Defining productivity and yield

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IRRI's project IR2, "Sustaining soil quality in intensive rice systems," uses a number of different terms relating to productivity and yield. These terms are sometimes not used consistently by agronomists and economists, and frequent misunderstandings occur on the part of policymakers. We present below definitions of the most important terms in the hopes of clarifying some of the misunderstandings and promoting more precision in future research.

Yield decline: *A decrease in grain yields over a period of at least several years.*

This phrase is commonly used in connection with long-term experiments at research stations. In this context, yield decline refers to a decline in the measured experimental yields of the highest-yielding cultivars under constant input levels and management practices. There is evidence of a long-term yield decline in some rice-rice systems at various Philippine experiment stations and in some long-term rice-wheat experiments in India, although such declines do not occur in all, or even most, experiments in Asia.

Because there is always substantial year-to-year variability in yields, yield declines are typically measured with a statistical trend analysis (ordinary least squares linear regression) that isolates longer-term trends from short-term "noise." In general, yield trends are never exactly equal to zero, but are positive or negative. But only yield trends with a large decline relative to the year-to-year variability of the data are statistically different from zero at a particular level of significance (e.g., 5%). For example, Figure 1A shows yield trends in the dry-season nitrogen response experiments conducted at IRRI from 1965 to 1988. The yield trend is –1.2% yr^{-1}, and it is statistically different from zero at the 5% level of significance. On the other hand, Figure 1B shows yield trends in the wet-season long-term fertility experiments conducted at IRRI from 1964 to 1991. The trend in this experiment is also negative, but the trend of –0.4% yr^{-1} is not statistically different from zero at the 5% level of significance.

Simple linear regression is most appropriate when management remains the same over the period for which the regression is being estimated. For example, in the long-term continuous cropping experiment at IRRI, substantial management changes occurred in the early 1990s. Among others, several fallow periods occurred, fewer varieties were used, and nitrogen application rates and timing were changed. Thus, a regression fit over the period 1968-91 (dry season) shows a statistically significant negative trend and appears to be an appropriate smoothing of the data (see Figure 1C). A regression fit over the period 1968-96, however, is obviously inappropriate because the yield decline was reversed from 1991 to 1996.

