WORKING PAPER No. 40

National Agricultural Research from a Regional and Agroecological Perspective

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International Service for National Agricultural Research

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Contents

Preface

This paper was prepared as a background paper at ISNAR for the standing committee on priority and strategies of the TAC/CGIAR. The authors thank Christian Bonte-Friedheim, Howard Elliott, Guido Gryseels and members of TAC for their comments on an earlier draft. Nevertheless, this paper represents the views of its authors, not ISNAR or TAC/CGIAR

NATIONAL AGRICULTURAL RESEARCH FROM A REGIONAL AND AGROECOLOGICAL PERSPECTIVE

Making effective use of scarce research resources is a difficult and multifaceted undertaking. Among other things, it requires achieving a socially desirable balance among the various dimensions of a research program, including its commodity, site, and technology emphasis. Within the CGIAR system, these tasks are being made even more difficult. In addition to the traditional emphasis on stimulating productivity growth for basic food crops and livestock commodities, the system is seeking to extend its commodity coverage to include forestry and fisheries, while at the same time attempting to give greater attention to environmental and resource management concerns (TAC/CGIAR 1991).

In practical terms this will require the system to generate a more sophisticated understanding of the (potential) spillover effects of its research program than has perhaps hitherto been the case, where such spillover effects may be across commodities at a given locale and/or across different locales. It appears primarily to be the spatial dimensions of these spillover effects that lie behind current moves to explicitly incorporate an agroecological perspective into the CG's strategic priority assessments. Cognizant of the fact that socioeconomic -- not just natural -- conditions constrain the effectiveness and spillover potential of the system's research endeavors, this agroecological aspect is being overlaid on a geopolitical or regional dimension to generate a so-called "ecoregional" perspective.

This paper is organized as follows. After providing a brief overview of past CGIAR investment trends, we pause briefly to examine the nature of factor use and productivity growth within agriculture from a regional, agroecological and, finally, an ecoregional perspective. There are certainly dramatic spatial differences in these agricultural input and productivity trends that have a direct bearing on the priority decisions currently facing the CGIAR.

We then turn to consider some quantitative indicators of agricultural research capacity among less-developed NARSs and, to the extent currently possible, place this quantitative evidence in an ecoregional framework.

1 CGIAR INVESTMENT PATTERNS

Despite the substantial changes afoot within the CGIAR and elsewhere, past patterns of investment as well as institutional precedents will play a large role in shaping the nature and effectiveness of future CGIAR endeavors. With this in mind we begin with a brief overview of the evolving nature of CG strategic priorities as revealed by changes in the system's historical pattern of expenditures.

1.1 Program and Commodity Allocations[1]

Table 1 gives a breakdown of the research component of CG core expenditures by its "commodity" or program orientation. While in nominal terms aggregate expenditures have grown by a factor of 10 since 1971 (see appendix A.1), the composition of this aggregate has changed substantially. In particular, the share allocated to cereals has declined steadily to about 40% while the share devoted to livestock research has almost doubled to nearly 20%. Within the system's crop research program, the proportion allocated to rice has been relatively stable and, at 17% of the total, this is the crop receiving the most attention. Research on maize was the second largest recipient during the initial years but has been reduced steadily to about 7%. Throughout the CG's history, the relative share of research on wheat, barley, and triticale declined only gradually. Although in relative terms the share of resources allocated to research on cereals declined, in real terms it more than tripled from 10.1 million constant 1980 US dollars during 1971-75 to 32.5 million in 1986-88. Meanwhile, the share allocated to potatoes and other roots and tubers has remained stable at around 11%.

About one-third of the funds for livestock research is allocated to research on animal diseases, and the balance is allocated for animal production. Research on food policy has increased steadily from 0.3% at its introduction as a CG activity in 1975 to 3.7% of core resources in 1986-88. Research on genetic resources has followed a similar path. Farming systems research (FSR) has been an important activity in most centers since the inception of the CGIAR, accounting for about 12% of the system's core research resources during 1971-75, but it has gradually declined since then. There are always definitional questions

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[1]This subsection and the one to follow draw heavily on Gryseels and Anderson (1991).

surrounding FSR (Simmonds 1985), and with changing donor enthusiasm for work in this area, it may well be that both the early emphasis and the subsequent fall in FSR efforts have been overstated.

Table 1: *"Commodity" Orientation of CGIAR Core Research Operating Expenditures*

	1971-75	1976-80	1981-85	1986-88
	%	%	%	%
Rice	21.5	17.2	17.3	17.2
Wheat, barley & triticale	13.8	10.9	10.3	9.1
Maize	19.5	9.3	7.2	7.3
Sorghum & millet	3.1	3.3	4.8	5.0
Subtotal cereals	*57.9*	*40.6*	*39.6*	*38.7*
Potatoes	4.6	7.0	6.1	6.8
Other roots & tubers	6.8	5.4	4.8	4.5
Legumes	8.1	11.4	11.2	12.9
Subtotal, crop research	*77.4*	*64.4*	*61.2*	*62.9*
Livestock	10.2	19.8	19.1	19.7
Subtotal commodity research	*87.6*	*84.2*	*80.8*	*82.6*
Farming systems	12.2	11.7	9.9	8.5
Food policy	0.1	2.0	3.1	3.7
Genetic resources	0.1	2.0	4.2	2.8
NARS capacity building	0.0	0.0	1.9	2.4
Subtotal, other research/activity	*12.4*	*15.8*	*19.2*	*17.4*
Total	100.0	100.0	100.0	100.0

Source: Gryseels and Anderson (1991); adapted from CGIAR Secretariat (1983, 1986, 1989).

Note: The 1971-85 shares are based on core operating research expenditures exclusive of an administrative component. This administrative component was included, apparently on a prorated basis, in the 1986-88 data. Column totals may not equal 100.0 because of rounding.

1.2 Regional Allocations

Since 1983, when data first became available on center operating expenditures by region, the major share of resources has been directed to Africa. In 1986-88, an average of 39% of expenditures was directed towards sub-Saharan Africa, 26% to Asia, 21% to Latin America, and 14% to West Asia & North Africa (table 2). Regional allocations among commodities and research activities vary considerably, however.

Table 2: *CGIAR Core Operating Expenditures by Category and Geographic Region, 1986-88 Average*

	Sub-Saharan Africa	Asia & Pacific[a]	Latin America & Caribbean	West Asia & North Africa
	%	%	%	%
Research Activities				
Rice	28	63	8	0
Wheat, barley, & triticale	21	14	20	44
Maize	43	18	34	6
Sorghum & millet	53	42	5	0
Subtotal, cereals	*33*	*40*	*16*	*11*
Potatoes	30	15	45	10
Other roots & tubers	45	0	55	0
Legumes	18	30	27	25
Subtotal, crop research	*30*	*33*	*24*	*13*
Livestock	68	0	21	11
Subtotal, commodity research	*39*	*25*	*23*	*13*
Farming systems	43	28	0	29
Food policy	42	55	2	1
Genetic resources	25	25	25	25
NARS building	25	25	25	25
Subtotal, other research/activity	*38*	*33*	*8*	*22*
Nonresearch Activities				
Information, communication, library, and documentation	47	22	18	13
Training and conferences	40	30	21	9
Total operating expenditures	39	26	21	14

Source: Gryseels and Anderson (1991). Adapted from CGIAR Secretariat (1989).

[a]Includes China.

Research on cereals is focused on Asia, while research on food legumes appears to be relatively equally balanced between the four major less-developed regions. CG-sponsored activities on roots and tubers are predominantly focused on sub-Saharan Africa and Latin America, while almost 70% of its investment in livestock research is concentrated in sub-Saharan Africa. Research on both genetic resources and NARS capacity building appears equally (and possibly, arbitrarily) divided among the four regions. Research on farming systems is largely concentrated in sub-Saharan Africa and West Asia & North Africa, but it is now receiving little attention in Latin America. Most of the food policy research is concerned with Asia and sub-Saharan Africa. Training efforts mirror the overall allocation of operating expenditures.

The distribution of CG resources by region, although not a perfect reflection of the degree of effort, provides an indication of regional emphasis within the system. As indicated in table 3, in 1986-88 approximately 39% of the CG core operating expenditures were allocated to sub-Saharan Africa. Data on regional allocations of special projects are not available but it is likely that the share of sub-Saharan Africa is well above that going to core operating expenditures. In fact, a survey carried out in 1986 (ISNAR 1986) showed that more than 42% of the centers' activities in sub-Saharan Africa were supported through special-project funding. It was noted that special-project funds gave centers the flexibility to respond quickly to identified problem areas, while the stability of core funding provided them with the long-term sustained commitment required for agricultural research. On the negative side, special-project funding can also be the tail that wags the center dog!

Table 3: *Distribution among Less-Developed Regions of Population, Poor, Agricultural GDP, and Research Expenditures by NARSs and the CGIAR*

	Less-Developed Countries			Research Expenditures	
	Population 1985	The Poor[a] 1985	AgGDP 1981-85	NARS (1981-85)	CGIAR (1986-88)
	%	%	%	%	%
Sub-Saharan Africa	12	16	8	10	39
China	29	19	26	26	26
Asia & Pacific, ex. China	40	53	41	32	
Central & South America	11	6	15	20	21
West Asia & North Africa	7	5	9	12	14

Source: Gryseels and Anderson (1991); population data extracted from FAO (1987), data on poverty adapted from World Bank (1990, table 2.1), agricultural GDP primarily taken from World Bank (1989), NARS expenditures from Pardey, Roseboom, and Anderson (1991a, table 7.1), and CGIAR expenditures from table 2.

[a]The poverty line in 1985 purchasing power parity (PPP) dollars used in World Bank (1990) is $370 per capita per year.

Unfortunately, data on the regional allocation of such expenditures are not available for the period prior to 1983. It has thus not been possible to estimate the size of the shift in CGIAR resource allocations in favor of sub-Saharan Africa and the extent to which resources have been diverted from other regions. Given the increase in funding available, it is likely that the shift has to some extent been financed from additional funding sources. The emphasis on Africa at the expense of Asia is revealed by contrasting the final column in table 3 with corresponding NARS 1981-85 expenditure shares: 11% for sub-Saharan Africa, 59%

for Asia (including China), 20% for Central & South America, and 10% for West Asia and North Africa. It can thus be hypothesized, especially when the prospects as opposed to the needs for success are taken into account, that the CG may have overinvested in sub-Saharan Africa, perhaps to Asia's ultimate cost.

2 AGRICULTURAL GROWTH AND PRODUCTIVITY PERSPECTIVES

The nature and level of research investments are driven, in part, by the productivity of conventional inputs to agriculture and will, in turn, affect their future productivity. Thus, an understanding of historical growth and development patterns and, in particular, the dynamics of factor substitution within agriculture is critical for analysis and choice in research policy.

To summarize global trends in land and labor productivity, we have adopted the graphical techniques used by Hayami and Ruttan (1971; 1985) to describe the development of agriculture in both a regional as well as an agroecological context. An additional graphic is presented that places these development patterns in an "ecoregional" perspective and thereby identifies the agroecological disparities in productivity growth *within* a regional context.

2.1 A Regional Perspective

Figure 1 plots agricultural output per unit labor and land on a regional basis for the 1961 to 1985 period. The output aggregate reported here represents AgGDP denominated in 1980 agricultural purchasing power parities (PPPs). The primary AgGDP data were compiled in nominal local currency units (LCUs); they were first deflated to base year 1980 using local AgGDP deflators and then converted to constant 1980 US dollars using base year agricultural PPPs as constructed by FAO (1986). These PPPs, which are constructed on the basis of cross-country comparisons of similar baskets of (agricultural) goods valued at local prices, attempt to overcome the problems that distorted or nonspecific exchange rates cause in international comparisons. The land measure is a stock of total hectares of land in agriculture, whether they be arable, permanently cropped, or pasture lands. The number of agricultural workers is represented by the economically active agricultural population. The dark arrows indicate the path of these two productivity measures, and the

