costs and expenditures were lower per unit of area on the OAM farms relative to the others (Table 3). The use of the farmers' own labor accounted for the largest difference between variable costs and expenditures across the farms, and was highest in the OAM, followed by CHM and THM.

Table 3. Economic analysis of maize production in the three systems of production conducted in the harvest of 2011–2012, estimation* for the harvest of 2010–2011 and average, family farms units (FF) in the far west region of Santa Catarina.

	OAM			CHM			THM		
	kg ha^{-1}	R$ ha^{-1}		kg ha^{-1}	R$ ha^{-1}		kg ha^{-1}	R$ ha^{-1}	
Harvest 2011–2012									
Costs		1,100.38	a		2,006.85	b		2,118.08	b
Disbursements		564.80	a		1696.46	b		2,118.08	b
Gross Revenue	3,322.2	1799.42	a	5,635.8	2348.31	a	5,263.2	2,193.04	a
Gross Margin		699.04	a		341.46	a		74.96	b
AddedValue		*1,234.62*	*a*		*651.85*	*ab*		*74.96*	*b*
Harvest 2010–2011*									
Costs		1,100.38	a		2,071.61	b		2,297.98	b
Disbursements		564.80	a		1717.34	b		2297.98	b
Gross Revenue	5,300.0	2,870.83	a	7,884.3	3,285.13	ab	9,844,5	4,101,89	b
Gross Margin		1,770.45	a		1,213.52	a		1,803.91	a
Added Value		*2,306.04*	*a*		*1,567.79*	*a*		*1,803.91*	*a*
Average Added Value		*1,770.33*	*a*		*1,109.82*	*ab*		*939.44*	*b*
Average area of cultivation (ha)		0.5	a		2.1	a		5.8	b
Added Value (maize)FF^{-1}		*988.96*	*a*		*1,971.70*	*a*		*5,779.23*	*a*

Notes: Averages (R$ ha^{-1}) followed by the same letters in the line did not differ among them by the test of Duncan: $p < 0.05$. Estimation* calculated by adapting the costs of the harvest 2011–2012 to the productivity of the harvest 2010–2011, with excellent distribution of rainfall.

OAM: organic agroecological maize with open-pollinated variety; CHM: conventional hybrid maize; THM: transgenic hybrid maize.

In the harvest of 2011–2012, gross revenue per unit area for the THM and CHM farms exceeded that of the OAM, although the difference was statistically insignificant. However, the gross margin was markedly inferior in the production areas of transgenic hybrid maize, and the value added even more so. Although gross margin was negative for one OAM farm, value added for OAM farms was always positive, but turned negative for three THM farmers, where values ranged from R–$735,48 ha^{-1} to R+$898,22 ha^{-1} (Figure 1). As

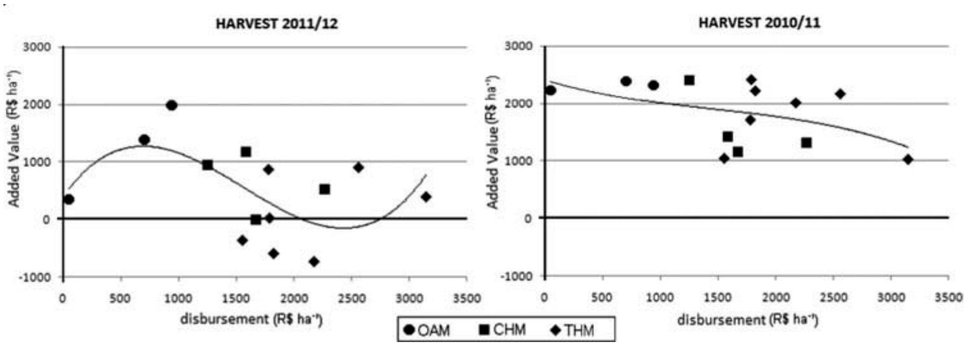

Figure 1. Relation between added value ha^{-1} and disbursements ha^{-1}, in the cultivation of maize, in three production systems of family productive units, in the far west of Santa Catalina—harvest for 2011–2012 and estimates for the harvest 2010–2011 (OAM: organic agroecological maize with open-pollinated variety. CHM: conventional hybrid maize. THM: transgenic hybrid maize).

the data on added value make clear, THM and CHM farming confront high levels of risk, reinforcing the need for crop insurance.