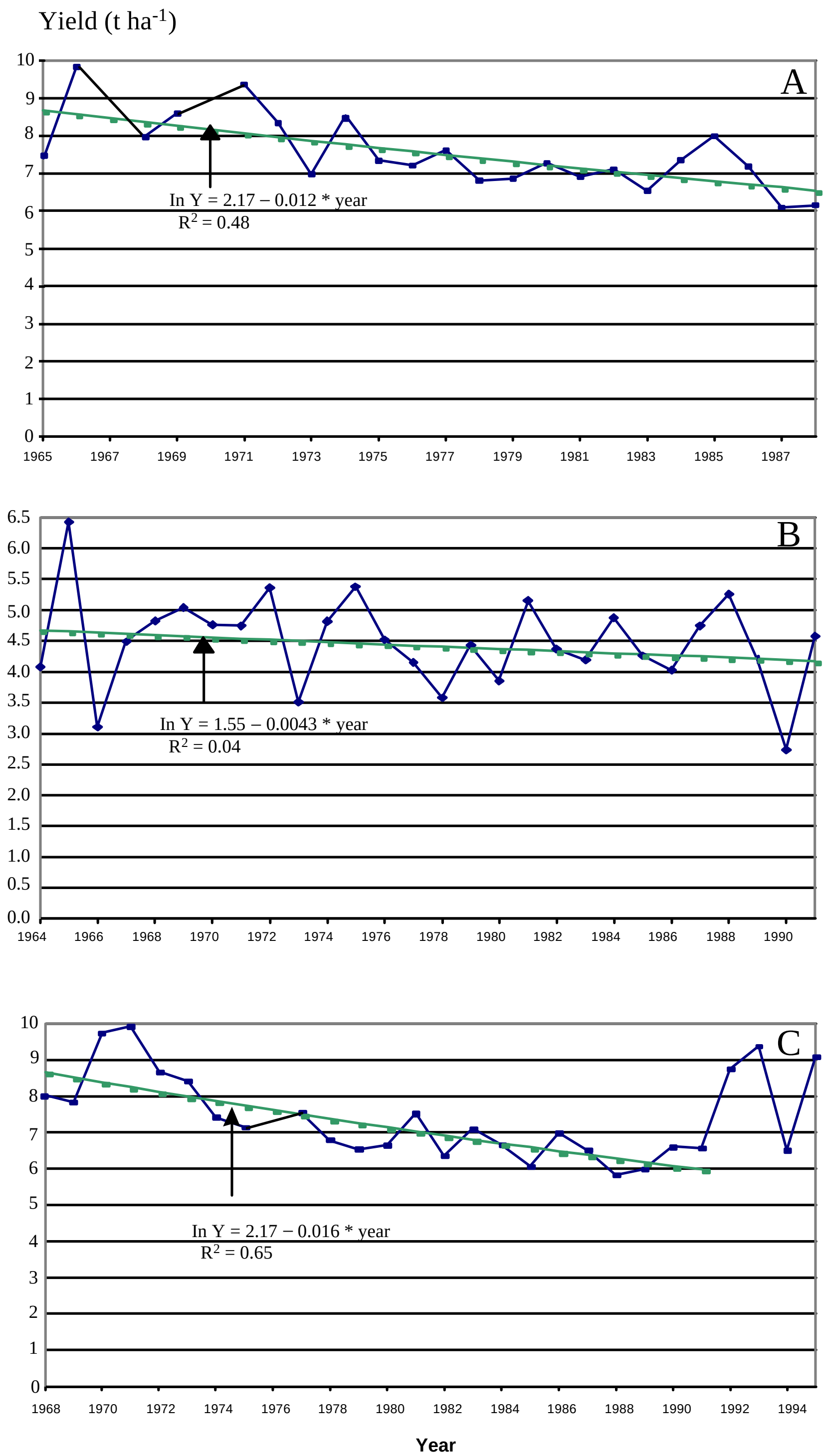

Fig. 1. Yield trends in selected trials at IRRI: (A) nitrogen response experiment, dry season; (B) long-term fertility experiment, wet season; (C) long-term continuous cropping experiment, dry season.

The varieties used in most long-term experiments have been changed many times since the beginning of those experiments as new, improved varieties have emerged from breeding programs. The change in varieties is necessary because of changes in the pest complex and the breakdown of resistance over time. This evolution of the varieties used in the experiments makes analysis of long-term trends more problematic. But an independent assessment of the yield potential of newer varieties indicates that their yield potential is even higher than that of the older varieties (see the definition of yield potential below). The new varieties are also more resistant to pests and diseases than the older varieties. These observations make the long-term yield decline even more troubling, and suggest that the decline in experimental yields is due to some feature of the environmental conditions that prevail in the long-term experiments, not to a decline in the yield potential of the rice plant.

We are unaware of any evidence for a long-term yield decline in farmers' fields. Yields at the national level declined slightly in Japan, North Korea, South Korea, and Pakistan from 1984 to 1996, however (Tables 1–3). To some extent, this decline is dependent on the choice of base year, but rice yields in these countries were at best stagnant during the past 12 years. For Japan and South Korea, this is due primarily to the high level of economic development, which has discouraged farmers from devoting much time to rice cultivation because of the high opportunity cost of their labor. Furthermore, some of the highest-yielding land has gone out of cultivation because of industrialization, which tends to exert a negative influence on national level yields. When conversion of high-yielding land is widespread, national-level yields can decline without a decline in yields in individual farmers' fields. Thus, national-level yield data are not necessarily evidence for a yield decline in farmers' fields.

In North Korea, economic problems are probably primarily responsible for the decline in yields as opposed to agronomic/soil problems. In Pakistan, there is a strong possibility that the yield stagnation/decline is due at least in part to environmental problems (Ali and Byerlee 1998). The rice ecosystem in Pakistan is substantially different from rice ecosystems elsewhere in the region, however, so such a phenomenon should not be extrapolated to other countries without careful study.