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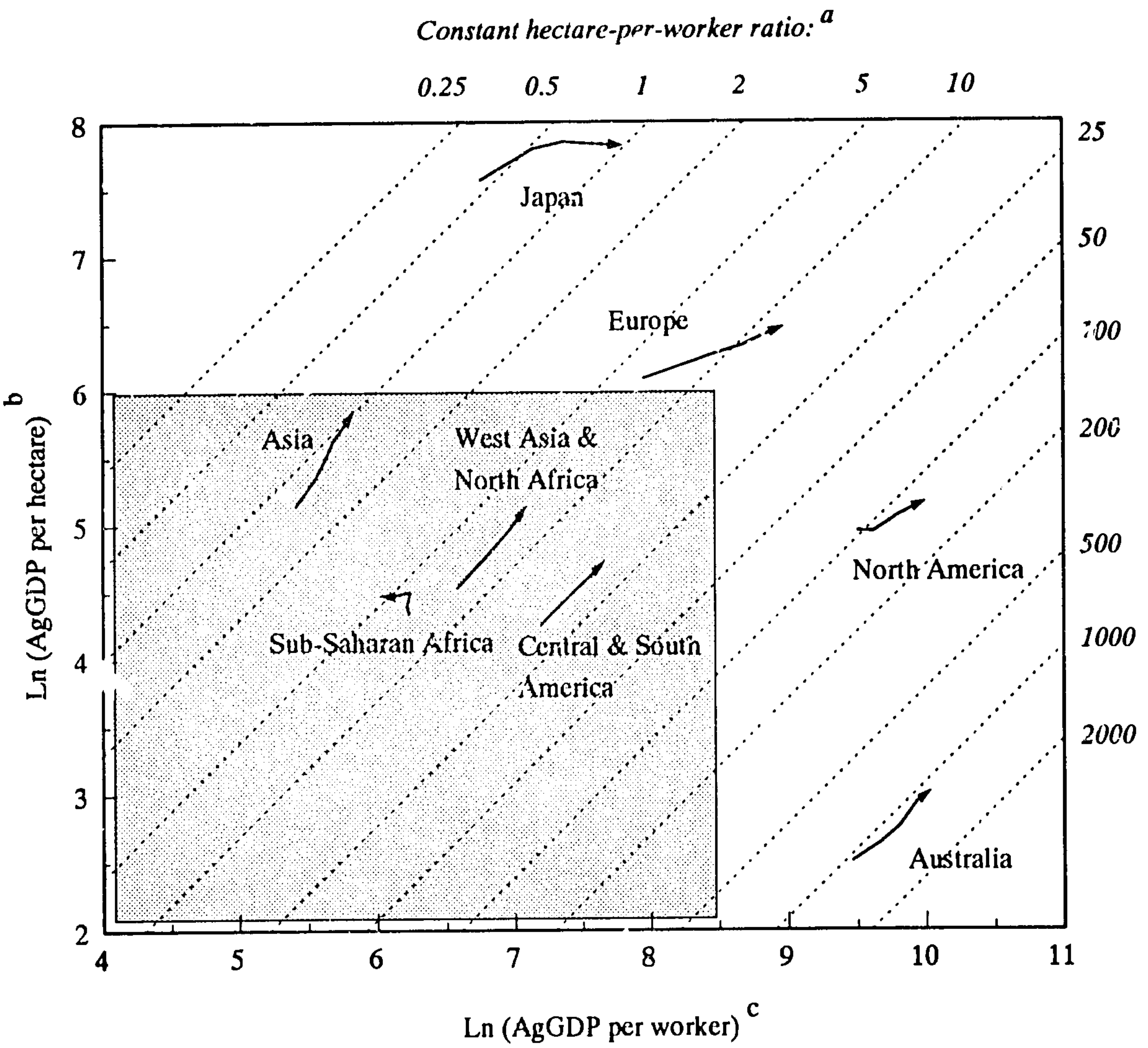
diagonals indicate constant land-labor ratios. A productivity path that crosses such a diagonal from left to right indicates an increase in the number of hectares per worker. Given the double log scale, the longer a productivity path is the greater the *percentage* change in productivity.

Figure 1: *Comparison of agricultural land and labor productivities by region, 1961-65 to 1981-85*



Source: Adapted from Craig, Pardey, and Roseboom (1991); AgGDP and implicit AgGDP deflator data primarily taken from World Bank (1989), final agricultural output PPPs from FAO (1986), agricultural labor from FAO (1987), and agricultural land from *FAO Production Yearbooks*.

Note: AgGDP in nominal local currency units was first deflated to base year 1980 using country-specific AgGDP deflators and then converted to US dollars using agricultural output PPPs. The number of countries on which the regional (weighted) averages are based is as follows: sub-Saharan Africa (18), Asia & Pacific including China (13), Central & South America (18), West Asia & North Africa (8), Europe (13), and North America (2).

[a]Hectares of agricultural land per economically active member of the agricultural population.
[b]Hectares of agricultural land includes arable plus permanently cropped and permanently pastured land.
[c]Agricultural workers are defined here as the economically active agricultural population.

As is evident from figure 1, there are considerable differences across regions both in the levels of these partial-productivity measures and their paths over time. The highest measured output per hectare occurs in Asia and Europe, and the lowest in Australia. Output per worker is highest in more-developed countries and is lowest in Asia. The paths of these partial-productivity measures over the past two decades display informative differences. In some regions such as Europe, North America, and especially Japan, increases in output per worker have exceeded increases in output per hectare (see appendix A.2), which has allowed increased output with fewer workers per hectare of land. In Asia, increases in land productivity have been dominant, and this region now employs the most workers per hectare of all the regions sampled. In Central & South America as well as West Asia & North Africa, productivity increases in both factors have been roughly equal, and their land-labor ratios have remained fairly static.

Sub-Saharan Africa's productivity path is clearly an outlier. Although there were some small increases in productivity in both labor and land in the immediate post-colonial period, this was followed by a noticeable deterioration in output per worker and stagnation in output per hectare. Without more detailed data, it is difficult to diagnose what has happened, but the decline in productivity can variously be attributed to deterioration in infrastructure, disturbances caused by wars in several of the countries in this region, government economic policies that have systematically discriminated against agriculture, and increased population pressure on marginal lands.

The results here indicate that land and labor endowments cannot tell the whole story. Initial factor endowments encouraged land-saving technological change in Japan and labor-saving technological change in North America and Australia — although for the last two regions, much of this change happened prior to the start of the sample reported here. However, in densely populated regions such as Japan and Europe, the most recent partial-productivity changes indicate the use of labor-saving rather than land-saving technologies. The fact that labor, and not land, has been induced to leave agriculture by the higher returns available in other sectors means that these regions have looked to other factors to substitute for the labor that has left agriculture and to augment the productivity of the workers remaining in the sector. While it is difficult to imagine a perfect substitute for land, there are many ways to alter the productivity of any given unit of land through complementary inputs such as fertilizers, irrigation, and both physical and human capital. The same purchased inputs can also augment the productivity of labor.

2.2 An Agroecological Perspective

At a most fundamental level, the issues associated with using agroecological concepts in both a priority-setting and resource-allocation context involve problems of *aggregation bias*. The nature and extent of this aggregation bias depends on a host of substantive issues, not least those concerning (a) classification criteria, (b) levels and nature of aggregation, and (c) "prorating factors."

For priority-setting purposes, it is appropriate to map or characterize geographical areas in terms of their agricultural (and, indeed, commodity-specific) production and research potential. Natural constraints to agricultural production and the (potential) impact of research relate in large measure to climate and soil characteristics, recognizing that particular agroecological conditions may only constitute a binding production constraint for particular commodities. The "regional agroecological zones" (RAEZs) being used for the CGIAR's current round of research priority deliberations represent agroecological characterizations based on prevailing thermal and moisture regimes as represented by "major climate" and "length of growing period" (table 4). As defined by FAO, major climate is determined by the mean daily temperature during the growing season while length of growing period is defined as the number of days when both moisture and temperature permit crop growth. A major limitation of this classification scheme is its failure to account explicitly for variations in soil and terrain attributes such as soil unit, class, slope, and phase. To the extent that such attributes substantially modify production and research potential both within and across agroecological zones, they deserve attention and preferably inclusion in the criteria for classification of agroecological zones.[2]

The nature and level of aggregation to be employed is not independent of the choice of classification criteria and clearly involves a set of decisions that relate directly to the uses envisaged for such a zonation exercise. In this instance, TAC has developed an agroecological classification scheme at the regional level that groups 122 less-developed countries into specific agroecological zones and prorates 33 of the "larger" countries (13 in sub-Saharan Africa, 14 in Central & South America, and 6 in Asia) across multiple

[2]Certainly any attempt to move beyond broad generalizations into specific recommendations concerning the siting and/or targeting of the CGIAR's research effort will clearly need to make such soil and terrain attributes (as well as additional climatic characteristics) explicit. See Wood and Pardey (1991) for a discussion of such matters in a national context.

Table 4: *Regional Agroecological Zones*

Acronym	Name	Length of growing period	Temperature	Additional details
RAEZ1	Warm, Semi-Arid Topics	75-180 days	> 20°C all year round	Arid moisture zone taken into account for the purposes of irrigation and range land assessments, and for reconciliation with political boundaries.
RAEZ2	Warm, Subhumid Tropics	180-270 days	> 20°C all year round	
RAEZ3	Warm Humid Tropics	270-365 days	> 20°C all year round	
RAEZ4	Cool Tropics	75-365 days	5-20°C during growing period	Comprised of semi-arid, subhumid, and humid moisture zones in the tropics. Arid moisture zone taken into account for the purposes of irrigation and rangeland assessments, and for reconciliation with political boundaries. Includes the moderately cool tropics major climate with daily mean temperature during the growing period in the range 15-20°C. Areas of cold tropics taken into account for reconciliation with political boundaries.
RAEZ5	Warm, Semi-Arid Subtropics (Summer Rainfall)	75-180 days	> 20°C during growing period	Arid moisture zone taken into account for the purposes of irrigation and rangeland assessments, and for reconciliation with political boundaries. Includes the warm, semi-arid temperate (summer rainfall) major climate in China.
RAEZ6	Warm, Subhumid Subtropics (Summer Rainfall)	180-270 days	> 20°C during growing period	Includes the warm, subhumid temperate (summer rainfall) major climate in China and Korea.
RAEZ7	Warm/Cool Humid Subtropics (Summer Rainfall)	270-365 days	> 20°C during one part of the growing period and 15-20°C during the other	Includes the warm, moderately cool subtropics major climate.

Table 4: *Regional Agroecological Zones*

Acronym	Name	Length of growing period	Temperature	Additional details
RAEZ8	Cool Subtropics (Summer Rainfall)	75-365 days	5-20°C during growing period	Comprised of semi-arid, subhumid, and humid moisture zones in the subtropics. Arid moisture zone taken into account for the purposes of irrigation and rangeland assessments, and for reconciliation with political boundaries. Includes the moderately cool subtropics (summer rainfall) and transitional, moderately cool subtropics (summer rainfall) major climates with daily mean temperature in the range 15-20°C. Areas of cold subtropics (summer rainfall) taken into account for reconciliation with political boundaries. Includes cool and cold temperate (summer rainfall) major climates in China, Mongolia, and Korea.
RAEZ9	Cool Subtropics (Winter Rainfall)	75-365 days	5-20°C during growing period	Comprised of semi-arid, subhumid, and humid moisture zones in the subtropics. Arid moisture zone taken into account for the purposes of irrigation and rangeland assessments, and for reconciliation with political boundaries. Areas of cold subtropics (winter rainfall) taken into account for reconciliation with political boundaries. Includes cool and cold temperate (winter rainfall) major climates in Turkey, Argentina, and Chile.

Source: Adapted from Kassam (1991).

Notes: Zones that have a mean monthly temperature, corrected to sea level, above 18°C for all months have been classified *tropical*. Zones with one or more months below 18°C but above 5°C are *subtropical* and zones with one or more months below 5°C are *temperate*.
Length of growing period has been defined as the period (in days) during the year when rainfed available soil moisture is greater than the half potential evapotranspiration (PET) rate. It includes the period required to evapotranspire up to 100m of available soil moisture stored in the soil profile. It excludes any time interval when mean daily temperature is less than 5°C.
Zones with mean daily temperature greater than 20°C during the growing period have been classified as *warm*. Zones with mean daily temperature between 5-20°C are *cool*, below 5°C are *cold*, and if one part of the growing period has temperatures greater than 20°C and the other is between 5-20°C they are classified as *warm/cool*.
Zones have been classified as *arid* if the length of growing period is less than 75 days, as *semi-arid* if the range is between 75-180 days, as *subhumid* if the range is between 180-270 days, and as *humid* if the range is greater than 270 days.

agroecological zones.[3] The goal of the exercise is to achieve a level of aggregation that strikes an appropriate balance between practicality on the one hand (i.e., generates a manageable set of zones) and accuracy on the other (i.e., groups countries or regions into zones that are in some sense "homogeneous"). Homogeneity in this case relates both to agricultural production potential as well as agricultural research opportunities and impact. The *average* production potential and research effects for any given agroecological zone are driven in turn by a host of economic factors, the commodity and type of technology under consideration, as well as the residual agroclimatic and edaphic (i.e., agroecological) diversity being aggregated into a single zone. Any classification scheme will surely introduce problems of aggregation bias into cross-zonal comparisons. The trade-off between practicality versus accuracy then comes into play, a trade-off that hinges largely on the uses to which such a classification scheme is to be put.

While agroecological zones are a useful device to identify spatial differences in the natural factors conditioning the (potential) response to new technologies, there are a host of market-related and indeed culturally related, factors that also play a role in this instance. Consequently, a consideration of research priorities in an agroecological framework that involves quantitative and not merely qualitative insights must achieve a spatial correspondence between the agroecological zones and the corresponding market-related data (such as the quantities and prices of specific commodities produced and consumed, input use and the like) that are compiled and reported on a geopolitical basis. To do this entails the development of a set of prorating factors that would allow one to regroup economic and other data reported on a geopolitical (i.e., country, provincial, district, etc.) basis into agroecological aggregates. Ideally, one would like access to prorating factors that are specific to the variable being reaggregated. In the case of agricultural labor, for instance, it would be desirable to have data of sufficient spatial disaggregation to allocate labor to specific agroecological zones within a geopolitical region.

Unfortunately, we are often presented with preaggregated data (be it at the provincial, state, or national level) on agricultural output, land, labor, NARS expenditures, and the like, that does not readily allow for reaggregations (or proratings) at a sufficient level of detail. The "fixes" that in this instance have been implemented to work around this problem involve (a) defining RAEZs at a level of aggregation such that, in many instances, individual countries lie within a unique RAEZ and/or (b) developing a prorating

[3]The assignment of countries to regions is detailed in appendix A.3.

factor for those countries spanning several RAEZs that represents the agroecological distribution of *arable land* within a particular country (see appendix A.3). If the spatial pattern of arable land fails to correspond to the spatial pattern that prevails for the other agricultural input and output data to be reaggregated, then an additional source of aggregation bias will be introduced into the analysis. While clearly cognizant of these difficulties, the aggregation method reported in Ryan and Davis (1990), and being further refined by Wood and Pardey (1991) and Davis (1991), has the major advantage of making these aggregation procedures transparent and subject to replication and systematic adjustment.

