EPTD Discussion Paper No. 124

SPATIAL PATTERNS OF CROP YIELDS IN LATIN AMERICA AND THE CARIBBEAN

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October 2004

ABSTRACT

From a theoretical perspective crop yields should tend to converge over time and space as: growth in yield potential exhibits diminishing returns; an increasing share of farmers shift to using high yielding varieties (HYVs); barriers to the free flow of knowledge and information are removed; and significant investments continue to be made in supporting institutions whose mandates include facilitating and accelerating the cross-border flow of improved agricultural technologies. Using a new, sub-national crop yield database for Latin America and the Caribbean (LAC) we examine whether convergence is indeed occurring, and discover it is not. On the contrary, there is evidence of divergence. We test three hypotheses that might help account for this finding: that technology generation has been biased towards production in more-favored production systems leaving behind persistent pockets of production in more marginal lands; that rainfall patterns have changed in ways that exacerbate yield divergence, and that technology spillover across borders remains more problematic than within-country spillover. We find evidence to support all three of these hypotheses. Further work is needed to assess the relative importance of these sources of yield divergence both across and within LAC. As anticipated, rainfall variability is poorly linked to the variability of irrigated crop yields, but more strongly linked to variability in rainfed crops. The results suggest while some countries and regions within countries forge ahead with crop yield improvements there are many areas, often in smaller countries, where the livelihoods of many farmers - and likely a disproportionate share of LAC's rural poor - continue to be constrained by low-productivity agriculture. There remains significant work ahead for national governments and for publicly-funded regional and international agricultural technology institutions to remedy this situation.

KEYWORDS: crop yields, maize, rice, soybeans, Latin America, Caribbean

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1. INTRODUCTION

The rapid spread of new technologies across regions is key to a country's economic prosperity and balanced development. Taking agriculture as an example, the diffusion of improved crop varieties has been a major source of agricultural productivity growth (Evenson and Gollin 2003). Facing the increasing pressures of population growth, proportionately greater increases in the demand for food, and dwindling stocks of suitable land resources, the global agricultural research community has made tremendous strides in developing new, high-yield varieties (HYVs) over the past several decades in order to avoid the Malthusian nightmare (Alston 2002). The Green Revolution, widely recognized as a major achievement of these efforts, significantly improved the yield of the world's major food staples, but especially of wheat, rice and later maize, averted widespread famine, and lifted millions of poor farmers out of poverty (Borlaug 1970; Hazell and Ramasamy 1991). However, the significant gains in potential crop yield accomplished during the Green Revolution did not reach everywhere, and have become increasingly difficult to emulate over time (Cassman *et al* 2003). We believe that the search for new sources of productivity growth can be aided by improving our understanding of the spatio-temporal evolution of crop yields.

Economists (Griliches 1957, Rosenburg 1982, Grossman and Helpman 1995) have long recognized the importance of spatial spillover of technological innovation for economic growth in general and increase in productivity in particular. As Wan (2004) argues strongly, it is much more challenging to develop a new technology than it is to adopt or adapt an existing one. In recognition of these strong economic arguments, the past several decades have witnessed the expansion of institutional mechanisms designed to foster the development and dissemination of agricultural technologies in a regional and sub-regional context.[1] Regardless of the institutional setting, however, the constant quest for incremental gains in the genetic yield potential of crops appears to be subject to the law of diminishing returns (Cassman et al. 2003). As yield potential increases, further improvement becomes more challenging. Furthermore, industry-scale yield growth in a region should diminish over time as farmers abandon traditional crop varieties and adopt HYV's (since the proportionate yield gain derived from the initial adoption of HYVs tends to be much larger than the individual yield increments made by adopting successive generations of HYVs). Given the generally ready access to agricultural technologies, technology latecomers may readily "catch up" simply by adopting existing technologies superior to their own. All of these factors suggest that, over time, one would expect crop yields to converge. On the other hand, agroecological factors play a more significant role in the potential for transferring agricultural technologies (i.e., technology spillover) than they do for industrial technologies (Wood and Pardey 1998). An HYV suited to cultivation in a certain location may not grow well in other areas due to differences in climate, terrain, or soil types. Spatial variations in agroclimatic conditions may be an impediment to the widespread transfer of agricultural technologies. Moreover, economic factors, such as relative prices of inputs and outputs, also matter to the adoption of all types of technologies, including HYVs. Whether the flow, adoption, and efficacy of technology have become more uniform over time and space is an empirical question we set out to address in this paper.

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[1] For example in LAC: IICA, Instituto Internacional para la Cooperación Agropecuaria, and FONTAGRO, Fondo Regional de Tecnología Agropecuaria, as well as three research centers of the Consultative Group on International Agricultural Research (CGIAR).

Many studies on technology adoption and transfer are at a micro scale and few have examined the spatial patterns of technology spillover in a broader, cross-country context, and at the industry scale, primarily because of data limitations. To address this analytical gap we use medium-resolution crop production data to examine patterns of yield variation and variability across a regional scale. We also provide some exploratory analysis of why such patterns might exist. Such insights are useful to regional and sub-regional funding and technical agencies seeking to design investment strategies that maximize cross-country technology spillovers. Our study uses a sub-national agricultural output data set for LAC for three major crops (rice, maize, and soybean). The dataset, spanning the period 1975 to 1998, has been compiled by IFPRI and the International Center for Tropical Agriculture (CIAT) over several years (Alston *et al* 2000; Pardey *et al* 2000). To our knowledge, this is the most comprehensive agricultural production data set available for the LAC region.

The first objective of this study is to document the changes in spatial patterns of crop yield using the new data set. Our results show that yield levels across the region do not appear to have converged over the time period examined. This could be due to a broad range of information, institutional and geographical barriers to the flow of technology, but also to a growing disparity in the ability of farmers across the region to utilize any given technological opportunity. Therefore, our second objective aims to understand why spatial variations persist, using geographic information system (GIS) tools and an inequality decomposition method.

We propose three hypotheses to explain the observed increasing regional yield disparities. First, crop and crop management technologies developed over the past several decades have been heavily biased toward more favored (e.g., irrigated) production systems. Most HYVs are very responsive to modern inputs such as fertilizer, especially nitrogen, and water.

Modern varieties, therefore, have usually been adopted only in areas having sufficient rainfall or irrigation facilities, and fewer terrain and soil constraints. If farmers know the optimal irrigation schedule, the variability in yields generally decreases with increased irrigation (Hazell 1989). In rainfed, especially upland, areas lower-input, lower-yielding traditional varieties still predominate. The expansion of irrigated areas, a key feature of LAC agriculture over the past forty years, has thus given rise to a broader spectrum of irrigated and rainfed production domains, often existing in close proximity (Sanint and Wood 1998, for the case of rice). At the same time, there is abundant evidence of the expansion of rainfed production into less productive areas, particularly in the hillsides of Central America and the Andean region, and a general decline in the fallow periods and consequently in the fertility of soils associated with many low-input rainfed systems (Pender & Scherr 1999). These factors support the notion of a yield divergence over time on a regional basis. We use rice yield data at the district (municipio) level in Brazil to test this hypothesis.