Decline in yield growth rate: *A slowdown in the (percentage) rate of increase in grain yield over time.*

For example, in Indonesia, the average nationwide rice yield grew by 4.8% yr^{-1} from 1967 to 1984, but by only 1.2% yr^{-1} from 1984 to 1996. Note that a decline in a positive yield growth rate implies that yields are still *increasing*, as long as the growth rate is still positive (decreasing yields would be reflected in negative growth rates). Thus, average yields in Indonesia increased from 3.9 t ha^{-1} in 1984 to 4.5 t ha^{-1} in 1996. Like Indonesia, most of Asia is currently experiencing a decline in yield growth rates. Table 1 shows that yield growth rates were generally slower from 1984 to 1996 than from 1967 to 1984.

Table 1. Rice production in Asia (unmilled basis).

Country/region[a]	Production 1996 (million t)	Growth rate (% per annum)	
		1967-84	1984-96
China	190.1	3.8	0.4
India	120.0	2.6	2.7
Indonesia	51.2	6.4	2.5
Bangladesh	28.0	1.6	2.1
Vietnam	26.3	3.1	4.5
Thailand	21.8	3.4	0.8
Myanmar	20.9	3.6	3.2
Japan	13.0	–1.4	–1.1
Philippines	11.3	3.2	3.1
Korea (South)	6.3	2.8	–2.0
Pakistan	5.6	4.8	0.9
Nepal	3.6	1.7	2.0
Cambodia	3.4	–3.9	8.6
Korea (North)	2.8	3.4	–1.8
Sri Lanka	2.2	4.4	–0.6
Malaysia	2.1	1.6	2.3
Lao PDR	1.3	2.9	–0.1
Southeast Asia 1	86.3	4.8	2.1
Southeast Asia 2	51.9	2.8	4.0
India	120.0	2.6	2.7
Other South Asia	39.4	2.2	1.7
China	190.1	3.8	0.4
Other East Asia	22.1	0.1	–1.4
Asia	509.7	3.2	1.5

[a]Southeast Asia 1 is Indonesia, Malaysia, Philippines, and Thailand. Southeast Asia 2 is Vietnam, Myanmar, Cambodia, and Lao PDR. Other South Asia is Pakistan, Sri Lanka, Bangladesh, and Nepal. Other East Asia is North Korea, South Korea, and Japan.
Source of basic data: FAO Stat, Version 1997.

Table 2. Rice area harvested in Asia.

Country/region[a]	Area 1996 (million ha)	Growth rate (% per annum)	
		1967-84	1984-96
China	31.4	0.5	–0.6
India	42.7	0.7	0.3
Indonesia	11.3	1.6	1.2
Bangladesh	10.0	0.2	–0.2
Vietnam	7.3	1.0	2.1
Thailand	9.2	2.4	–0.4
Myanmar	6.5	–0.1	2.9
Japan	2.1	–2.0	–0.8
Philippines	4.0	–0.1	1.7
Korea (South)	1.0	0.0	–1.5
Pakistan	2.3	2.0	1.0
Nepal	1.5	1.4	0.3
Cambodia	2.0	–2.6	3.4
Korea (North)	0.7	2.0	–0.2
Sri Lanka	0.8	2.9	–0.8
Malaysia	0.7	0.3	0.5
Lao PDR	0.5	–2.2	–1.9
Southeast Asia 1	25.2	1.6	0.7
Southeast Asia 2	16.2	–0.1	2.4
India	42.7	0.7	0.3
Other South Asia	14.6	0.7	0.0
China	31.4	0.5	–0.6
Other East Asia	3.8	–1.0	–0.9
Asia	133.9	0.6	0.3

[a]Southeast Asia 1 is Indonesia, Malaysia, Philippines, and Thailand. Southeast Asia 2 is Vietnam, Myanmar, Cambodia, and Lao PDR. Other South Asia is Pakistan, Sri Lanka, Bangladesh, and Nepal. Other East Asia is North Korea, South Korea, and Japan.
Source of basic data: FAO Stat, Version 1997.

Table 3. Rice yields in Asia (unmilled basis).