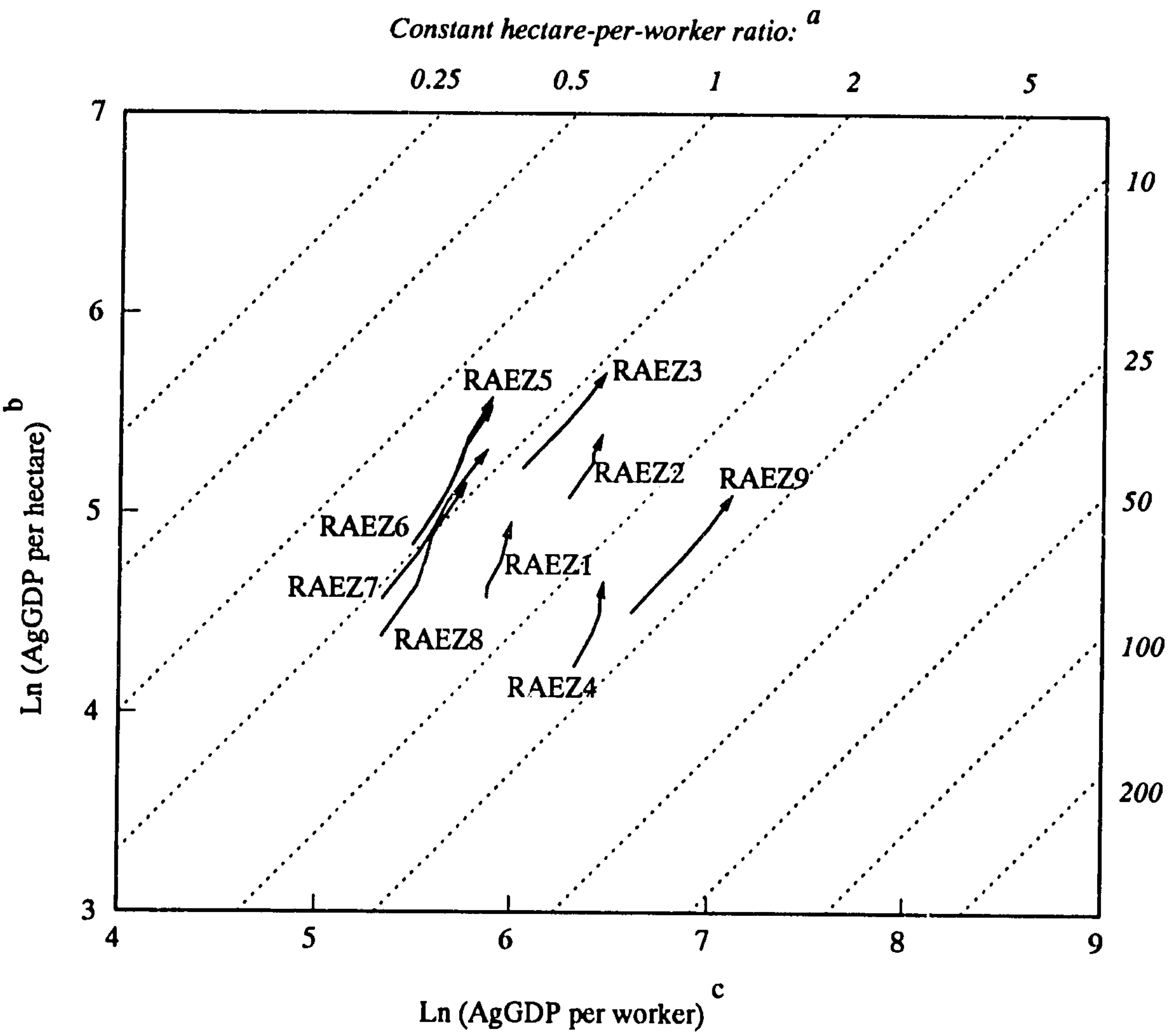
Productivity Patterns by RAEZs

Putting to one side the aggregation-bias issues addressed in the previous section, figure 2 presents agricultural land and labor productivity patterns over the past 25 years for all less-developed countries reaggregated into the nine RAEZs as defined in table 4. These RAEZs represent spatial aggregates that are more or less homogeneous with respect to basic moisture and temperature regimes. Despite the fact that these RAEZs span several geopolitical regions and incorporate countries that are at various stages of development, there is some (not entirely unexpected) uniformity in the zonal patterns of productivity revealed by the data in figure 3.

There is a similar if not converging pattern of land-labor ratios for those subtropical zones receiving summer rainfall (i.e., RAEZ5, 6, 7, and 8) so that all these zones have relatively labor-intensive systems and employ as little as one and a half to two hectares of land per agricultural worker. By contrast, the cool tropics and subtropical zones, where mean daily temperatures during the growing season are in the range of five to 20 degrees (i.e., RAEZ4 and 9), have relatively land-intensive agricultural systems by less-developed country standards and average between seven to 10 hectares per unit of labor. The warm tropical zones (i.e., RAEZ1, 2, and 3) are bounded by these extremes and employ somewhere between two to five hectares per agricultural worker.

As indicated by the respective lengths of these productivity paths, RAEZ1, 2, and 4 have witnessed the smallest proportionate increase in both land and labor productivities since 1961, while the cool subtropics (i.e., RAEZ8 and 9) have experienced the largest rate of increase in these partial-productivity ratios. Finally, with the exception of RAEZ3 and 9, all other zones have apparently moved toward more labor-intensive production regimes over the past 25 years.[4]

Figure 2: *Comparison of agricultural land and labor productivities by agroecological zone, 1961-65 to 1981-85*



Note: For sources and notes see figure 1.

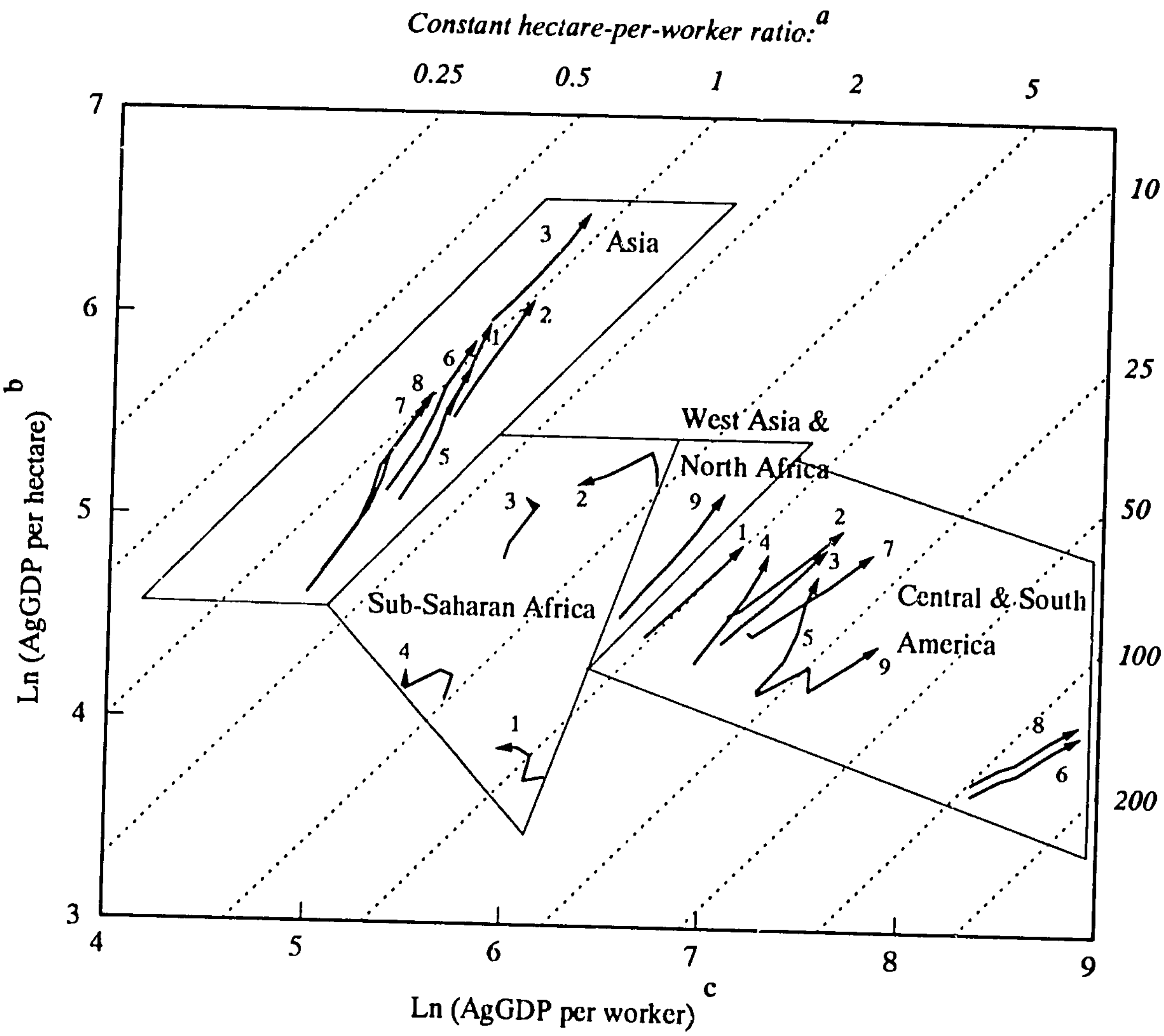
2.3 An "Ecoregional" Perspective

Figure 3 juxtaposes regional (figure 1) against zonal (figure 2) productivity trends to reveal the ecoregional diversity in development patterns within agriculture over the past 25 years. In contrast to the substantial

[4]Given that the land and labor variables are unavoidably measured in stock rather than flow terms, it is not possible to be definitive on this issue.

degree of uniformity in the zonal productivity patterns, there is quite dramatic variability in productivity trends at the ecoregional level, and most important, differences in zonal patterns of development seem to be strongly conditioned by regional factors.

Figure 3: *Comparison of agricultural land and labor productivities in an "ecoregional" context, 1961-65 to 1981-85*



Note: For sources and notes see figure 1.

For Asia, while zonal factor ratios have been converging to around one hectare per worker (table 5), there are considerable differences in the level of output per hectare and per unit labor across RAEZs. Over time, however, these differences appear to have narrowed somewhat. This is because of a more rapid increase in productivity in the cooler subtropics (RAEZ7 and 8) that initially lagged in productivity terms.[5]

Table 5: *Trends in Agricultural Land-Labor Ratios by Region and Agroecological Zone*

Region/RAEZ	1961-65	1966-70	1971-75	1976-80	1981-85
			(hectares per worker)[a]		
Sub-Saharan Africa (18)[b]	*6.6*	*6.1*	*5.6*	*5.2*	*4.7*
RAEZ1	11.9	11.0	10.0	9.0	8.1
West Africa	12.1	11.2	10.2	9.2	8.3
East Africa	13.0	12.0	10.9	9 8	8.9
Southern Africa	5.9	5.5	5.0	4.6	4.2
RAEZ2	4.8	4.4	4.0	3.6	3.2
West Africa	3.4	3.1	2.8	2.5	2.2
East Africa	4.7	4.2	3.8	3.5	3.2
Southern Africa	8.1	7.9	7.5	6.9	6.3
RAEZ3	3.2	3.1	3.0	2.8	2.7
RAEZ4	4.9	4.5	4.1	3.8	3.5
Asia & Pacific (13)	*1.3*	*1.2*	*1.1*	*1.1*	*1.0*
RAEZ1	1.2	1.1	1.1	1.0	0.9
RAEZ2	1.2	1.2	1.1	1.1	1.0
RAEZ3	0.9	0.9	0.9	0.9	0.9
RAEZ5	1.4	1.3	1.2	1.1	1.1
RAEZ6	1.3	1.2	1.1	1.0	0.9
RAEZ7	1.4	1.3	1.2	1.1	1.0
RAEZ8	1.4	1.3	1.2	1.1	1.0
Central & South America (18)	*18.7*	*18.8*	*18.8*	*18.9*	*18.8*
RAEZ1	9.7	9.8	9.8	9.9	9.9
RAEZ2	13.1	13.6	14.1	14.7	15.1
RAEZ3	14.6	14.7	15.1	15.3	15.4
RAEZ4	14.1	13.5	13.0	12.4	11.7
RAEZ5	22.0	21.7	20.1	18.1	16.8
RAEZ6	107.6	115.4	122.1	129.3	137.7
RAEZ7	15.7	16.4	17.3	18.7	19.8
RAEZ8	101.8	108.6	114.8	121.8	129.4
RAEZ9	22.4	25.4	28.4	30.9	32.2
West Asia & North Africa[c] *(8)*	*7.8*	*7.6*	*7.6*	*7.4*	*7.0*

Source: Labor data extracted from FAO (1987) and land data from *FAO Production Yearbooks*.

Note: The land-labor ratios presented here correspond with the partial-productivity graphs. Although the sample size is smaller than it is in the tables to follow, a larger sample does not give significantly different land-labor ratios. The 57 countries included here represent about 82% of the total agricultural land area in less-developed countries.