Since yields of rainfed crops are strongly linked to weather conditions (Walker 1989), the second hypothesis is that changes in rainfall patterns during the period 1975-1998 have exacerbated yield divergence across LAC. Either a downward trend in annual rainfall totals or an increase in rainfall variability could plausibly be associated with the type of crop yield divergence observed. Third, we hypothesize that technology transfers across borders are often less efficient than those within a country due to lack of institutional arrangements and domestic research capacity to adapt new (“spillin”) technologies. This may create large between-country variations in yields. To test this hypothesis, we decompose total variation into *between-country* and *within-country* variations. If the variation is largely due to between-country difference, then regional (multi-country) technology intervention strategies and mechanisms, such as those supported by IICA and the sub-regional networks (“PROCI’s”) they convene, FONTAGRO, and the CGIAR, are particularly important.

2. COMPREHENSIVE LAC DATA SET

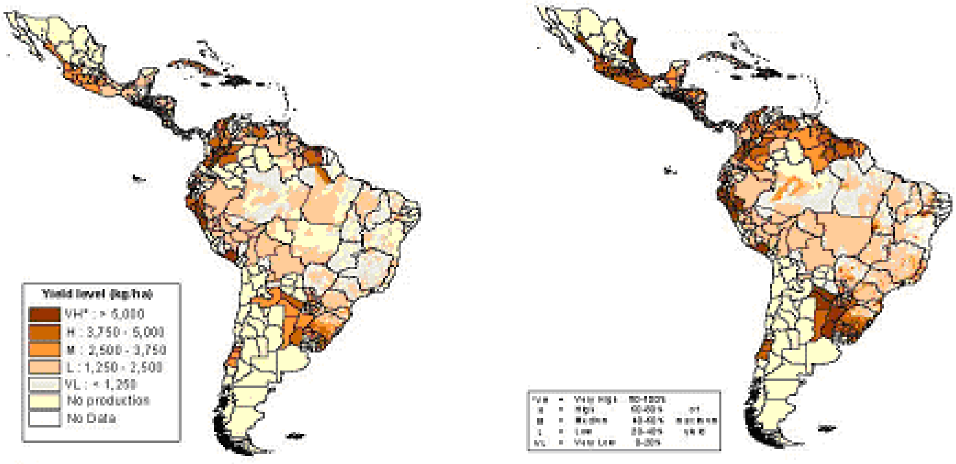
In cooperation with various partners, notably CIAT, IFPRI compiled a sub-national data series for Latin America and the Caribbean (Pardey et al 2000). These data are taken from various sources such as national agricultural census and statistical publications. We developed a time series (from 1975-1998) of basic production statistics for eight crops, namely rice, wheat, maize, edible beans, sorghum, cassava, potato and soybean at the province or department level, focusing on obtaining disaggregated spatial information for geographically large countries, or those having a significant regional share of the production of those commodities. For Brazil, we have more detailed data at the district (municipio) level. To facilitate cross-country comparison of yield data derived from a wide variety of sources, we recalibrated sub-national area and production totals in each year by applying sub-national shares derived from the disaggregated data to published FAO national area and production totals.

In the current study, we choose to examine the yields of soybean, maize and rice because of their relative importance to LAC agriculture. Based on the value of production in 2000, soybean, maize and rice rank first, second and sixth respectively (FAOSTAT 2002 and authors’ calculations). Furthermore, the three crops are widely distributed across LAC, providing a spatially representative picture of LAC agriculture.

3. SPATIAL PATTERNS OF CROP YIELDS

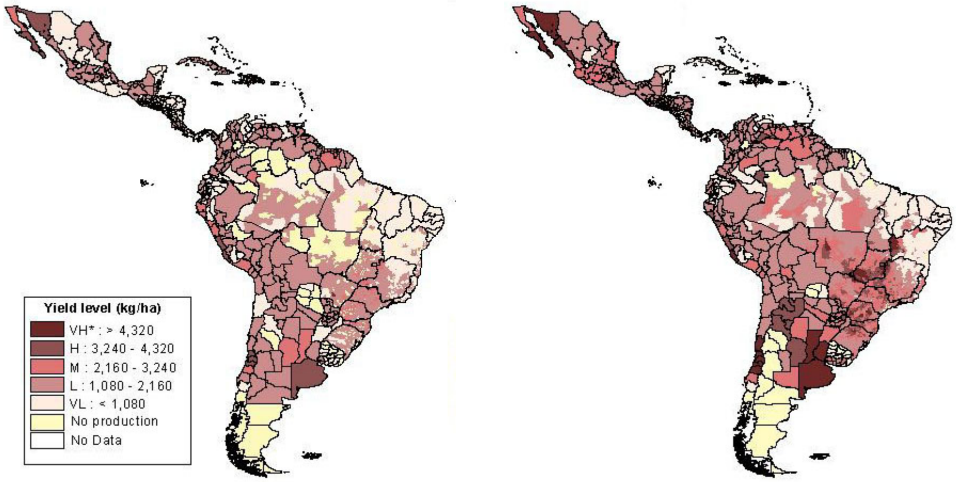
Maps 1-3 shows the spatial patterns of yield levels of rice, maize and soybean, respectively, in 1975 and 1995.