The 2010–2011 season, in which rainfall was optimal, provides an interesting contrast with 2011–2012. THM farms showed almost the same gross margin as OAM farms, and there was no statistical difference across all three farming practices. Although OAM farms had higher value added than the others, differences again were not statistically significant. In short, OAM generated superior economic results (added value ha^{-1}), during the years of water shortages, while all three farming practices were statistically equivalent in the years of good rainfall distribution.

Although our small sample size weakens the confidence of our results, OAM appears to be the most lucrative farming practice in years of drought, while all three practices are roughly competitive in good years. Averaging both harvests, value added per hectare is greater for OAM than for THM, although neither is statistically different from CHM. All else equal, an enterprise with greater value added should be less risky, since the farmer can choose to self-exploit in order to continue farming. In contrast, farmers with negative value added, including three THM farms in 2011–2012, could be forced to take on high interest debt in bad years, which is riskier than self-exploitation. Assuming that OAM can be scaled up, it should be the rational choice of net income maximizing farmers in areas subject to drought. Given that OAM likely has fewer environmental and health impacts than CHM and THM, its relative advantages for society as a whole are even greater. Even if risk-averse farmers do not adopt OAM, they should avoid excessive fertilizer applications when rainfall is uncertain and water could prove to be the limiting factor. Why then are THM farms greater in size and number than OAM farms, and why do both CHM and THM farmers over-apply fertilizers? We offer two explanations.

First, discussion so far has largely ignored government policy, in particular SEAF, the crop insurance program. SEAF insures certain crops against failures stemming from various environmental factors, including water scarcity. The program guarantees a minimum income to the farmer and reimburses for expenditures.[6] Our research verified Vasconcelos (2012) findings that conventional farmers feel protected by crop insurance, but OAM farmers are denied access. SEAF allows farmers to externalize risk, leading them to apply more fertilizers and incur higher expenditures than they should when drought is a risk. Furthermore, farmers are not penalized for the health costs or ecological degradation caused by excessive fertilizer applications. When economic actors are not required to pay the costs of an activity, they are likely to engage in the activity beyond the point where marginal costs exceed marginal benefits.

Second, we must explain why Brazil's public policy for family agriculture encourages economically inefficient production with high environmental impacts. This is particularly difficult to understand for farming activities that use inputs with patents held by foreign corporations, such as many transgenic seeds, which allows those corporations to extract nearly all the surplus income that these technologies can generate (Farley and Perkins 2013). When state subsidies allow farmers to earn more from transgenic seeds, rational farmers will be willing to pay more for those seeds relative to open-pollinated varieties, and royalty flows from Brazil to foreign corporations will increase. Foreign corporations, therefore, benefit from Brazil's agricultural policies. We suspect that these perverse subsidies must be due to the productivist, NPK mentality, in which output per hectare and the use of modern, high-energy, high-input production methods are mistaken for efficiency, while impacts on the environment and human health are treated as unavoidable collateral damage. Our research, therefore, suggests that Brazil's public policy for family agriculture encourages economically inefficient production with high environmental costs.