[a]Agricltural land comprises the total area classified by FAO as arable land, permanent crops, and permanent pastures. Agricultural labor has been measured here in terms of the economically active agricultural population.
[b]Bracketed figures indicate the number of countries included in the regional totals.
[c]Includes only countries in RAEZ9.

[5]These particular RAEZs are dominated by developments within China.

In marked contrast with the Asian experience, the four tropical zones that characterize sub-Saharan Africa (RAEZ1 2, 3, and 4) showed no tendency to converge and, in fact, displayed quite erratic patterns of development over time. The warm subhumid tropics (RAEZ2) experienced a fairly sustained decline in both land and labor productivity over the past 15 to 20 years, driven to a degree by developments in Angola and Mozambique, while the warm humid tropics (RAEZ3) was the only zone to display measurable but still quite modest gains in both land and labor productivities. As indicated in table 5, all zones paralleled developments at the regional level and experienced declines in their land-labor ratios.

Across zones in Central & South America there were relatively small differences in land productivities but quite marked differences in levels of output per worker. As one would expect, the zones consisting principally of the Andean, Caribbean, and Central American countries have ratios of hectares per worker in the 10 to 15 range while the pampean and cool subtropical zones of the Southern Cone (RAEZ9 and, particularly, RAEZ6 and RAEZ8) have zonal land-labor ratios ranging from two to seven times higher than the regional average of 19 hectares per worker.

The differences in land and labor productivity as sketched in these partial-productivity graphs can be explained in part by differences in the use of purchased inputs like fertilizers and machinery. Consumption data in table 6 indicate some substantial spatial differences as well as changes over time in fertilizer usage over the past two decades. It is not surprising that Asia, the region with the highest output per hectare as well as the highest rate of growth in output has also experienced the highest fertilizer application rates as well as the largest increase (10-fold since 1961). The relatively intensive use of fertilizers in those subtropical areas subject to summer rain (RAEZ5, 6, 7, and 8) is driven principally by conditions in China. Although fertilizer use has increased more than fourfold in sub-Saharan Africa, it is still extremely low compared with other regions. In Central & South America, fertilizer use seems to be relatively similar among the region's different agroecological zones, except for RAEZ6, RAEZ8, and to a lesser extent RAEZ9. These three zones have relatively high land-labor ratios that reflect extensive farming systems similar to those of the US and Australia. Comparing similar agroecological zones across regions shows a sharp contrast between the Asian RAEZ6 and RAEZ8 on the one hand and the corresponding South American zones on the other. Specifically, for the data reported here, ratios of labor per unit land in Asia are around 160-fold higher than for corresponding agroecological zones in South America (table 5), while Asian fertilization rates on average are approximately 30-fold higher than the corresponding rates in South America.

These dramatic differences in production regimes serve to highlight the fact that there are a host of regional factors (often reflecting local socioeconomic conditions) that affect the transferability of research results, even across zones that ostensibly have similar agroclimatic characteristics.

Table 6: *Fertilizer Use by Region and Agroecological Zone*

Region/RAEZ	1961-65	1966-70	1971-75	1976-80	1981-85
			(kg per hectare)[a]		
Sub-Saharan Africa (41)[b]	*1.6*	*2.7*	*4.4*	*5.4*	*7.2*
RAEZ1	2.4	3.9	6.6	6.9	8.9
West Africa	0.6	1.0	2.1	3.7	5.2
East Africa	1.9	3.3	5.2	4.5	6.2
Southern Africa	7.0	10.7	18.0	17.6	21.1
RAEZ2	0.7	1.3	2.2	3.7	5.8
West Africa	0.2	0.6	1.0	2.7	6.4
East Africa	0.7	1.2	1.9	1.8	1.8
Southern Africa	2.7	3.8	6.3	9.4	10.1
RAEZ3	1.5	2.3	3.4	5.0	6.4
RAEZ4	1.0	2.3	3.5	4.3	6.1
Asia & Pacific (17)	*8.3*	*18.9*	*31.1*	*53.9*	*82.8*
RAEZ1	3.6	10.5	17.2	27.9	43.9
RAEZ2	3.7	9.0	13.8	22.0	34.1
RAEZ3	9.6	15.6	24.7	40.2	63.6
RAEZ5	5.3	15.0	25.8	46.7	72.5
RAEZ6	17.9	34.6	55.5	84.2	117.9
RAEZ7	16.5	36.4	60.8	113.9	174.5
RAEZ8	13.2	31.3	53.4	100.2	155.9
Central & South America (31)	*9.7*	*14.3*	*24.5*	*36.7*	*35.1*
RAEZ1	8.1	14.0	25.7	42.2	43.7
RAEZ2	11.2	16.6	33.0	50.4	44.1
RAEZ3	13.1	18.5	31.6	46.9	44.7
RAEZ4	18.1	24.4	35.0	44.5	49.0
RAEZ5	8.5	15.7	25.2	34.5	48.8
RAEZ6	0.9	2.2	2.2	2.9	3.6
RAEZ7	7.7	11.5	25.9	45.3	34.8
RAEZ8	2.2	4.4	5.0	5.6	5.5
RAEZ9	15.7	21.0	23.9	20.7	24.5
West Asia & North Africa (19)	*6.7*	*11.7*	*20.9*	*34.7*	*49.1*
RAEZ1	0.0	0.0	5.2	18.7	37.8
RAEZ4	0.0	0.1	0.9	3.9	9.9
RAEZ9	6.8	12.0	21.3	35.4	49.7
Total (107)	*7.1*	*14.2*	*23.6*	*39.0*	*54.2*

Source: Fertilizer data extracted from FAO (1990a) and arable land & permanently cropped land from *FAO Production Yearbooks*.

[a]Unweighted sum of mass of nitrogen, phosphorus (as oxide), potassium (as oxide) divided by the area of arable and permanently cropped land.
[b]Bracketed figures indicate the number of countries in the regional totals.

The use of capital services in agriculture over the past two decades is virtually impossible to document. Even information on agricultural capital stock is spotty. Complete information on tractors, animal traction, combines, harvesters, threshers, milking machines, irrigation equipment, storage facilities, and public infrastructure is available for very few countries. Even if the data were available, aggregating such stocks over a region and converting them to a useful measure of the service flow from capital requires detailed information on capital prices, utilization rates, economic depreciation rates, and the lifespan of different capital types.

In table 7, total tractors in use in agriculture are reported. These figures are available for a wide range of countries, but they provide -- at best -- a crude indicator of total services from capital. Changes in the stock of tractors have been used as a proxy for the change of capital use in agriculture. The danger in doing this lies in the possibility of forgetting changes in the quality of tractors over time and the probably more significant cross-sectional differences in average tractor quality. Again, sub-Saharan Africa stands out as a region that uses considerably fewer purchased inputs than other less-developed regions. In 1981-85, the number of tractors per million hectares of agricultural land in sub-Saharan Africa was only about one-tenth the level prevailing in the other less-developed regions; over the whole period under consideration (1961-65 to 1981-85) the gap had widened.

3 NARS CAPACITY

3.1 A Global Overview[6]

The pattern of global investment in public agricultural research has undergone dramatic change over the past two decades. Global agricultural research capacity grew substantially, while at the same time, the less-developed countries significantly increased their share in the global capacity. However, recent trends indicate a marked departure from this historical pattern of growth. There are signs that new investment is slowing, particularly with regard to financial support for agricultural research in sub-Saharan Africa and Central & South America, the two regions most affected by the debt and economic crisis of the 1980s.

[6] This section draws heavily on Pardey, Roseboom, and Anderson (1991a).

Table 7: *Tractors in Use in Agriculture by Region and Agroecological Zone*

Region/RAEZ	Total number of tractors in use in agriculture 1961-65	1966-70	1971-75	1976-80	1981-85	Growth rate[a]	Number of tractors per million hectares of agricultural land 1961-65	1966-70	1971-75	1976-80	1981-85
	(thousands)					(%)					
Sub-Saharan Africa (40)[b]	*55.4*	*74.1*	*98.1*	*113.5*	*128.8*	*4.3*	*80*	*105*	*137*	*157*	*178*
RAEZ1	31.4	39.2	51.1	58.4	67.1	3.9	77	95	122	139	159
West Africa	0.7	1.6	3.5	4.4	5.0	10.5	4	9	21	26	30
East Africa	12.5	14.6	19.3	22.6	29.4	4.4	101	117	155	180	234
Southern Africa	18.2	23.1	28.4	31.4	32.7	3.0	154	186	224	246	256
RAEZ2	10.3	14.7	20.9	24.4	27.1	5.0	95	133	186	217	239
West Africa	0.4	1.0	2.9	3.8	4.5	12.9	12	29	85	109	130
East Africa	6.7	7.4	8.2	8.9	9.9	2.0	236	258	279	300	328
Southern Africa	3.2	6.3	9.8	11.8	12.7	7.1	69	131	202	243	262
RAEZ3	4.5	7.8	11.3	14.3	16.7	6.8	48	83	118	147	170
RAEZ4	9.2	12.3	14.8	16.4	17.8	3.3	106	139	166	184	200
Asia & Pacific[c] (17)	*130.6*	*289.3*	*576.8*	*1095.1*	*1688.4*	*13.7*	*186*	*408*	*808*	*1523*	*2341*
RAEZ1	20.6	40.5	97.0	172.6	269.5	13.7	224	437	1036	1823	2869
RAEZ2	12.3	24.4	51.1	93.7	158.8	13.6	274	532	1082	1932	3228
RAEZ3	17.0	27.9	42.5	65.9	102.6	9.4	302	468	677	1017	1544
RAEZ5	25.5	58.0	120.9	242.2	392.7	14.7	195	442	915	1820	2951
RAEZ6	8.7	20.7	41.9	80.7	123.1	14.1	157	371	753	1451	2216
RAEZ7	24.4	61.9	117.1	230.5	336.9	14.0	145	368	698	1378	2012
RAEZ8	22.1	56.0	106.4	209.5	304.8	14.0	141	360	685	1350	1961
Central & South America (33)	*426.1*	*546.1*	*676.2*	*907.9*	*1187.0*	*5.3*	*686*	*838*	*991*	*1285*	*1637*
RAEZ1	20.0	28.0	38.4	57.9	78.4	7.1	525	699	919	1334	1750
RAEZ2	46.2	66.5	97.3	161.6	223.7	8.2	596	781	1052	1649	2188
RAEZ3	53.5	72.3	97.1	144.1	192.1	6.6	646	822	1027	1452	1864
RAEZ4	46.4	58.0	67.5	76.3	95.7	3.7	448	561	633	701	862
RAEZ5	29.7	37.7	41.9	45.2	60.1	3.6	699	887	984	1057	1396
RAEZ6	22.1	26.7	28.2	27.7	32.6	2.0	796	948	994	976	1149
RAEZ7	50.0	75.2	115.3	204.8	290.6	9.2	521	698	978	1619	2180
RAEZ8	122.2	145.0	153.2	152.9	175.9	1.8	896	1050	1107	1102	1267
RAEZ9	36.1	36.8	37.3	37.4	37.9	0.3	2108	1994	1893	1839	1846
West Asia & North Africa (19)	*142.0*	*220.6*	*360.0*	*633.4*	*894.4*	*9.6*	*404*	*624*	*1010*	*1785*	*2558*
RAEZ1	0.4	1.0	1.6	2.3	2.9	10.5	38	100	160	221	281
RAEZ4	0.2	0.4	0.7	1.8	2.1	12.5	24	43	75	197	256
RAEZ9	141.4	219.2	357.7	620.4	889.4	9.6	425	657	1061	1875	2686
Total (109)	*754.1*	*1130.1*	*1711.1*	*2749.8*	*3898.7*	*8.6*	*318*	*467*	*693*	*1099*	*1548*

Source: Tractor data extracted from FAO (1990b) and agricultural land data from *FAO Production Yearbooks*.

[a]Average annual compound growth rate between 1961-65 and 1981-85.
[b]Bracketed figures indicate the number of countries included in the regional totals.
[c]Includes China.

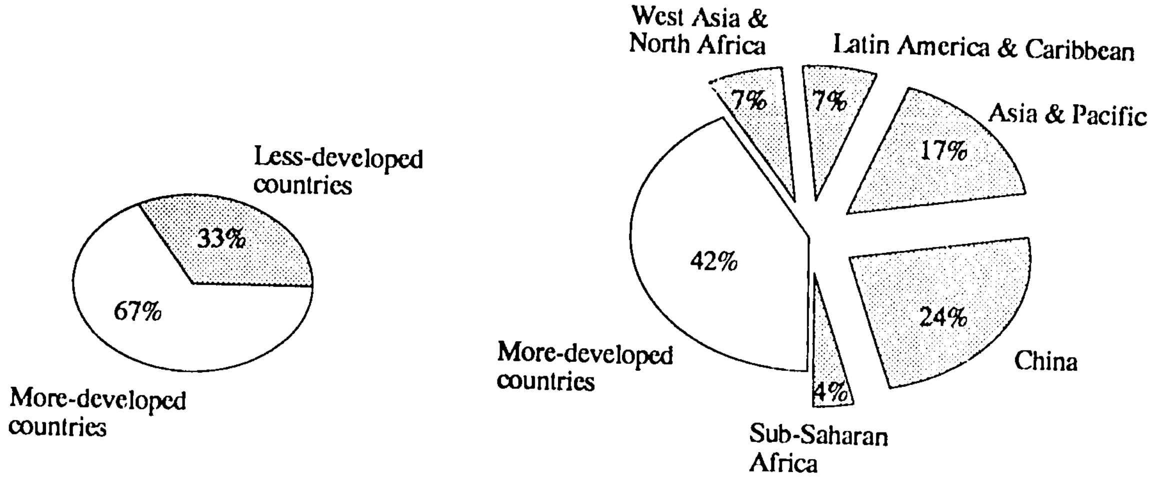
Averaged over the 1981-85 period, the less-developed country total of agricultural researchers working in the public sector stood at slightly more than 76,000 full-time equivalents (figure 4a). Since the 1961-65 period, the number of researchers in less-developed countries grew at just over four times the annual rate (7.1%) of the more-developed countries (1.7%). As a result, the global share of researchers in less-developed countries increased from 33% in 1961-65 to 58% in 1981-85. The Asian region (including China) accounted for about 70% of the less-developed country total in 1981-85. Central & South America and West Asia & North Africa each accounted for between 10% to 12%, while the remaining less-developed country researchers (6.5%) worked in sub-Saharan Africa. Significantly, the total number of researchers in sub-Saharan Africa would increase by around 39% if the region were redefined to include the Republic of South Africa's public research system.