Country/region[a]	Yield 1996 (t ha^{-1})	Growth rate (% per annum) 1967-84	Growth rate (% per annum) 1984-96
China	6.1	3.3	1.0
India	2.8	1.9	2.3
Indonesia	4.5	4.8	1.2
Bangladesh	2.8	1.4	2.2
Vietnam	3.6	2.1	2.3
Thailand	2.4	1.0	1.1
Myanmar	3.2	3.8	0.3
Japan	6.2	0.6	–0.3
Philippines	2.9	3.4	1.4
Korea (South)	6.1	2.8	–0.5
Pakistan	2.5	2.7	–0.1
Nepal	2.4	0.4	1.7
Cambodia	1.7	–1.3	5.0
Korea (North)	4.1	1.4	–1.6
Sri Lanka	2.8	1.5	0.2
Malaysia	3.1	1.3	1.8
Lao PDR	2.5	5.3	1.8
Southeast Asia 1	3.4	3.2	1.4
Southeast Asia 2	3.2	2.9	1.6
India	2.8	1.9	2.3
Other South Asia	2.7	1.5	1.7
China	6.1	3.3	1.0
Other East Asia	5.8	1.1	–0.6
Asia	3.8	2.5	1.2

[a]Southeast Asia 1 is Indonesia, Malaysia, Philippines, and Thailand. Southeast Asia 2 is Vietnam, Myanmar, Cambodia, and Lao PDR. Other South Asia is Pakistan, Sri Lanka, Bangladesh, and Nepal. Other East Asia is North Korea, South Korea, and Japan.
Source of basic data: FAO Stat, Version 1997.

Productivity decline: *A decline in total factor productivity (TFP) over time, where total factor productivity is the productivity of all inputs taken together (see definition of TFP below). An alternative way to define productivity decline is as an inward shift over time in the production function (see the definition of production function below).*

A productivity decline is *not* the same as a decline in production or a decline in yields. When the phrase “productivity decline” is used, it is understood that this refers to a decline in total factor productivity (not the partial factor productivity of a single input) unless otherwise specified.

Production and yields of rice are increasing in most Asian countries. Nevertheless, it is possible to have declining TFP while production and yields are increasing, because the use of at least some other inputs, such as fertilizer and machinery, is also increasing. If yield were increasing, and the use of *all* inputs were declining, then we could be sure that TFP was increasing without doing any further quantitative analysis. Both outputs and the use of several inputs are increasing on most farms in Asia, so TFP could be either increasing or decreasing. Without further analysis of quantitative data, it is impossible to tell.

Statistical estimation of production functions represents an alternative method to measure productivity.[1] Provided the necessary quantitative data are available, estimation of production functions can be used to determine what the yield would have been if farmers had held all inputs constant over many years, even if individual farmers have not held all inputs constant. If yields would have declined over time had farmers held all inputs constant, then, by definition, productivity would have declined. If yields would have remained constant or increased, then productivity would have remained constant or increased. The answer that emerges from the statistical analysis is of course not perfect, but it is perhaps the best that can be expected. Measurements of productivity, either by calculation of TFP or by estimation of production functions, are attempts to address an important issue that is not easily ignored—namely, that farmers use many inputs, they vary these inputs frequently, and variation in the use of these inputs affects yields.

Both changes in the environment and advances in technology can affect productivity, and these effects are additive. If productivity declines due to a deterioration in the environment are large, rapid advances in technology (e.g., through higher yield potential) will be required to keep productivity increasing. It is important to continually increase productivity because, without such increases, there is likely to be an erosion of farm profits and, as a result, farmland may go out of production. In other words, a decline in productivity may be incompatible with sustainability of the cropping system (Lynam and Herdt 1989). Thus, declining productivity might be a leading indicator of the need for future improvements in technology (e.g., improved varieties, changes in the cropping system) that can reverse the decline.

Cassman and Pingali (1995) cite some evidence that TFP has declined on rice farms in the Philippines (Central Luzon and Laguna) and India (Ludhiana, Punjab, and Krishna District, Andhra Pradesh).[2] But there is significant year-to-year variability in their figures for TFP that makes it difficult to detect underlying trends and makes the decline in TFP dependent on which years are compared. This high variability in TFP appears to be due primarily to fluctuations in yield that most likely result from random changes in the weather. For example, in Central Luzon, yields were abnormally high in 1982, causing TFP to be high in that year. Thus, TFP for the wet-season rice crop declined from 1982 to 1990, but increased from 1979 to 1990 (see Table 4). A similar phenomenon occurs in the data for Laguna Province. In addition, their TFP calculations are for single crops, not the entire cropping system (see the discussion at the end of the

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[1] Economists also estimate other types of functions, such as cost functions and profit functions, that have some advantages (and disadvantages) relative to production functions. For a discussion of these techniques, consult an advanced microeconomics textbook.