Summary and conclusions

Our analysis largely confirms our initial expectations. THM and CHM showed higher variable costs and far higher expenditures than OAM, although there is no significant difference between THM and CHM. While gross revenue ha^{-1} was significantly higher for THM than for OAM in a year with optimal rainfall, with CHM in between, the differences between CHM and the other two were not statistically different. In a drought year, there was no statistically significant difference in revenue between the three systems. As a result of higher costs, the gross margin, a conventional measure of net income, was actually lowest for THM in a drought year and highest for OAM, although the difference between OAM and CHM was not statistically significant. In a year of optimal rainfall, there was no significant difference in gross margins. Added value, a measure of net income if we ignore the self-exploitation of labor, was highest for OAM with optimal rainfall and with drought, although the difference was only significant during the drought year, and only between OAM and THM. The average added value across both years showed the same rankings and statistical significance as in the drought year. Based on these two years, the net income from OAM is greater than or equal to the alternatives, and the risk is lower. Based on the criteria assessed here, rational farmers should prefer OAM, especially when rainfall may be the limiting factor of production.

When we account for environmental costs, this conclusion is much stronger. Excessive nitrogen fertilizers on CHM and THM farms contributes to water contamination (FAO 2013; Varnier and Hirata 2002), foods with nitrates and nitrites (Kreutz et al. 2012), greater energy use (Pimentel et al. 2005; Capellesso and Cazella 2013), greater emissions of greenhouse gasses, and an increase in plants sensitivity to pests and diseases (Chaboussou, Francis. 2006). Rational policymakers should therefore prefer OAM even more than individual farmers, and should adopt policies that promote it.

The fact the more farmers practiced THM and CHM than OAM would appear to be the result of perverse government policy, in particular PRONAF, which provides subsidized credit for purchased inputs, and SEAF which insures expenditures in the case of crop failures. These policies are perverse from an economic perspective since they encourage excessive expenditures on fertilizers, pesticides, and seeds with diminishing marginal returns; from an ecological perspective since they encourage environmental degradation with rising marginal costs; and from a balance of trade perspective owing to royalty payments to foreign corporations. It would appear, however, that policymakers are also trapped in the NPK mentality, leading them to consider only yields per hectare at the expense of the environment and economic efficiency.

Unfortunately, petrochemicals and mined phosphorous depend on nonrenewable resources, and degrade renewable resources that generate essential ecosystem services. This approach to agriculture is therefore inherently unsustainable. The NPK mentality, however, is closely related to the widespread belief among economists and policymakers that technology will always provide substitutes for resource depletion, which can, therefore, safely be ignored (Neumayer 2003; Daly 1974). However, if technology is indeed so powerful, then it should be fairly simple to dramatically reduce the use of environmentally harmful and nonrenewable resources without the loss of production. Agroecological systems are already quite competitive with conventional production even though the latter has received far more investments in research and development (Vanloqueren and Baret 2009). Government support for agroecological research and devlopment, for example, into the improved management of nitrogen fixing cover crops, could significantly increase economic returns to OAM and other agroecological practices while reducing risks to farmers and society. If the yields from agroecology can match those of conventional agriculture, the debate between land sparing and land sharing approaches to conservation will be over.

Notes

1. Trangenic "Bt" maize expresses the toxins CRY 1A, CRY 1 F, CRY 1A 105, and CRY2A02 from the bacteria *Bacillus thuringiensis*. It is registered for use in Brazil to control the caterpillars of the fall armyworm (*Spodoptera frugiperda*), the corn earworm (*Helicoverpa zea*), and the sugarcane borer (*Diatraea scaccharalis*) (Carneiro et al. 2009).
2. Equivalent to federal insurance contributions in the United States.
3. On the one hand, farmers who own machinery can use it at the ideal time on their own crops, and earn income providing services to other farmers. On the other hand, when

machinery is used at less than full capacity, it can raise fixed costs above their market prices. The efficiency with which farmers use their machinery is not relevant to the goals of this study.

4. Gross margin is usually defined as total revenue minus total costs. However, for reasons explained earlier, we are ignoring fixed costs in our calculations.
5. The harvest (agriculture year) in Brazil starts in July of one year and ends in June of the next.
6. Through 2011–2012—the time relevant to this study—the program did not reimburse farmers for the use of their own labor and capital, but began to do so the following year (Capellesso, Cazella, and Rover 2014).

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