Global spending on public agricultural research averaged $8.4 billion per annum in 1981-85, up by a factor of 2.6 on the level of real expenditures two decades earlier. The expenditure share of the less-developed countries grew from 33% in 1961-65 to only 43% in 1981-85 (figure 4b). This is considerably less than the corresponding fraction of agricultural researchers (58%) who work in the public-sector NARSs of these less-developed countries.

The 6.2% rate of increase in real spending for the less-developed countries was approximately 50% larger than the increase for the more-developed countries over the period from 1961 to 1985. However, it fell short of the 7.1% increase in research personnel experienced by the less-developed countries over the corresponding period. By contrast, the more-developed countries increased their real research expenditures at more than double the rate of increase of research personnel.

Asia (excluding China) is the only less-developed region for which the overall annual rate of growth in real expenditures (6.7%) exceeded the rate of growth in number of researchers (6.3%). In fact, this region has exhibited the largest rate of increase in real expenditures but the slowest growth in research personnel over the past two decades, when compared with other less-developed regions. The sub-Saharan Africa region experienced the slowest rate of growth in real spending levels of any of the less-developed country regions, despite (or perhaps, to a degree, in response to) substantial donor support, while research personnel growth was in line with the less-developed country average.

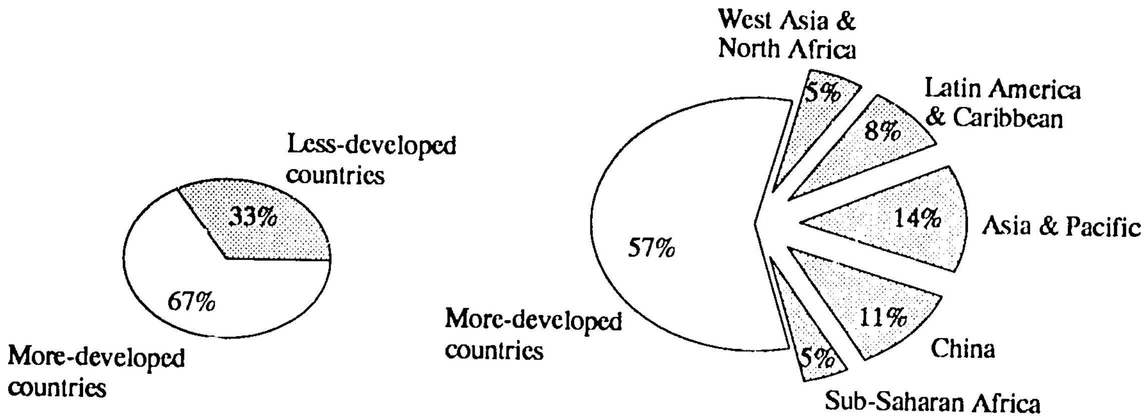
Figure 4a: *Agricultural researchers, regional shares*



1961-65: 60,148 researchers

1981-85: 134,113 researchers

Figure 4b: *Agricultural research expenditures, regional shares*



1961-65: 3284 million 1980 PPP $

1981-85: 8443 million 1980 PPP $

Source: Pardey, Roseboom, and Anderson (1991a)

Note: Percentages do not sum to 100 because of rounding.

An inspection of investment patterns over the 1961-65 to 1981-85 period reveals a general contraction in the growth of agricultural research expenditures in the less-developed countries during the latter period of the sample, except in West Asia & North Africa. The precipitous decline in the rate of growth in real spending for sub-Saharan Africa over this same period reflects a widespread slowdown throughout the region. This was compounded by a 23% decline in total spending by the Nigerian system, which alone accounts for approximately one-quarter of public spending on agricultural research in sub-Saharan Africa. Anecdotal evidence suggests that this contractionary pattern of support has continued or even accelerated over the more recent past for many less-developed countries and may have been matched in some of the more-developed countries as well. Central & South America also witnessed a widespread slowdown in total agricultural research spending between 1976-80 and 1981-85, with 16 of the 38 countries in the region experiencing declines in absolute terms.

Real Expenditures per Researcher

The ratio of expenditures per researcher exhibits a substantial degree of variability, both within a region over time and among regions during any given period. With real expenditures measured in terms of 1980 purchasing power parity (PPP), the overall ratio of spending per researcher for more-developed countries increased steadily from $54,200 in 1961-65 to $85,400 in 1981-85.[7] The more-developed countries have continued to move toward more capital-intensive — in both human and physical terms — research systems over the past two decades. Evidence based on detailed data from the US state agricultural experiment stations on the changing factor mix of their research systems points to a significant increase in human capital relative to physical capital over the long run. By contrast, a mixed pattern of capital deepening appears to characterize the national research systems of the less-developed countries since the early 1960s. The less-developed countries spent $55,400 per researcher on average in 1961-65. This amount peaked during the early 1970s, followed by a steady decline, and reached $46,700 by 1981-85.

One widely observed factor that has contributed to the overall decline in spending per researcher among less-developed countries can be traced to the substantial growth in university graduates resulting from an expansion in local university capacity. Governments in numerous less-developed countries often oblige public-sector agencies, including public-sector research agencies, to offer employment to these graduates. However, in many instances the governments fail to provide sufficient matching funds to preserve spending-per-researcher ratios.

Most Asian countries display levels of real support per researcher that have historically been low when

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[7]This increase is driven, in part, by Japan's exceptionally rapid increase in spending per researcher from a relatively low $32,300 in 1961-65 to $69,100 by 1981-85.

compared with other regions of the world. When translating research expenditures that are measured in nominal local currency units into real aggregates, we attempted to account for the relatively low average price levels that have prevailed in Asia. Compared with the alternative translation procedures used by others in the past, this substantially increased (in fact, it doubled) the region's share of the global volume of resources committed to agricultural research. As a consequence, our translation procedures narrowed but certainly did not eliminate regional differences in the volume of resources expended per researcher.

Economies of size and scope accruing to the large (and, in some ways, less fragmented) research systems that dominate Asia would tend to lower average costs per unit of research output. They would also account, to some extent, for the region's lower spending per researcher. In addition, relatively lower labor costs, resulting from a comparative abundance of labor, would induce a substitution of labor for capital and other inputs in the knowledge-production process. This would also tend to reduce the region's ratio of spending per scientist.

One striking feature of our data is the historically high level of expenditures per researcher in sub-Saharan Africa. This peaked in the late 1960s at $123,400 and has declined steadily since. During the 1960s, recently decolonized NARSs in the region were still staffed by a high proportion of relatively expensive expatriate researchers (ex-colonial initially but now increasingly American and other). The region's infrastructure was poorly developed at that time, and this also raised the cost of securing basic communication, transport, and electrical services. Research hardware and instrumentation often had to be imported. Further, the region includes numerous small NARSs, many of which are attempting to address production issues arising from diverse agroecological and socioeconomic environments, which give rise to diseconomies of size and scope that further force up average research costs.

While infrastructural constraints surely remain, and in some instances have probably intensified, the substantial decline in the levels of support per researcher may in part reflect the Africanization of the research system that has occurred during this period. Several forces are at work here. There has clearly been a trend to replace more expensive expatriate researchers with less expensive (but on average, possibly less skilled) local researchers. Anecdotal evidence suggests that, in the late 1950s prior to independence, about 90% of the agricultural researchers in the region were expatriates. By the late 1960s the share of expatriates had declined to around 60%, according to data provided by Cooper (1970) for some 30 sub-Saharan African countries. Our data suggest that the decline has continued to the extent that, by 1981-85, the share of expatriates had fallen to less than 30%. There have also been substantial changes in the financial support for research in many countries of the region. Donor funds continue to account for a major share of total funding for public agricultural research, but the coming of independence saw a shift from institution-based support through various colonial administrations to largely project-based, bilateral support mechanisms. As a consequence, the policy forces that shape staffing decisions have, to an apparently increasing degree, been decoupled from at least some of the forces that determine funding levels.

Size of NARSs

When measured in terms of full-time equivalent researchers, the average size of public-sector NARSs has more than doubled over the two decades since 1961-65, from approximately 400 to 880 researchers. The average size of less-developed country systems had increased from 150 to 600, while more-developed country systems grew, on average, from 1840 to 2560 researchers.[8] Average research expenditures, expressed in constant 1980 PPP dollars, increased from around $22 million per system to $56 million. There were 74 NARSs in 1961-65 with fewer than 25 researchers, but by 1981-85 there were only 39. All of the smaller NARSs in this sample (i.e., those with fewer than 25 researchers) are located in less-developed regions, in particular the Caribbean (12), Pacific (9), and sub-Saharan Africa (10). Correspondingly, the number of larger NARSs employing more than 1000 researchers increased from nine to 26, of which six now employ more than 4000 researchers.

In spite of the increasing number of medium- to large-sized NARSs, there remain a substantial number of small NARSs with little capacity to undertake anything but highly focused adaptive research on a few commodities or to maintain search and screening capabilities on a slightly broader front to endeavor to capture potential research spillovers. Cross-country research spillovers arise through various channels ranging from technology transfers by private seed, machine, and chemical companies to formal and informal networking structures among public-sector NARSs. Success in capturing these potential spillovers in a timely

[8]Excluding China from these totals reduces average system size in 1981-85 from 880 to 790 researchers and the average size of research systems in less-developed countries from 600 to 350 researchers.

manner continues to elude many of the smaller systems.

3.2 An Ecoregional Perspective on NARSs

To do justice to an analysis of national agricultural research systems in an ecoregional framework would require detailed information on the site specificity of a system's research endeavors (or those of its components). In the absence of such detailed information, we must be content with identifying the site of origin rather than the (potential) site of impact of these research endeavors. Certainly research carried out in one particular locale may target yet another site and have secondary impacts in additional nontargeted locations. Determining the site specificity of a research program is, however, a complex matter that at a minimum depends on the (sub-)commodity, technology, and problem focus of the research.[9] But, given that rather broad spatial aggregates presented in this paper, there is likely to be a high correspondence between where the research is executed versus where it is targeted. For those countries (89 in all) that, by construction, fall within a unique RAEZ, the regional as opposed to zonal focus of their national research program is in fact coincident. For those 33 countries that span multiple AEZs, the reaggregation procedure used here implies that national research programs are targeted to corresponding AEZs in direct proportion to the zonal share of arable land within a particular country -- a tolerable first approximation.

Table 8 groups agricultural research personnel and expenditure data together with various agricultural output and input measures on a regional and zonal basis. An overwhelmingly large proportion of the less-developed world's agricultural research capacity is to be found in the Asia & Pacific region. The distribution of public agricultural research capacity across agroecological zones is somewhat more even. The exceptions are the cool tropics (RAEZ4) and warm subhumid subtropics (RAEZ6) that account for a relatively minor share of the less-developed world's research resources. But, their research shares are more or less congruent with their corresponding agricultural output, land, and labor shares.

In contrast to the zonal distribution of research resources, there is a highly uneven incidence of national agricultural research systems (or parts thereof) across agroecological zones (table 9). Four of these

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[9]See Wood and Pardey (1991) for a fairly detailed discussion of these issues. Here the technology focus of a research program refers to its orientation to genetic improvement, pest and disease control, and crop management.

Table 8: *Summary of Agricultural Research, Output, and Input Indicators by Region and Agroecological Zone, 1981-85 Average*

Region	Research expenditures		Researchers		AgGDP		Agricultural labor		Agricultural land	
	1980 dollars	Share	FTE	Share	1980 dollars	Share	Number	Share	Hectares	Share
Region	*(million)*	*(%)*		*(%)*	*(billion)*	*(%)*	*(million)*	*(%)*	*(million)*	*(%)*
Sub-Saharan Africa (40)[a]	371	11	4,918	6	75.6	9	124.1	13	723.2	29
Asia & Pacific[b] (16)	2076	59	54,558	72	578.2	68	740.0	79	719.4	29
Central & South America (30)	695	20	8,861	12	120.1	14	39.0	4	724.6	29
West Asia & North Africa (17)	369	11	7,836	10	79.0	9	29.2	3	302.1	12
Agroecological zone										
RAEZ1 (35)	438	12	7,176	9	122.7	14	147.5	16	571.3	23
RAEZ2 (28)	350	10	5,445	7	85.0	10	86.4	9	264.8	11
RAEZ3 (43)	644	18	8,978	12	148.2	17	108.0	12	265.8	11
RAEZ4 (18)	164	5	2,048	3	40.7	5	35.5	4	208.5	8
RAEZ5 (5)	369	11	10,276	13	106.3	12	128.5	14	176.1	7
RAEZ6 (4)	170	5	4,941	6	49.4	6	58.8	6	83.9	3
RAEZ7 (5)	587	17	16,247	21	117.3	14	180.4	19	300.7	12
RAEZ8 (6)	407	12	13,137	17	104.1	12	158.8	17	294.3	12
RAEZ9 (15)	381	11	7,926	10	79.0	9	28.4	3	303.8	12
Less-Developed Country Total (103)	*3511*	*100*	*76,174*	*100*	*852.8*	*100*	*932.3*	*100*	*2469.3*	*100*

Source: See appendix 4.