Map 1--Spatial change of rice yields in Latin American and Caribbean



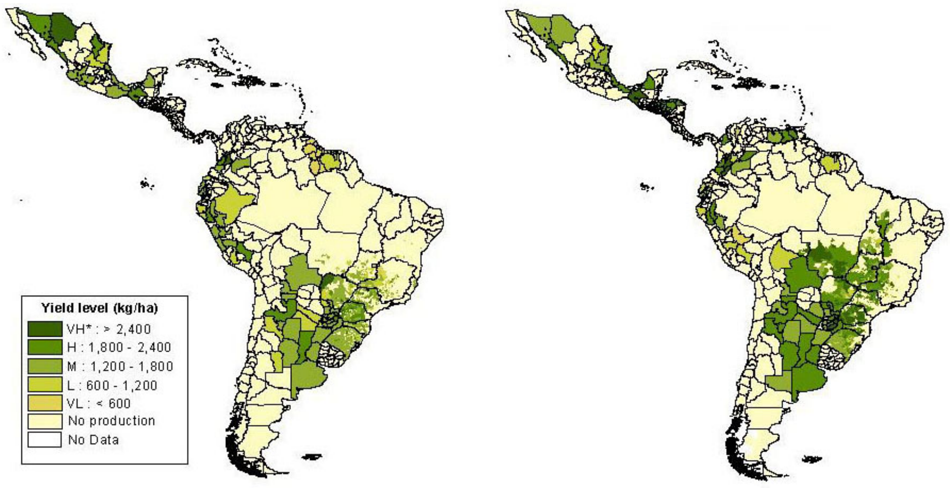
(a) 1975-77 Average (b) 1993-95 Average

Map 2--Spatial change of maize yields in Latin American and Caribbean



(a) 1975-77 Average (b) 1993-95 Average

Map 3--Spatial change of soybean yields in Latin American and Caribbean



(a) 1975-77 Average

(b) 1993-95 Average

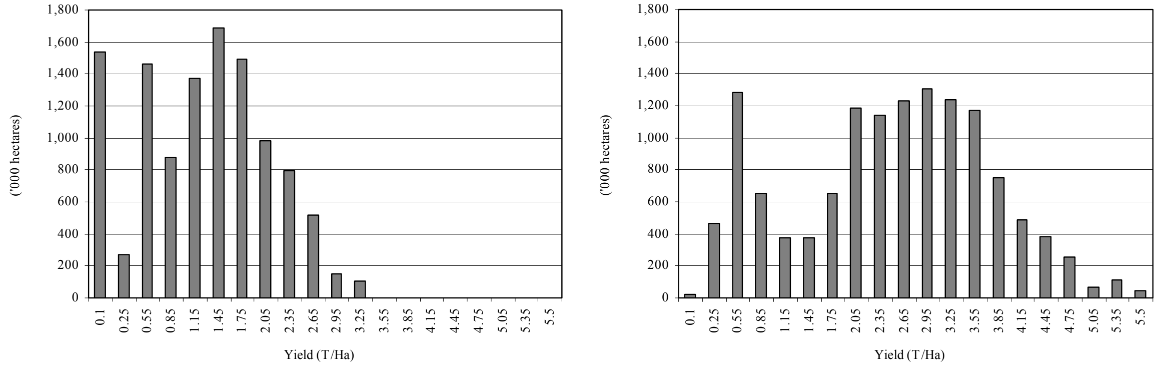
Two general trends are apparent from these maps. First, planted areas for all three crops have expanded and overall the yield levels have increased. In 1975, the highest rice yields were being obtained in the western parts of the Colombian savannah, and the Pacific coast areas of Peru and Ecuador. By 1995, the rice yields in those areas still remained high, but new high-yielding areas had emerged in the coastal areas of southern Mexico, Atlantic coastal regions of Guyana and Surinam, and the region along the joint borders of Brazil, Paraguay, Argentina and Uruguay. For example, rice yields in Santa Catarina, Brazil reached very high levels from a world perspective, even though the overall yields in Brazil are lower than the world average. Maize is widely grown in LAC, and Brazil shows obvious maize production expansion in its mid-west regions. Northern Mexico and East Argentina bordering Uruguay had the highest regional maize yields in both 1975 and 1995. The area along the south and east boundaries of Goias in Brazil shows dramatic increase in maize yields between 1975 and 1995. Soybean production exhibits perhaps the most dramatic change over the 1975-95 period. In 1975, most soybean production occurred to the south of the 30-degree latitude. Since then soybean production has advanced northward (Pardey et al, in press). In 1975, the highest yields of soybean were to be found in Northern Mexico. In 1995, the midwest and southeast regions of Brazil, West Bolivia and North and West Argentina all have higher soybean yields.

The maps provide a useful visualization of the spatial patterns and trends between the two snapshot years. To obtain a more quantitative sense of the changes involved, we further present histograms of yield distribution in Brazil and “LAC except Brazil” in Figures 1 and 2, respectively.