[a]Bracketed numbers denote the number of countries, or part thereof, included in each region or RAEZ.
[b]Includes China.

Table 9: *Regional and Size Characteristics of NARSs Stratified by Agroecological Zones*

Region/Zone	Regional Distribution of Systems[a]					Size of Systems[b]				
	SSA	A&P	C&SA	WANA	Total	< 25	25-99	100-399	400-999	≥ 1000
Region	41	17	33	20	111	22	35	33	7	14
Zone										
RAEZ1	24	2	6	3	35	4	13	12	1	5
RAEZ2	15	4	12	-	31	6	7	13	-	5
RAEZ3	12	10	23	-	45	10	13	13	3	6
RAEZ4	8	-	9	1	18	1	6	8	2	1
RAEZ5	-	3	2	-	5	-	-	-	-	5
RAEZ6	-	3	1	-	4	-	-	-	-	4
RAEZ7	-	2	3	-	5	-	1	-	-	4
RAEZ8	-	4	2	-	6	-	1	-	1	4
RAEZ9	-	-	2	16	18	2	4	4	2	3

Note: Table reports number of systems *or parts thereof* that fall within a particular regional agroecological zone.

[a]SSA represents sub-Saharan Africa, A&P – Asia & Pacific, C&SA – Central & South America, and WANA – West Asia & North Africa.
[b]Measured in terms of 1981-85 full-time equivalent researchers.

RAEZs support fewer than seven systems each, while the warm humid tropics (RAEZ3) alone encompasses 45 national systems. Moreover, the zonal distribution of national systems varies quite markedly across different geopolitical regions. All of the systems within sub-Saharan Africa fall within four RAEZs, while 80% of the systems within WANA (including Egypt) have been grouped into a cool tropical aggregate. There is a much broader zonal incidence of systems within both Asia & Pacific and Central & South America, although in both instances it is the warm humid tropics (RAEZ3) that is the most densely "populated" zone.

Asymmetries in the zonal incidence of national agricultural research systems versus agricultural research investments stems from the particular spatial distribution of NARSs of varying sizes. Table 9 shows that an overwhelmingly large number of smaller NARSs (or parts thereof) are located in just three zones (namely, RAEZ1, 2, and 3), the warm semi-arid and subhumid tropics (RAEZ5 and 6, respectively) are only populated by NARSs employing more than 1000 researchers apiece, while the cool suptropics (RAEZ9) has a fairly even distribution of NARSs when measured in terms of full-time equivalents.

An analysis of research personnel numbers and expenditure levels tells only so much. Juxtaposing these research-input indicators against various measures of agricultural output and conventional inputs brings these data closer to the issues of agricultural growth and development that are of ultimate concern here.

Research Intensity and Agricultural Output

Agricultural research intensity ratios (ARIs), which express agricultural research expenditures as a percentage of agricultural output (AgGDP), are subject to a variety of interpretations. From a demand-side perspective, they can, with appropriate caveats, be used in conjunction with other indicators to gain insights to the forces that shape support for public agricultural research (Roe and Pardey 1991).

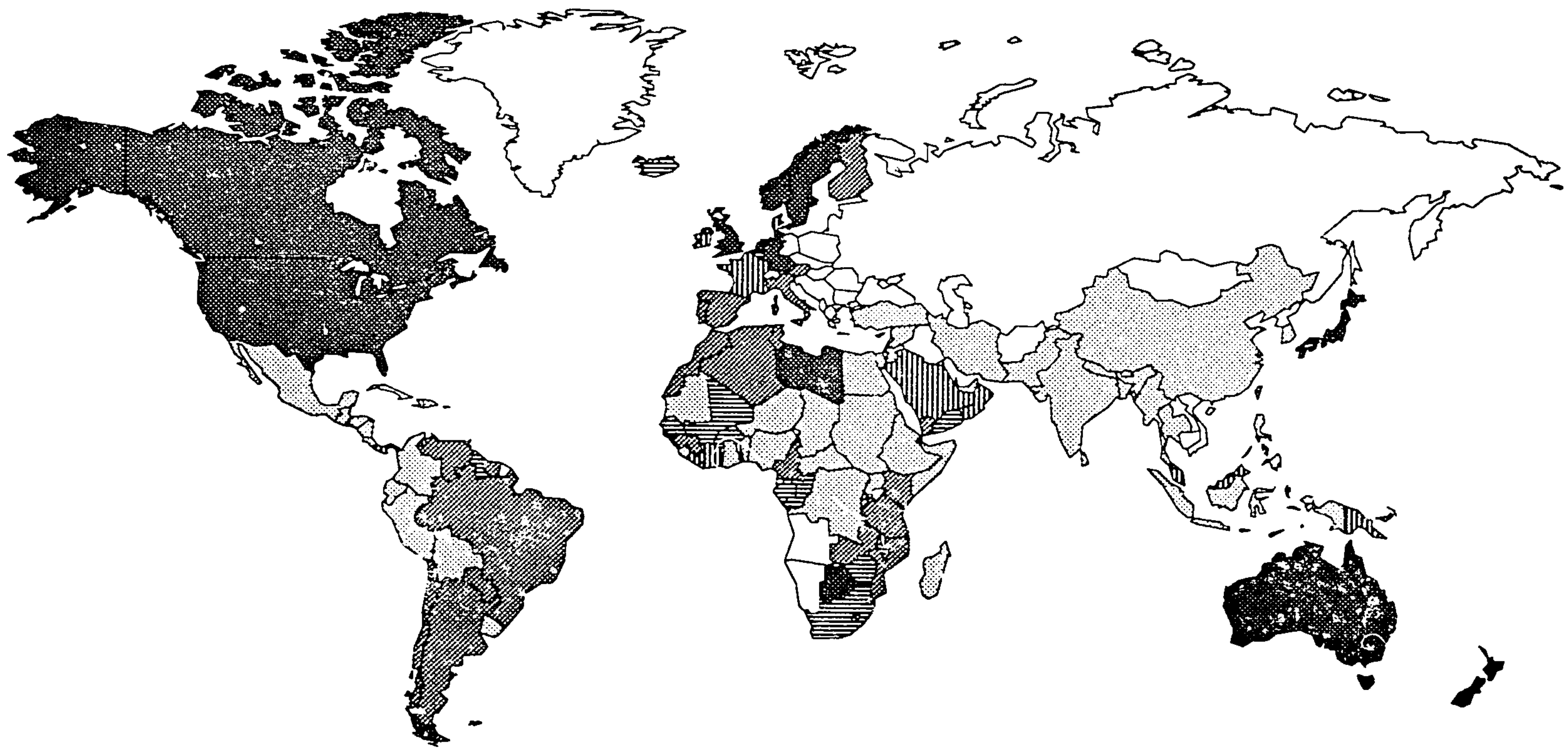
Table 10 presents agricultural research intensity ratios for 103 less-developed countries grouped by region and agroecological zone, while figure 5 plots these same intensity ratios on a global basis. Research spending as a percentage of AgGDP is lowest for the Asian region (0.36%) and highest for Central & South America (0.58%), with the weighted less-developed country average of 0.41% being less than a quarter of the corresponding more-developed country average of 2.02%. The variability in agricultural research intensity ratios across RAEZs at the global level is rather muted, ranging from a low of 0.34% for the warm subhumid

Table 10: *Agricultural Research Intensity Ratios by Region and Agroecological Zone, 1981-85 Average*

Region/RAEZ	Research expenditures as a % of AgGDP	Research expenditures per unit AgLabor	Research expenditures per ha AgLand	Researchers per billion AgGDP	Researchers per million AgLabor	Researchers per million ha AgLand
Sub-Saharan Africa (40)[a]	0.49	2.99	0.51	65	40	7
RAEZ1 (24)	0.56	3.36	0.33	79	48	5
West Africa (10)	0.63	3.90	0.43	88	55	6
East Africa (6)	0.32	2.35	0.27	54	39	4
Southern Africa (8)	1.07	3.85	0.26	129	46	3
RAEZ2 (14)	0.45	2.83	0.78	58	37	10
West Africa (6)	0.46	3.70	1.60	61	49	21
East Africa (3)	0.40	2.02	0.64	57	29	9
Southern Africa (5)	0.48	2.03	0.28	49	21	3
RAEZ3 (12)	0.47	3.62	0.97	58	45	12
RAEZ4 (8)	0.46	1.90	0.53	59	25	7
Asia & Pacific (16)	0.36	2.81	2.89	94	74	76
RAEZ1 (2)	0.27	2.34	2.53	51	44	47
RAEZ2 (4)	0.29	2.75	2.69	57	55	53
RAEZ3 (9)	0.39	5.58	6.41	57	82	94
RAEZ5 (3)	0.34	2.60	2.46	102	78	74
RAEZ6 (3)	0.34	2.74	2.89	100	81	86
RAEZ7 (2)	0.45	2.55	2.65	146	83	86
RAEZ8 (4)	0.38	2.28	2.32	130	78	79
Latin America & Caribbean (30)	0.58	17.81	0.96	74	227	12
RAEZ1 (6)	0.56	12.12	1.22	66	141	14
RAEZ2 (10)	0.67	18.99	1.26	86	246	16
RAEZ3 (22)	0.63	18.73	1.30	80	240	17
RAEZ4 (9)	0.38	11.47	0.98	48	145	12
RAEZ5 (2)	0.47	16.57	0.98	44	153	9
RAEZ6 (1)	0.53	47.55	0.35	92	818	6
RAEZ7 (3)	0.76	21.31	1.08	97	272	14
RAEZ8 (2)	0.52	43.67	0.34	89	757	6
RAEZ9 (2)	0.96	43.73	1.36	99	452	14
West Asia & North Africa (17)	0.47	12.63	1.22	99	268	26
RAEZ1 (3)	1.05	19.89	0.72	183	345	12
RAEZ4 (1)	0.37	7.55	0.96	32	64	8
RAEZ9 (13)	0.46	12.73	1.25	100	275	27
Less-Developed Countries (103)	0.41	3.77	1.42	89	82	31
RAEZ1 (35)	0.36	2.97	0.77	59	49	13
RAEZ2 (28)	0.41	4.05	1.32	64	63	21
RAEZ3 (43)	0.43	5.96	2.42	61	83	34
RAEZ4 (18)	0.40	4.62	0.79	50	58	10
RAEZ5 (5)	0.35	2.87	2.10	97	80	58
RAEZ6 (4)	0.34	2.90	2.03	100	84	59
RAEZ7 (5)	0.50	3.25	1.95	138	90	54
RAEZ8 (6)	0.39	2.56	1.38	126	83	45
RAEZ9 (15)	0.48	13.43	1.26	100	279	26

[a]Numbers in brackets denote the number of countries included in each region or RAEZ.

Figure 5: *Agricultural research intensity ratios, 1981-85 average*



Legend: 0.5% <; 0.5 - 1.0%; 1 - 1.5%; 1.5 - 2%; > 2%; na tropics (RAEZ6) to a high of 0.50% for the warm/cool humid tropics (RAEZ7).

There is, however, rather more spatial variability in ARIs when they are viewed from an ecoregional perspective. The disparities across RAEZs within sub-Saharan Africa are considerable, ranging from 0.32% in East Africa to 1.07% in Southern Africa. The variability across zones within West Asia and North Africa is of a similar order of magnitude.

In general these zonal and ecoregional disparities in ARIs are congruent with the observed spatial variability in researcher-agricultural output intensity ratios. The exceptions are several zones in Asia (i.e., RAEZ5, 6, 7, and 8) and the cool subtropics (RAEZ9) in WANA that have higher ratios of researchers to output than expected due to the particularly low expenditure per researcher in China and Egypt.

All but 18 (more- and less-developed) countries spent more on agricultural research relative to AgGDP in 1981-85 than they did in 1961-65. But, over the more recent 1976-80 to 1981-85 period, 37% of the less-developed countries in our sample had declining ARI ratios, with approximately half of these countries (i.e., 16 in all) located in sub-Saharan Africa. By contrast only three (17%) of the more-developed countries experienced declines in their ARI ratios over the corresponding period.

Research Intensity and Factor Input

To the extent that agricultural research is eventually subject to diminishing returns and that it generates factor-saving (or -using) productivity gains in agriculture, an analysis of agricultural research investments as a proportion of conventional inputs to agriculture (i.e., land and labor) can also usefully inform research policy choices at the strategic level.[10]

In 1981-85, the less-developed countries spent nearly $4 on agricultural research per agricultural worker while the more-developed countries spent over $210. These factor intensities represent a 2.5- and 4.4-fold increase for the less- and more-developed countries, respectively, over the corresponding ratios that prevailed in the 1961-65 period. There is substantial regional diversity in the pattern of factor intensities presented in table 10. Both sub-Saharan Africa and Asia (including China) spent just under $3 per agricultural worker on agricultural research in 1981-85, compared with nearly $13 for the WANA region and

[10]See Pardey, Roseboom, and Anderson (1991a) for more details.

$18 for Central & South America.

By contrast, at about $3 per hectare, research expenditures per unit of land for the Asian region are substantially larger than they are for all other less-developed regions and more than fivefold higher than they are for sub-Saharan Africa, the region with the lowest level of research expenditures per unit of agricultural land. Of course, as indicators of research-factor intensities these ratios can be misleading -- to the extent that they fail to account for significant interregional differences in the average quality of agricultural land and labor. In particular, if land aggregates were formed in terms of quality-adjusted or "effective" land units, these interregional relativities between research expenditure and land input would be markedly changed. For example, in the Asian region, 32% of arable land and permanently cropped land is under irrigation, compared with 19% in West Asia & North Africa, 8% in Central & South America, and only 3% in sub-Saharan Africa. Also, Asia has a markedly higher proportion of agricultural land that is either arable or under permanent crops -- 49%, compared to a less-developed country average of 31%. Factoring in these differences would substantially lower the Asian ratio of research expenditures per unit of quality-adjusted land vis-à-vis the other less-developed regions of the world.

Agricultural research investments by agroecological zone relative to land and labor inputs are rather homogeneous. Only RAEZ9 displays some deviation from the average in terms of research investments per unit labor. It is, however, also the zone with the highest output per unit labor (see figure 2 and appendix A.2). At the ecoregional level, the RAEZs display somewhat more heterogeneity. Those RAEZs that stand out as investing relatively more per unit of labor or land generally have relatively higher land and labor productivity levels.

3.3 Commodity Orientation of NARSs

One of the more important policy and management dimensions of a NARS is its overall commodity orientation. Although a considerable quality of detailed data has been used in constructing the NARS aggregates presented above, in most instances the data were not detailed enough to permit a breakdown of expenditures or researchers by commodity. The data did permit, however, a rough classification of the researchers into four broad commodity categories: crops, livestock, forestry, and fisheries.

Based on a sample of 83 less-developed countries,[11] table 11 provides the share of each of the four commodity groups from the total number of agricultural researchers. Research on forestry and fisheries production constitutes a larger proportion of agricultural research in Asia & Pacific than in Central & South America, with the share of fisheries research differing the most between these two regions. Crop-oriented research is more dominant in West Asia & North Africa than in the other regions.

Table 11: *Agricultural Researchers in Less-Developed Regions by Research Orientation, 1981-85 Average*

Region	Crops	Livestock	Forestry	Fisheries
	%	%	%	%
Sub-Saharan Africa (29)[a]	67.3	20.0	7.3	5.4
Asia & Pacific (18)	63.7	17.4	9.4	9.6
Central & South America (22)	68.7	24.1	5.4	1.8
West Asia & North Africa (14)	75.4	16.2	5.7	2.7
Less-Developed Countries (83)	68.3	18.7	7.3	5.7

Source: Pardey, Roseboom, and Anderson (1991b).

Note: Data may not add up exactly because of rounding.

[a]Bracketed numbers represent number of countries included in the regional samples.

A more relevant comparison may be a congruence test, for example, between the share of crop research in agricultural research and crop production's share of value-added in agriculture (AgGDP). Data on a breakdown of AgGDP in all four production categories, however, are not presently available. UN National Account Statistics decompose AgGDP into three categories (crops & livestock, forestry, and fisheries) for a limited, but still reasonably large, number of countries. The degree of congruence between production and research for these three production categories can be assessed from the data in table 12.

[11]This sample has a bias towards the smaller NARSs because for large NARSs it was often more difficult to construct a breakdown that would cover the whole system. A breakdown of the data by RAEZ has not been attempted because in our view the data are insufficient to warrant such treatment.

Table 12: *Congruence between AgGDP and Agricultural Research Personnel*

	Crops & Livestock		Forestry		Fisheries	
Region	AgGDP	Research	AgGDP	Research	AgGDP	Research
	%	%	%	%	%	%
Sub-Saharan Africa (22)[a]	88.6	87.3	4.7	7.3	6.6	5.4
Asia & Pacific (10)	89.7	81.1	5.2	9.4	5.0	9.6
Central & South America (20)	94.2	92.8	2.9	5.4	2.8	1.8
West Asia & North Africa (7)	95.9	91.6	2.4	5.7	1.7	2.7
Less-Developed Countries (59)	90.7	87.0	4.6	7.3	4.6	5.7

Source: Pardey, Roseboom, and Anderson (1991b).

Note: Data may not add up exactly because of rounding.

[a]Bracketed numbers represent the number of countries included in the regional samples on which the AgGDP breakdown is based. As shown in table 11, the research breakdown is based on regional samples that include a somewhat larger number of countries.

Assuming the samples are representative enough to justify the comparison, it can be concluded that in the less-developed world, the share of crop & livestock research is smaller than might be expected on the basis of its share in production. Conversely, in all four regions, forestry research accounts for a larger than congruent share of agricultural research; for fisheries research, this is the case in the Asia & Pacific and WANA regions.

The major conclusion that can be derived from our data is that forestry and fisheries research do not appear, as has been argued previously,[12] to have received less than congruent attention at the national level than crops & livestock. More generally, in fact, the opposite appears to be the case. The absolute size of national research capacities in the areas of forestry and fisheries are, however, in most less-developed countries rather small. Of the 130 less-developed NARSs in our sample, around 75% had fewer than 200 researchers and 50% averaged fewer than 100 researchers in 1981-85. Combining this information with the shares of forestry and fisheries research in the total NARS capacity, suggests that 75% of the NARSs had fewer than 15 researchers in forestry and 11 in fisheries, while 50% had even fewer than seven forestry and six fisheries researchers. It is clear from these estimates that many national systems have yet to achieve a critical mass of researchers with respect to forestry and fisheries issues and at best have little more than search and screening capacities in these areas.

[12]See Mergen et al. (1988) for an assertion along these lines in the case of forestry research.

4 Concluding Comments

In reviewing investment trends in NARSs, we saw fairly substantial but asymmetric rates of growth in research expenditures and personnel over the past two decades. Unfortunately, earlier rates of growth do not appear to have been sustained in more recent years. This is no doubt due to a variety of factors, not least of which are the substantial international debt liabilities and the ensuing structural adjustment programs that got underway in numerous less-developed countries during this time. The exceptions to this generalization are the NARSs of numerous Asian countries whose strong and growing economies have spared their research systems from the cutbacks experienced elsewhere.

Contemporary investments in NARSs need to be viewed within the context of declining donor investment in agricultural research. Given the pressure to divert investment to Eastern Europe and nonresearch programs (such as health, education, population, and the environment), coupled with an apparently waning interest in expanding or even maintaining current levels of development aid in some donor countries,[13] growth in public agricultural research in the 1990s is likely to depend (to an ever-increasing degree) on enhanced local funding for agricultural research.

When analyzing spatial patterns of investment in NARSs, we noted (with one or two exceptions) fairly muted differences across agroecological zones. But, when these same zones were viewed in a regional context, a substantial degree of variability emerged. In general terms, some ecoregions were credibly endowed with national research capabilities while others were not. In particular, there is a marked unevenness in the spatial distribution of NARSs, whether viewed in terms of the number of systems within a particular zone or the size distribution of systems across zones. A fairly widespread lack of national research capacity in the fish and forestry areas was also noted, although the level of effort was generally in line with the relative output shares of these sectors. While the unavoidably aggregate evidence presented here can inform the degree to which the CGIAR attempts to complement or substitute for a nation's research endeavors, there will certainly be a need for more disaggregated and probably qualitative or impressionistic evidence on the relative strengths and weaknesses of these NARSs and their components. A structured and on-going process of consultation with knowledgeable individuals from NARSs will be needed to provide such

[13]See Ruttan (1991) for prognostications on the US case.

data as well as to ensure that the NARSs themselves become active stakeholders in the CG's priority-setting process. Such a process of consultation would, at minimum, need to generate information on their target commodities, agroecological zones, technologies, research problems, and the like, before the details of a collaborative national-international research effort based on an ecoregional perspective can move beyond broad generalizations to the operational level.

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Appendix A.1: *Total CGIAR Core and Special-Project Expenditures by Center, in Millions of Current US Dollars*

	IRRI	CIMMYT	IITA	CIAT	CIP	ICRISAT	ILRAD	ILCA	WARDA	IBPGR	ICARDA	IFPRI	ISNAR	CGIAR
1960	7.4													7.4
1961	0.2													0.2
1962	0.4													0.4
1963	0.9													0.9
1964	0.6													0.6
1965	1.0		0.3											1.3
1966	1.1	0.5	0.4											2.0
1967	1.2	1.2	1.0											3.4
1968	2.4	1.8	2.6	0.2										7.0
1969	2.5	3.0	4.7	1.4										11.6
1970	2.9	5.1	4.4	2.3										14.8
1971	3.7	6.1	6.8	3.6										20.2
1972	4.4	6.5	6.4	4.5	0.5	0.3								22.7
1973	4.6	7.7	6.4	6.4	1.3	2.7								29.1
1974	7.8	7.5	7.2	6.1	2.3	3.8	0.7	0.3	0.5					36.2
1975	10.6	9.1	9.8	6.7	2.9	6.2	2.1	1.7	0.6	0.5		0.3		50.4
1976	12.3	10.7	11.1	7.0	4.7	7.3	4.7	4.3	0.8	0.9	1.5	0.8		66.0
1977	15.4	11.4	12.8	10.2	5.9	11.2	5.4	6.7	1.3	1.3	4.6	1.2		87.4
1978	15.8	13.9	17.4	13.0	5.8	14.1	7.9	7.5	1.9	1.7	7.6	1.6		108.3
1979	18.7	16.8	19.5	15.2	7.4	13.5	7.4	9.0	2.9	2.4	10.6	1.9		125.2
1980	21.1	18.3	20.0	17.3	8.2	14.4	9.1	10.0	3.3	3.0	13.1	2.5	1.1	141.5
1981	22.4	20.4	22.8	18.9	9.6	15.7	9.9	10.5	4.1	3.6	15.8	3.2	1.6	158.5
1982	25.0	21.1	27.2	21.6	9.9	19.5	8.9	10.5	5.3	3.1	15.6	4.2	2.9	174.8
1983	24.6	20.6	25.9	23.1	11.9	20.9	9.3	12.0	6.4	4.5	20.6	5.0	4.1	188.5
1984	26.9	24.9	27.9	24.0	11.7	21.1	9.1	14.6	5.9	4.2	20.8	5.9	4.3	201.4
1985	31.3	24.9	33.5	23.3	11.1	24.5	9.6	16.3	4.9	4.5	21.9	6.5	4.7	216.9
1986	29.8	27.2	36.4	24.3	13.8	31.6	10.7	18.5	6.9	5.0	21.8	7.2	6.1	239.3
1987	32.7	28.4	35.9	29.6	15.3	41.0	12.2	16.3	5.9	5.3	23.6	8.0	7.1	261.1
1988	31.0	32.4	41.3	29.7	18.2	39.3	13.3	18.5	6.8	6.9	24.0	8.8	8.8	279.0
1989	33.9	34.1	32.1	32.6	21.9	36.3	14.1	20.6	6.3	7.6	22.6	10.9	9.8	282.8

Source: Gryseels and Anderson (1991).

Appendix A.2: *Agricultural Labor and Land Productivities by Region and Agroecological Zone, 1961-65 to 1981-85*

Region/(R)AEZ	AgGDP per unit labor					AgGDP per unit land				
	1961-65	1966-70	1971-75	1976-80	1981-85	1961-65	1966-70	1971-75	1976-80	1981-85
Sub-Saharan Africa (18)[a]	*505*	*498*	*510*	*451*	*413*	*77*	*81*	*90*	*88*	*88*
RAEZ1 (13)	498	450	464	433	390	42	41	46	48	48
West Africa	505	444	464	415	336	42	40	45	45	41
East Africa	462	406	420	442	424	35	34	39	45	48
Southern Africa	639	671	664	474	463	107	123	131	104	110
RAEZ2 (6)	851	847	830	665	571	178	195	209	186	176
West Africa	661	543	601	510	387	194	176	216	207	175
East Africa	815	885	891	784	701	172	212	235	227	222
Southern Africa	1383	1498	1254	756	725	170	190	167	110	114
RAEZ3 (5)	395	406	463	454	440	122	132	156	161	165
RAEZ4 (5)	296	309	291	243	244	61	69	70	64	70
Asia & Pacific (13)	*224*	*257*	*277*	*295*	*341*	*171*	*210*	*243*	*278*	*347*
RAEZ1 (2)	292	302	323	338	361	245	267	303	335	389
RAEZ2 (4)	302	330	361	398	448	245	281	320	368	439
RAEZ3 (7)	362	406	454	528	588	396	441	495	587	676
RAEZ5 (3)	231	261	279	290	330	161	195	225	252	312
RAEZ6 (3)	217	255	275	289	337	169	213	248	283	355
RAEZ7 (1)	146	188	201	209	263	102	142	167	191	262
RAEZ8 (4)	157	197	211	218	271	113	153	179	204	275
Central & South America (18)	*1325*	*1446*	*1625*	*1871*	*2116*	*71*	*77*	*86*	*99*	*113*
RAEZ1 (6)	815	896	1028	1180	1323	84	92	104	119	133
RAEZ2 (9)	1233	1314	1552	1842	2184	94	97	110	125	145
RAEZ3 (11)	1196	1315	1515	1766	2023	82	89	100	116	131
RAEZ4 (9)	1047	1206	1341	1452	1499	74	89	103	118	128
RAEZ5 (2)	1431	1646	1753	1822	1941	65	76	87	101	115
RAEZ6 (1)	4279	4956	5388	6415	7403	40	43	44	50	54
RAEZ7 (4)	1367	1395	1649	2052	2557	87	85	95	110	129
RAEZ8 (2)	4287	4938	5359	6362	7324	42	45	47	52	57
RAEZ9 (2)	1439	1870	1864	2352	2648	64	74	66	76	82
West Asia & North Africa (8)[b]	*716*	*80[illegible]*	*911*	*1051*	*1196*	*92*	*106*	*121*	*143*	*171*
Less-Developed Countries (57)	*325*	*359*	*386*	*406*	*451*	*111*	*128*	*145*	*163*	*194*
RAEZ1 (21)	353	355	379	388	399	97	102	116	127	141
RAEZ2 (19)	536	566	605	607	635	160	173	191	199	220
RAEZ3 (23)	423	466	525	591	646	185	205	232	266	300
RAEZ4 (15)	554	605	631	631	642	69	81	90	96	105
RAEZ5 (5)	256	288	308	321	362	138	166	191	215	264
RAEZ6 (4)	241	280	298	314	362	126	156	179	204	253
RAEZ7 (4)	206	247	269	287	353	96	120	137	156	203
RAEZ8 (6)	206	247	257	266	319	80	103	117	132	172
RAEZ9 (10)	738	835	936	1083	1229	90	103	116	137	162
Japan	857	1253	1580	1949	2446	1940	2438	2583	2540	2503
Europe (13)	2827	3832	4792	5797	7822	440	489	529	560	647
North America (2)	13381	15101	17238	17627	21784	142	141	154	157	175
Australia	12881	15688	17991	20514	22599	12	14	16	19	20

[a]Bracketed numbers denote the number of countries (partly) covered by region or RAEZ.
[b]Includes only countries in RAEZ9.