Figure 1--Crop yield distributions in Brazil: 1975-77 and 1993-95

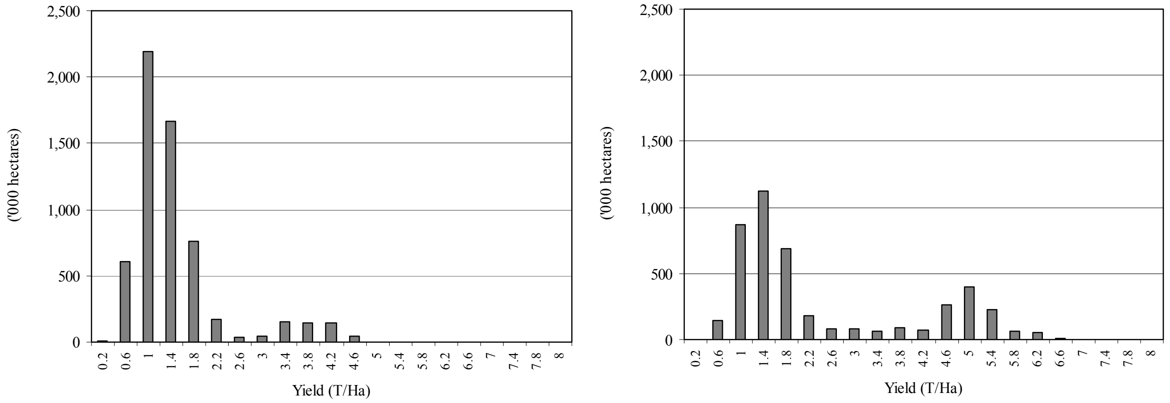
Maize, 1975-77

Maize, 1993-95



Rice, 1975-77

Rice, 1993-95



Soybean, 1975-77

Soybean, 1993-95

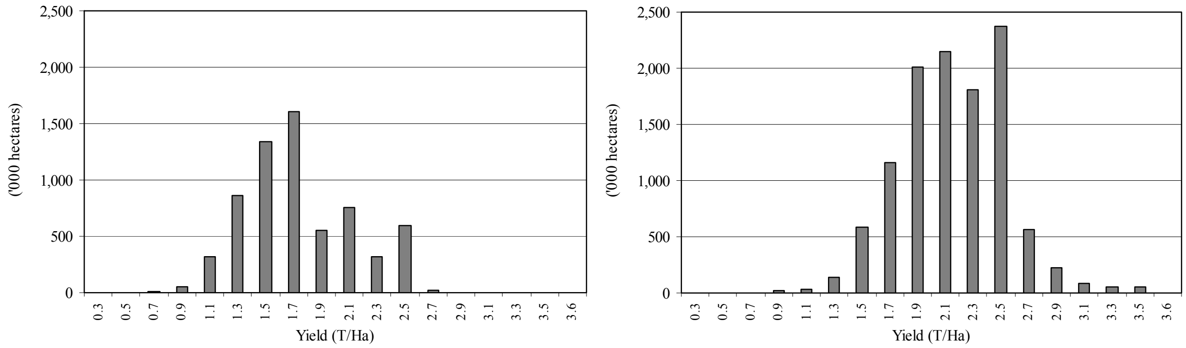
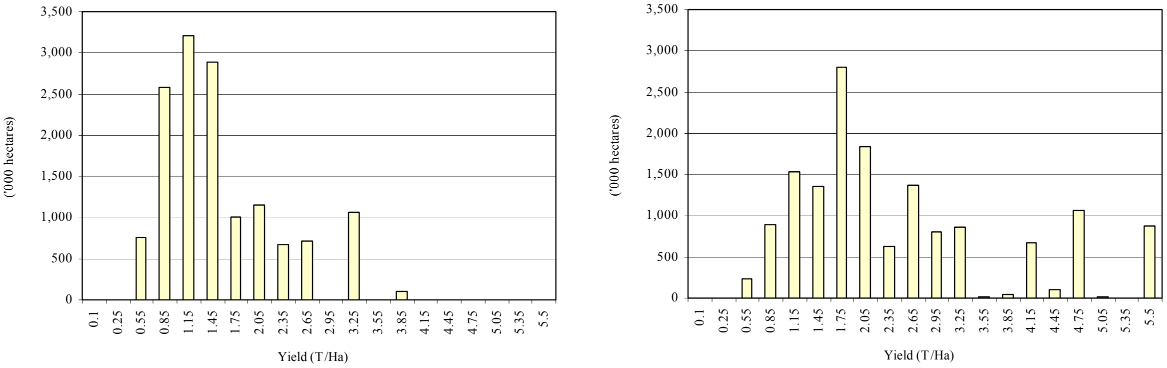
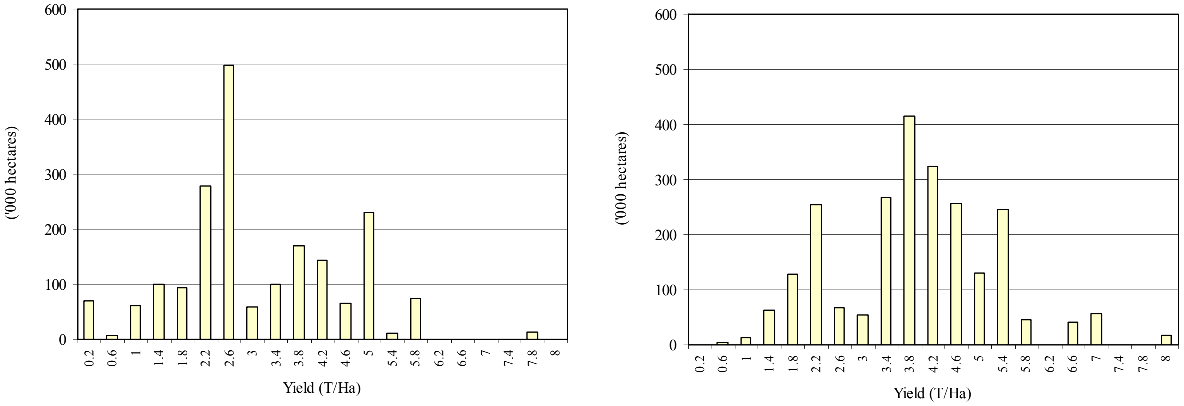


Figure 2--Crop yield distributions in Latin American and Caribbean except Brazil: 1975-77 and 1993-95



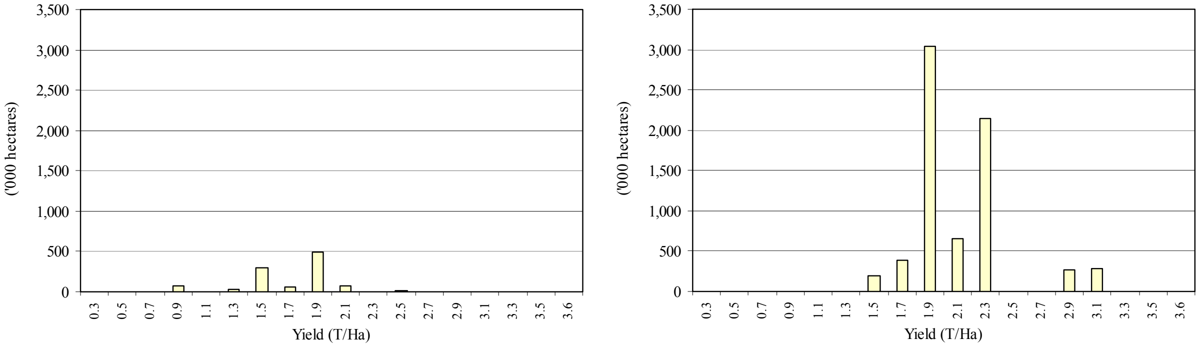
Maize, 1975-77

Maize,1993-95



Rice, 1975-77

Rice, 1993-95



Soybean, 1975-77

Soybean, 1993-95

The histograms show the range and distribution of yields across LAC in terms of area harvested, and represent over 4,500 observations, including 4,276 municipalities in Brazil and 225 departments for the rest of LAC. For all three crops, the generally increasing yield trend is illustrated by the rightward shift of the yield distributions between 1975 and 1995. On average, LAC yields increased from 1.6 to 2.5 t ha^{-1} for maize, 1.9 to 2.9 t ha^{-1} for rice, and 1.7 to 2.2 t ha^{-1} for soybean.

The figures also reveal an increasing spread of yield values. In 1975, most maize yields lay between 0.1 and 3.5 t ha,$^{-1}$ with no yield higher than 4 t ha.$^{-1}$ In 1995, regional maize yields were almost uniformly distributed between 0.1and 4.5 t ha^{-1}. Rice shows an apparent structural shift into a bimodal distribution between 1975 and 1995, reflecting a growing polarization between irrigated and rainfed production systems. Brazil dramatically increased its high-yielding irrigated rice area between 1975 and 1995, but over two-thirds of its total rice production area is still rainfed with average yields of no more than 1.5 t ha^{-1}. For the rest of Latin America, yield increases are more spatially uniform, and over half of the rice area has yields of 4 t ha^{-1} or more. Changes in the distribution of soybean yields are the inverse of those seen for maize. In 1995, in both Brazil and rest of LAC, large commercial soybean producers dominated regional production. Soybean yields are clustered around 2.0 t ha^{-1} for most of the harvested area. At the same time, the total area planted to soybean has increased dramatically, making soybean the most extensive crop in LAC.

Table 1 reports spatial yield variability for three major crops at the department level using a generalized entropy measure (see the Appendix for technical details).

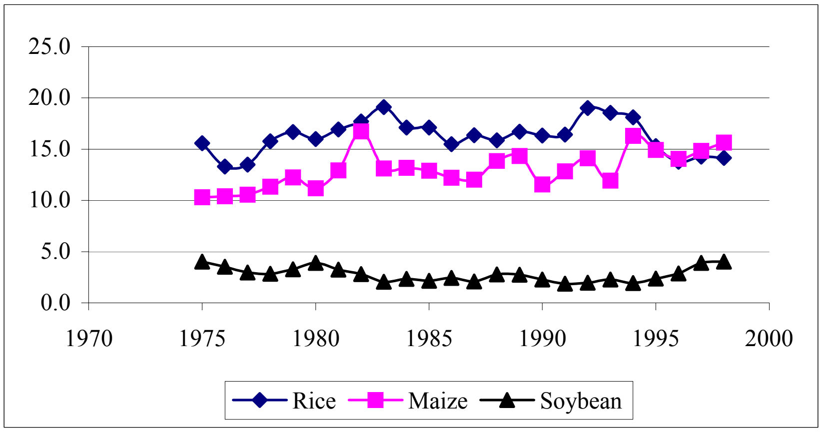
Table 1--Spatial yield variability in LAC: Maize, rice and soybean, 1975-95.

	Total Variation (Generalized Entropy Index)			Between-country /total variation (%) (Polarization Index)		
Year	Rice	Maize	Soybean	Rice	Maize	Soybean
1975	15.6	10.3	4.0	44.8	29.7	65.7
1976	13.3	10.4	3.5	46.3	25.2	60.0
1977	13.5	10.6	2.9	45.0	26.8	52.2
1978	15.8	11.3	2.8	49.1	35.5	53.0
1979	16.7	12.3	3.3	52.5	43.7	60.3
1980	16.0	11.2	3.9	51.0	29.4	66.3
1981	16.9	12.9	3.2	50.1	26.3	59.5
1982	17.7	16.8	2.8	46.9	17.5	62.1
1983	19.1	13.1	2.1	43.3	21.9	59.1
1984	17.1	13.2	2.3	42.8	21.1	67.5
1985	17.1	12.9	2.2	39.2	26.1	64.7
1986	15.5	12.2	2.4	38.6	33.4	68.4
1987	16.4	12.0	2.1	37.0	29.1	60.4
1988	15.9	13.8	2.8	36.5	26.6	58.7
1989	16.7	14.3	2.7	33.2	21.4	54.3
1990	16.3	11.6	2.3	29.9	24.3	69.0
1991	16.4	12.8	1.9	25.7	20.7	70.2
1992	19.0	14.1	2.0	23.4	26.8	80.5
1993	18.5	12.0	2.3	19.7	35.8	65.4
1994	18.1	16.3	1.9	23.0	24.1	64.4
1995	15.3	14.9	2.4	25.8	25.8	57.2
1996	13.8	14.1	2.9	29.4	27.3	53.8
1997	14.3	14.9	3.9	28.2	28.7	55.4
1998	14.2	15.6	4.0	30.3	35.4	55.6

Note: Definitions of the indices is contained in the appendix. The Generalized Entropy index, I, is assessed with c=0. The Polarization Index, P, is the ratio of between-country variation relative to total variation for the three major crops. The entropy measures for rice and maize are weighted by planted area. Due to a significant number of missing values for area data, we assume equal weights in calculating the yield variation in soybean.

Figure 3 further plots the spatial variations in yield for the three major crops over the whole period. It is apparent that crop yields have not become convergent over the years. The spatial variation in maize yield has even increased. Smallholder farmers are the major producers for rice and maize. Maize production relies primarily on rainfall while rice production increasingly depends upon irrigation. Soybean yields seem less variable because the production scale/systems are more homogeneous, e.g. more commercial farmers, and fewer small-scale and subsistence producers than for rice and maize. In order to better check the robustness of this finding, we calculate rice yield variability at municipal level in Brazil for the period of 1975-1995.

Figure 3--Spatial variability of rice, maize and soybean yields in LAC



The data set includes more than four thousand observations for each year. As shown in Figure 4, rice yields have become more spatially variable within Brazil, driven by the large increase in the spatial variability of rainfed rice systems. The large and persistent spatial yield variability in rainfed rice production suggests there may be still be large payoffs to improving the flow of and access to new rainfed rice technologies across regions in Brazil. Uncovering the causes of this large variation might provide information that is useful in helping the less productive areas to catch up.

4. UNDERLYING CAUSES

To explain the observed patterns of yield variability, we propose three hypotheses. The first hypothesis is that agricultural R&D in the past several decades has been biased toward generating technologies for use in more favorable production environments, e.g., areas with better access to reliable water supplies. The efficacy of many agricultural technologies is often highly location specific. For example, a large part of agricultural R&D is aimed at ameliorating site specific constraints to crop production – for example, increasing the frost, drought, or water-logging tolerance of plants, or changing the susceptibility of crops and animals to different pests and diseases. A salient feature of agricultural R&D is that it has favored irrigated regions where scale effects are more pronounced than in rainfed areas. The potential for agricultural R&D spillover is greater for the relatively more homogenous irrigated areas than for the agro-ecologically heterogeneous rainfed areas. Complex aspects of agroecological specificity may inhibit technology spillover to less-favored production areas, and therefore reduce the potential payoffs to research investment. For these reasons, agricultural R&D systems generally prefer research agendas related to broad homogenous regions (Alston 2002). However, technologies developed for irrigated regions are generally not well-suited to rainfed areas having more erratic water inputs.

Taking rice as an example, an estimated 275 new varieties have been released in LAC over the past three decades. About 90 percent of those varieties were targeted to flooded production environments (Sanint and Wood 1998).[2] As shown in Table 2, the area of modern varieties planted in irrigated regions has increased from zero to over three million hectares. In contrast, the area devoted to modern varieties in rainfed systems shows little increase. Average yields in irrigated regions rose from 2.8 tonne per hectare in the mid 1960s to 4.4 t ha^{-1} in the mid 1990s, while average yields in rainfed regions have changed little over four decades.

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[2] Flooded areas include irrigated and rainfed wetland areas.