Appendix A.3: *Prorating Factors Used to Construct RAEZ Aggregates Based on Arable Land*

Country	Region Code[a]	Agroecological zone (RAEZ)								
		1	2	3	4	5	6	7	8	9
AFGHANISTAN	4									100
ALGERIA	4									100
ANGOLA	1c	14	56		30					
ARGENTINA	3					8	16	5	69	2
BAHRAIN	4									100
BANGLADESH	2			100						
BARBADOS	3			100						
BELIZE	3			100						
BENIN	1a	8	92							
BHUTAN	2								100	
BOLIVIA	3	18	14	19	49					
BOTSWANA	1c	100								
BRAZIL	3	7	29	20				45		
BRUNEI	2			100						
BURKINA FASO	1a	68	32							
BURMA	2		100							
BURUNDI	1				100					
CAMEROON	1			100						
CAPE VERDE	1a	100								
CENTRAL AFRICAN REPUBLIC	1			100						
CHAD	1a	100								
CHILE	3									100
CHINA	2					15	10	40	35	
COLOMBIA	3			32	68					
COMOROS	1c		100							
CONGO	1			100						
COSTA RICA	3		7	10	82					
CUBA	3	58	42							
CYPRUS	4									100
DOMINICA	3			100						
DOMINICAN REPUBLIC	3		100							
ECUADOR	3	27	3	21	50					
EGYPT	4									100
EL SALVADOR	3		41		59					
EQUATORIAL GUINEA	1			100						
ETHIOPIA	1b	11	10		79					
FRENCH GUYANA	3			100						
GABON	1			100						
GAMBIA	1a	100								
GHANA	1			100						
GUADELOUPE	3		100							
GUATEMALA	3			3	97					
GUINEA	1a		100							
GUINEA-BISSAU	1a		100							

Appendix A.3: *Prorating Factors Used to Construct RAEZ Aggregates Based on Arable Land (Contd.)*

Country	Region Code[a]	Agroecological zone (RAEZ)								
		1	2	3	4	5	6	7	8	9
GUYANA	3			100						
HAITI	3	100								
HONDURAS	3			29	71					
INDIA	2	52	15			25	7		1	
INDONESIA	2			100						
IRAN	4									100
IRAQ	4									100
IVORY COAST	1			100						
JAMAICA	3			100						
JORDAN	4									100
KAMPUCHEA	2			100						
KENYA	1b	35			65					
KOREA, DPR	2						34		66	
KOREA, REPUBLIC OF	2						74		26	
KUWAIT	4									100
LAO, P.D.R.	2			100						
LEBANON	4									100
LESOTHO	1				100					
LIBERIA	1			100						
LIBYA	4									100
MADAGASCAR	1c	6	15	40	39					
MALAWI	1c	18	82							
MALAYSIA	2			100						
MALI	1a	100								
MARTINIQUE	3		100							
MAURITANIA	1a	100								
MAURITIUS	1			100						
MEXICO	3	12	15	17	27	29				
MONGOLIA	2								100	
MONTSERRAT	3			100						
MOROCCO	4									100
MOZAMBIQUE	1c	57	43							
NAMIBIA	1c	19	81							
NEPAL	2								100	
NICARAGUA	3			100						
NIGER	1a	100								
NIGERIA	1a	31	41	28						
OMAN	4	100								
PAKISTAN	2					100				
PANAMA	3			100						
PAPUA NEW GUINEA	2			100						
PARAGUAY	3		2					98		
PERU	3			6	94					
PHILIPPINES	2			100						
PUERTO RICO	3			100						

Appendix A.3: *Prorating Factors Used to Construct RAEZ Aggregates Based on Arable Land (Contd.)*

		Agroecological zone (RAEZ)								
Country	Region Code[a]	1	2	3	4	5	6	7	8	9
QATAR	4									100
REUNION	1			100						
RWANDA	1				100					
SAUDI ARABIA	4									100
SENEGAL	1a	100								
SIERRA LEONE	1			100						
SINGAPORE	2			100						
SOMALIA	1b	100								
SRI LANKA	2		51	49						
ST. KITTS	3			100						
ST. LUCIA	3		100							
ST. VINCENT	3			100						
SUDAN	1b	100								
SURINAME	3			100						
SWAZILAND	1c	8	92							
SYRIA	4									100
TAIWAN	2							100		
TANZANIA	1b	43	36		21					
THAILAND	2	6	54	40						
TOGO	1a		100							
TRINIDAD & TOBAGO	3			100						
TUNISIA	4									100
TURKEY	4									100
UGANDA	1b	12	88							
UNITED ARAB EMIRATES	4	100								
URUGUAY	3								100	
VENEZUELA	3	38	46	16						
VIET NAM	2			100						
YEMEN, ARAB REPUBLIC	4				100					
YEMEN, P.D.R.	4	100								
ZAIRE	1			100						
ZAMBIA	1c	100								
ZIMBABWE	1c	100								

Source: Kassam (1991).

Note: Arable land refers to land under temporary crops (double-cropped areas are counted only once), temporary meadows used for mowing or pasture, land under market and kitchen gardens (including cultivation under glass), and land temporarily fallow or lying idle (*FAO Production Yearbook*).

[a]1 represents sub-Saharan Africa (with a, b, and c representing western, eastern, and southern Africa, respectively), 2 represents Asia & Pacific, 3 represents Central & South America, and 4 represents West Asia & North Africa.

Appendix A.4: *Agricultural Research, Output, and Input Indicators by Region and Agroecological Zone, 1981-85 Average*

Region/(R)AEZ	Researchers		Research expenditures		Agricultural land		Agricultural labor		AgGDP	
	FTE	Share	1980 dollars	Share	Hectares	Share	Number	Share	1980 dollars	Share
		%	(million)	%	(million)	%	(million)	%	(billion)	%
Sub-Saharan Africa (40)[a]	*4918*	*6.5*	*371*	*10.6*	*723.2*	*29.3*	*124.1*	*13.3*	*75.6*	*8.9*
RAEZ1 (24)	1974	2.6	139	4.0	422.1	17.1	41.4	4.4	25.0	2.9
West Africa (10)	1018	1.3	72	2.1	168.5	6.8	18.6	2.0	11.6	1.4
East Africa (6)	556	0.7	33	0.9	125.8	5.1	14.2	1.5	10.3	1.2
Southern Africa (8)	400	0.5	33	0.9	127.9	5.2	8.6	0.9	3.1	0.4
RAEZ2 (14)	1150	1.5	89	2.5	113.5	4.6	31.3	3.4	19.8	2.3
West Africa (6)	734	1.0	56	1.6	34.9	1.4	15.1	1.6	12.1	1.4
East Africa (3)	275	0.4	19	0.5	30.1	1.2	9.5	1.0	4.8	0.6
Southern Africa (5)	141	0.2	14	0.4	48.5	2.0	6.7	0.7	2.9	0.3
RAEZ3 (12)	1181	1.6	96	2.7	98.4	4.0	26.5	2.8	20.5	2.4
RAEZ4 (8)	612	0.8	47	1.4	89.2	3.6	24.9	2.7	10.3	1.2
Asia & Pacific (16)	*54558*	*71.6*	*2076*	*59.1*	*719.4*	*29.1*	*739.9*	*79.4*	*578.2*	*67.8*
RAEZ1 (2)	4436	5.8	237	6.8	93.9	3.8	101.3	10.9	87.3	10.2
RAEZ2 (4)	2630	3.5	132	3.8	49.2	2.0	48.2	5.2	45.9	5.4
RAEZ3 (9)	6095	8.0	415	11.8	64.8	2.6	74.4	8.0	106.5	12.5
RAEZ5 (3)	9884	13.0	327	9.3	133.1	5.4	126.0	13.5	97.4	11.4
RAEZ6 (3)	4772	6.3	160	4.6	55.5	2.2	58.6	6.3	47.6	5.6
RAEZ7 (2)	14416	18.9	443	12.6	167.5	6.8	173.7	18.6	98.5	11.6
RAEZ8 (4)	12325	16.2	360	10.3	155.5	6.3	157.7	16.9	95.0	11.1
Latin America & Caribbean (30)	*8861*	*11.6*	*695*	*19.8*	*724.6*	*29.3*	*39.0*	*4.2*	*120.1*	*14.1*
RAEZ1 (6)	636	0.8	55	1.6	44.8	1.8	4.5	0.5	9.7	1.1
RAEZ2 (10)	1664	2.2	129	3.7	102.1	4.1	6.8	0.7	19.3	2.3
RAEZ3 (22)	1702	2.2	133	3.8	102.6	4.2	7.1	0.8	21.3	2.5
RAEZ4 (9)	1367	1.8	108	3.1	111.0	4.5	9.4	1.0	28.2	3.3
RAEZ5 (2)	392	0.5	42	1.2	43.1	1.7	2.6	0.3	9.0	1.1
RAEZ6 (1)	169	0.2	10	0.3	28.4	1.2	0.2	0.0	1.8	0.2
RAEZ7 (3)	1831	2.4	143	4.1	133.3	5.4	6.7	0.7	18.8	2.2
RAEZ8 (2)	813	1.1	47	1.3	138.8	5.6	1.1	0.1	9.1	1.1
RAEZ9 (2)	289	0.4	28	0.8	20.5	0.8	0.6	0.1	2.9	0.3

Appendix A.4: *Agricultural Research, Output, and Input Indicators by Region and Agroecological Zone, 1981-85 Average (Contd.)*

Region/(R)AEZ	Researchers		Research expenditures		Agricultural land		Agricultural labor		AgGDP	
	FTE	Share	1980 dollars	Share	Hectares	Share	Number	Share	1980 dollars	Share
		%	*(million)*	%	*(million)*	%	*(million)*	%	*(billion)*	%
West Asia & North Africa (17)	*7836*	*10.3*	*369*	*10.5*	*302.1*	*12.2*	*29.2*	*3.1*	*79.0*	*9.3*
RAEZ1 (3)	131	0.2	8	0.2	10.5	0.4	0.4	0.0	0.7	0.1
RAEZ4 (1)	69	0.1	8	0.2	8.4	0.3	1.1	0.1	2.2	0.3
RAEZ9 (13)	7637	10.0	353	10.1	283.3	11.5	27.8	3.0	76.1	8.9
Less-Developed Countries (103)	*76174*	*100.0*	*3511*	*100.0*	*2469.3*	*100.0*	*932.3*	*100.0*	*852.8*	*100.0*
RAEZ1 (35)	7176	9.4	438	12.5	571.3	23.1	147.5	15.8	122.7	14.4
RAEZ2 (28)	5445	7.1	350	10.0	264.8	10.7	86.4	9.3	85.0	10.0
RAEZ3 (43)	8978	11.8	644	18.3	265.8	10.8	108.0	11.6	148.2	17.4
RAEZ4 (18)	2048	2.7	164	4.7	208.5	8.4	35.5	3.8	40.7	4.8
RAEZ5 (5)	10276	13.5	369	10.5	176.1	7.1	128.5	13.8	106.3	12.5
RAEZ6 (4)	4941	6.5	170	4.8	83.9	3.4	58.8	6.3	49.4	5.8
RAEZ7 (5)	16247	21.3	587	16.7	300.7	12.2	180.4	19.4	117.3	13.8
RAEZ8 (6)	13137	17.2	407	11.6	294.3	11.9	158.8	17.0	104.1	12.2
RAEZ9 (15)	7926	10.4	381	10.9	303.8	12.3	28.4	3.0	79.0	9.3

Source: Research personnel and expenditures — Pardey, Roseboom, and Anderson (1991); agricultural land — *FAO Production Yearbooks*; agricultural labor — FAO (1987); AgGDP — World Bank (1989).

[a]Bracketed numbers denote the number of countries (partly) covered by each region or RAEZ.