Table 2--Rice production in irrigated and rainfed areas in LAC

			1967	1981	1989	1995
Irrigated						
	Area		1,573.1	2,470.9	3,248.3	3,802.8
		MSV	-	1,546.5	2,801.4	3,340.3
		Trad.	1,573.1	924.4	446.8	462.4
	Production		4,436.2	9,566.7	14,218.5	16,890.7
		MSV	-	6,281.5	12,490.7	15,201.9
		Trad.	4,436.2	3,285.3	1,727.8	1,693.0
	Yield		2.8	3.9	4.4	4.4
		MSV	-	4.1	4.5	4.6
		Trad.	2.8	3.6	3.9	3.7
Rainfed						
	Area		4,258.1	5,785.0	4,427.4	3,048.5
		MSV	-	499.0	580.3	675.3
		Trad.	4,258.1	5,285.9	3,847.1	2,373.2
	Production		5,945.2	6,160.7	5,610.3	4,190.2
		MSV	-	556.9	1,287.0	1,509.4
		Trad.	5,945.2	5,607.3	4,323.4	2,680.8
	Yield		1.4	1.1	1.3	1.4
		MSV	-	1.1	2.2	2.2
		Trad.	1.4	1.1	1.1	1.1
Totals						
	Area		5,831.2	8,255.9	7,675.7	6,851.2
	Production		10,381.7	15,727.4	19,828.8	21,100.9
	Yield		1.8	1.9	2.6	3.1

Note: personal communications from Luis Roberto Sanint. MSV stands for modern semidwarf varieties and is equivalent to high yielding varieties (HYVs).

Modern rice varieties now account for around 98 percent of all rice production in irrigated area and one third of rice production in rainfed areas (Table 3).

Table 3--Share of modern semi-dwarf rice varieties in rice production and area

Production System	Percentage in production				Percentage in area			
	1965	1981	1989	1995	1965	1981	1989	1995
Irrigated	0.0	79.3	88.1	98.3	0.0	76.4	84.7	97.6
Mechanized rainfed	0.0	6.9	13.3	24.7	0.0	5.8	10.3	18.0
Traditional rainfed	0.0	30.0	30.0	30.0	0.0	26.0	28.2	31.2
Total LAC	0.0	49.9	67.5	80.3	0.0	28.2	43.6	58.8

Source: Sanint and Wood (1998, p.406).

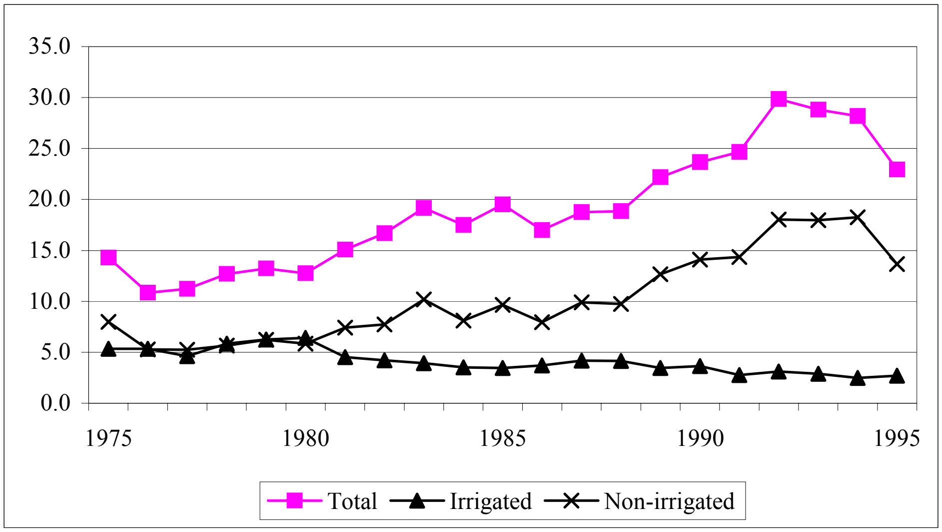
The difference in yield between traditional and modern varieties as well as the more rapid adoption of modern varieties in irrigated areas may thus be contributing to the observed increase in yield variation in LAC. We again use the Brazil municipio data to empirically test this hypothesis. Table 4 shows the mean and dispersion of rice yield in Brazil on average and for irrigated and non-irrigated areas, while Figure 4 plots the spatial variability for total, irrigated, and rainfed areas, respectively.

Table 4--Rice yield and dispersion in Brazil

Year	Average	Irrigated	Rainfed	Between variation/total variation
1975				
Mean (tonne/hectare)	1.5	3.5	1.2	
Variation	14.3	5.3	8.0	46.3
	(11.1, 16.9)	(3.6, 7.0)	(5.7, 9.9)	(32.9, 53.3)
1995				
Mean (tonne/hectare)	2.6	4.8	1.7	
Variation	22.9	2.7	13.7	53.9
	(21.8, 25.7)	(1.8, 3.4)	(9.1, 19.4)	(37.7, 76.1)
Changes in dispersion	8.6	-2.6	5.7	7.7
	(6.2, 11.4)	(-4.1, -0.2)	(2.6, 9.9)	

Note: Calculated by authors using the method developed by Biewen (2002). The figures in parentheses are 95% confidence intervals with 100 bootstrap replications.

Figure 4--Spatial variability of rice yields in Brazil

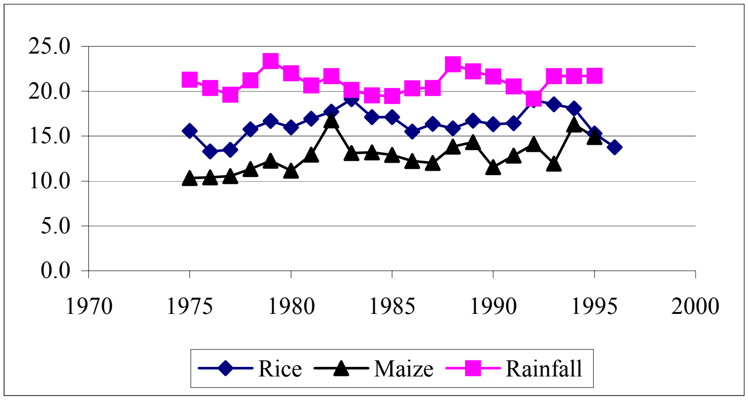


Rice yields in irrigated areas increased from 3.5 to 4.8 t ha^{-1} over the period 1975-1995, while in rainfed areas yields reached only 1.7 t ha^{-1} by 1995. The entropy index of yield dispersion in irrigated area has declined from 5.3 to 2.7, while in rainfed areas it has increased from 8.0 to 13.7. As shown in the last column of Table 4, all the changes are statistically significant at the 95% confidence level. This is consistent with the maize dispersion story for LAC as a whole shown in Table 1. Moreover, the yield spread between irrigated and rainfed areas has widened. The percentage share of total variation explained by variation between irrigated and rainfed area yields increased from 46.3 to 53.9. The findings seem to support our first hypothesis.

Our second hypothesis is related to weather variability. Agricultural production systems are intrinsically location specific and clearly a contributing factor to the spatial differences among yields is the relative resource endowment among locations, particularly for low-input production systems. The quality of these local resources can also change over time, and perhaps exacerbate variability among locations. For example, variability of and change in soil quality are considered to be key determinants of the productivity of LAC, but reliable regional data on the spatial patterns of change in soil quality do not exist. However, we do have access to long term information on another resource, rainfall. There is growing evidence from some parts of the world about long-term trends and increased variability in agricultural production as a consequence of global warming and increased El Nino Southern Oscillation (ENSO) activity (see, for example, Dai *et al* 1997 and Adams et al 1999). We therefore examine whether these phenomena are observable over the period of our production data using a rainfall time series dataset covering the LAC region.

The Climate Research Unit of University of East Anglia constructed a 0.5 degree latitude/longitude gridded dataset of monthly rainfall data over the whole world for the period 1901-1996 (New, Hulme, and Jones 2000). From these gridded data, we calculate the annual rainfall for the sub-national geopolitical regions (departments) in LAC from 1975-95. Figure 5 plots regional variability in annual rainfall and the yields of rice and maize for the whole period.

Figure 5--Spatial variability in rainfall and the yields of rice and maize in LAC

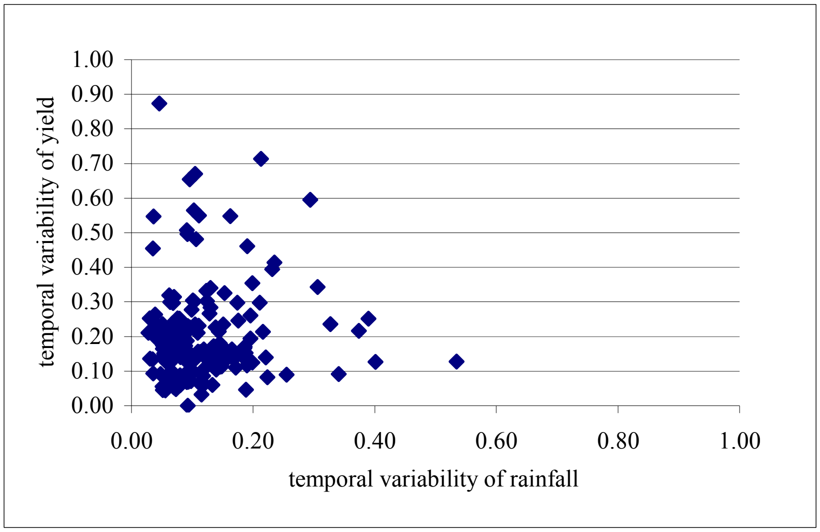


Firstly, of note, is that rainfall is more variable than yield, and that aggregate rice yields (including both irrigated and rainfed production) are more variable than maize yields. Second, there is a small but statistically significant downward trend in annual rainfall (a slope of -1.40 mm per year, with a *t* value of -4.47, controlling for fixed effects across departments). Third, in the case of rice, the association between rice yield and rainfall variability is very weak (correlation coefficient –0.02). Rice and rainfall indices do not show co-movement for most years, nor does there appear to be a systematic divergence or convergence of the two series. Fourth, in the case of maize, the association of yield with rainfall variability appears much stronger (correlation coefficient 0.18), and maize yield variability appears to have increased over time. These findings are congruent with the changes in maize and rice yield distributions between 1975-77 and 1993-95 observed in Figure 1. The higher rice yield variability reflects the aggregation of both rainfed and irrigated rice systems in our regional database. Based on our Brazil analysis using data disaggregated by systems, we assume that most of the rice yield variability is attributable to rainfed rice production. The apparent growth in maize yield variability suggests that while significant progress has been made in the development and adoption of higher yielding maize varieties in many parts of LAC, there are large and pockets of subsistence production that still rely upon low yielding traditional varieties.

The finding of a downward trend in LAC annual rainfall over the 1975-95 period supports the hypothesis that changing weather patterns may have contributed to increasing yield divergence, since drier conditions are associated with lower yields in rainfed systems. To corroborate this finding we examined other literature on LAC rainfall trends. Dai *et al* (1997), in their study of global land precipitation variation between 1900 and 1988 also report an observed decline in land precipitation over the tropics in the 1970s and 1980s using a different data source. And while the IPCC assessment of regional impacts of climate change (1998) reported generally increasing rainfall trends in South America, east of the Andes, over the period 1901-95, annual rainfall time plots for Latin America and for the Caribbean region in the same report do suggest steady or declining average annual rainfall trends during the 1975-95 period.

For a particular region, however, there are likely more covariate patterns of variability of rainfall and yield (Walker, 1989). To check this, we further calculate temporal variability in rainfall and crop yield for the whole period (1975-1995) in each region.[3] Figures 6 and 7 show these temporal variances in rainfall and yields of rice and maize, respectively. Figure 6 does not exhibit any apparent patterns between rainfall variability and yield variability in rice in the regions considered. In fact, the R^2 value is less than 0.1.

Figure 6--Temporal variability in rice yield and rainfall



Note: Rice yield is de-trended to remove the effect of technology change on temporal variability. In total, there are 176 observations at the department level.

However, Figure 7 exhibits some positive correlation when excluding several outliers, perhaps reflecting the fact that a much greater share of maize is produced under rainfed conditions and in other types of less-favored environments than is rice.

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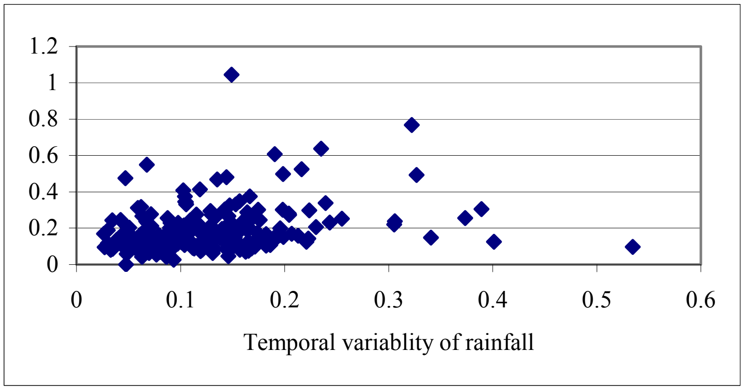
[3] Because there is an upward trend in rice yields due to technology progress, we removed the time trend when calculating rice yield variability. Soybean and maize yields were treated in a similar way.

Figure 7--Temporal variability in maize yield and rainfall



Finally, agricultural production technologies generated in one country often spillover to other countries with similar agroecological conditions if regional or local capacity to adapt and disseminate the technologies is available. However, the capacities of national research and extension systems differ widely among countries. Many countries do not have enough research capacity to adapt the modern varieties to local needs, and many national agricultural research and development systems are experiencing increasing budget stringency (Alston *et al* 1998; Pardey *et al*, in process). And in addition to research and extension capacity, adopting new crop varieties requires a well-functioning sector to produce and market new technical inputs for the modern varieties and a literate labor force to use the new knowledge and technology effectively (Ruttan 2001). Therefore, ability to modify and adapt new technologies can differ significantly among countries. The differences in research capacity and institutions and human resource endowment may create barriers to country-to-country spillovers. This is our third hypothesis to test.

To capture the between-country variance in yield, we apply Shorrock's decomposition method to quantify the relative contributions of *between-country* and *within-country* to overall spatial inequality. As shown in the last three columns in Table 1, the between-country variation in rice yield accounts for a large share of total variation, but that share has generally declined over the whole period. For maize, the between-country contribution has been lower but more variable. Between-country variation in soybean yield has consistently contributed over half of the total variation. The finding calls for a better understanding of spillovers among countries. There seems to remain significant scope for improving the flow of information about new technologies, as well as flow of the technologies themselves among LAC countries.

5. CONCLUSIONS

We have examined the spatial and temporal patterns of variation in the yield of rice, maize, and soybean in LAC using sub-national data. Our analyses show that yields of three major crops in the LAC region have not converged over time. The yield dispersion for maize has even increased. Thus possible influences of technology convergence over time, have been counteracted by larger, yield diverging effects. We then explored some possible sources of such divergence: 1) divergence arising from technology bias to the more-favored production environments; 2) divergence arising from changing rainfall patterns; and 3) divergence arising from country-specific factors.

The large difference in yield between irrigated and rainfed areas does appear to play a significant role, particularly in the case of rice. Although irrigation may be effective in reducing yield variability in those areas where irrigation replaces rainfed production, it has lead to greater variability across locations since a significant share of LAC production remains in rainfed and mixed rainfed-irrigated farming systems. It appears that in LAC, as in the rest of the world, agricultural research has been biased against generating technologies applicable to less-favored production environments. And poorer farmers on poorer land are often less willing or able to adopt improved technologies if they involve larger costs or risks. With growing evidence on the higher potential payoffs to investment in marginal lands, there is now much debate about the growth as well as the equity consequences of such historic biases (Fan, Hazell and Thorat 1999). The spatial variation in yield for soybean is much smaller than that for rice and maize, largely because soybean is grown as an industrial crop rather than as a food staple in LAC, often in larger-scale farm enterprises where external inputs such as water and fertilizer are used much more intensively to increase and stabilize yields. It seems that technology spillovers among such commercially-oriented farmers may be more efficient than those among smallholders. Therefore, in addition to developing technologies that can be adopted by and are more profitable for farmers in less-favored production environments, fostering improved diffusion of suitable existing technology among small-scale farmers also deserves high attention, and may often be more cost-effective.

Our empirical results also provide some support for the second hypothesis concerning linkages between observed increases in yield diversity and changing rainfall patterns, as the rainfall data show a small (about 1.4 mm yr^{-1}) downward trend in annual rainfall. But comparison with longer-term rainfall data suggests that this may be part of a short-term cycle. Yield variability in maize, a crop grown widely under rainfed, subsistence conditions in LAC, has increased over time and exhibits a greater correlation with rainfall variability than does rice, a crop grown extensively under irrigated (commercially-oriented) conditions. Finally, using an inequality decomposition method, we estimated the contribution of between-country variation to overall spatial inequality and found that the between-country component is rather large – though declining in the case of rice - suggesting the existence of persistent barriers to country-to-country spillovers of technology. These results should be of concern to those, often smaller, countries where yield growth rates appear to be falling behind LAC yield-growth leaders (e.g., many parts of Argentina, Brazil and Mexico). They also send a message to the international, regional and sub-regional agricultural technology research and development community who clearly still face many challenges in achieving their goals of facilitating and accelerating the flow of improved technologies across the region, particularly those technologies targeted to smallholders.

While LAC as a region is well endowed with water, the increasing trend of urbanization and industrialization will likely limit the expansion of water use for irrigation in many areas, and reduce future growth potential of irrigated agriculture and the stabilization of crop yields. Therefore, improving the water use efficiency of crops remains an important research objective. But a central challenge to the research and development community is to make agricultural production more profitable and competitive by providing technology that can sustainably reduce unit production costs in less favored (non-irrigated) areas where the majority of LAC's farmers, and a disproportionate share of its rural poor, are to be found. It appears that significant potential may still remain for large payoffs to the continued strengthening of regional and national information, institutional, and physical capacities to promote the spillover of new knowledge and technologies and to make them more accessible to all farmers throughout the region.

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APPENDICES

APPENDIX 1--THE GENERALIZED ENTROPY (GE) MEASURE (SHORROCKS, 1980 AND 1984) CAN BE WRITTEN AS:

$$I(y)= \begin{cases} \sum_{i=1}^{K} f(y_i)\left\{\left(\frac{y_i}{\mu}\right)^c - 1\right\} & c \neq 0,1 \\ \sum_{i=1}^{K} f(y_i)\left(\frac{y_i}{\mu}\right)\log\left(\frac{y_i}{\mu}\right) & c = 1 \\ \sum_{i=1}^{K} f(y_i)\log\left(\frac{\mu}{y_i}\right) & c = 0 \end{cases} \tag{1}$$

In the above equation, y_i is yield in the i^{th} region, μ is the total sample mean, $f(y_i)$ is the area share of the i^{th} region in the total planting area and K is the number of regions.

For K exogenously given countries indexed by g, the overall GE measure can be expressed as:

$$I(y) = \sum_{g}^{K} w_g I_g + I(\mu_1 e_1, \ldots, \mu_K e_K) \tag{2}$$

where $w_g = \begin{cases} f_g\left(\frac{\mu_g}{\mu}\right)^c & c \neq 0,1 \\ f_g\left(\frac{\mu_g}{\mu}\right) & c = 1 \\ f_g & c = 0 \end{cases}$

where I_g is inequality in the g^{th} country, μ_g is the mean of the g^{th} country and e_g is a vector of 1's of length n_g, where n_g is the planting area of the g^{th} country. If n is the total planting area of all countries, then $f_g = \frac{n_g}{n}$ represents the share of the g^{th} country's area in the total planting area. The first term on the right side of (2) represents the within-group inequality. $\frac{w_g I_g}{I(y)} * 100$ is the g^{th} group's contribution to total inequality. The second term is the between-group (or inter-group) component of total inequality.

Following Zhang and Kanbur (2001), we define the polarization index, P, as:

P = between-group inequality/total inequality (3)

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