[2] Productivity has declined on the experimental plots at which yield declines were measured. This is because yields declined while inputs were held constant. These two facts imply that productivity must be falling.

Table 4. Total factor productivity on Philippine farms.

Area	Year	Input index	Output index	TFP index
Central Luzon	1966	68	65	95
	1970	73	71	96
	1974	101	61	61
	1979	101	99	99
	1982	100	114	114
	1986	91	99	109
	1990	100	100	100
Laguna	1966	80	57	72
	1970	80	81	102
	1975	93	88	94
	1978	100	92	92
	1981	96	115	119
	1984	103	136	132
	1987	96	102	106
	1990	100	100	100

paper for a discussion of some of the practical difficulties involved in calculating measures of TFP). These authors also stressed that calculation of a decline in TFP does not provide any information as to *why* the change in productivity occurred.

With the exception of the data being collected in project IR2, we are not aware of any multiyear data sets pertaining to irrigated rice farms in Asia that contain information on both socioeconomic variables and biophysical indicators. These data being collected will allow estimation of production functions that include both socioeconomic and biophysical variables. Not only will this allow inferences to be drawn regarding trends in productivity; it will also allow inferences to be made about *why* these trends are occurring.

The following definitions provide more detail on some of the technical concepts that underlie the above definitions.

Yield potential: *The maximum grain yield of a given variety in a given environment without water, nutrient, competition, pest, or disease constraints.*

The yield potential of a variety will be different in environments differing in temperature and solar radiation regimes.

Fertilizer response function: *A function that relates yield (output per hectare) to the amount of fertilizer used (input per hectare), holding all other inputs constant.*[3]

Fertilizer response functions are usually estimated statistically in quadratic form, which allows for the incremental responsiveness of the crop to decline as larger amounts of

[3] A fertilizer response function is a two-dimensional slice through the production function (see the next footnote).

fertilizer are used. Such a functional form also allows for a finite maximum possible yield (i.e., the yield potential). A hypothetical example of a fertilizer response function would be:

$$Y = 2943 + 19N - 0.06N^2$$

where Y is yield in kg paddy rice ha^{-1} and N is applied fertilizer in kg N ha^{-1}. If applied nitrogen is zero, then yield would be 2.9 t ha^{-1}. If applied nitrogen is 100 kg ha^{-1}, then yield would be 4.2 t ha^{-1}.

Response functions can shift for many reasons, either technological, environmental, or economic. For example, the introduction of new varieties with improved nitrogen response will shift up the fertilizer response function, resulting in more yield for the same level of fertilizer input. The new plant type and hybrid rice are examples of such technologies. Improved knowledge about the optimal timing of nitrogen applications would also shift up the nitrogen response function. On the other hand, other factors can shift the response function down (resulting in less yield for the same level of fertilizer input). Examples of such factors are a decline in the nutrient-supplying capacity of the soil, a decline in the uptake capacity of the root system due to factors such as root pathogens or nematodes, or a decline in the internal physiological nutrient-use efficiency of the rice plant because of soil toxicities or deficiencies of micronutrients. If the use of inputs other than fertilizer changes because of economic forces, such as changes in the availability of labor or the wage rate, this would also cause a shift in the fertilizer response function.

Shifts in the response function must manifest themselves as shifts in the level of the function (i.e., the entire function shifts up or down by the same amount at all nitrogen levels; see Fig. 2A), shifts in the curvature of the function (i.e., yields change more at some nitrogen levels than at others; see Fig. 2B), or both (see Fig. 2C). In the context of a long-term experiment where management and inputs are held constant, a decline in the level of the response function might indicate a change in the nitrogen-supplying capacity of the soil, since this would mean that yields decline even when applied nitrogen is zero. A flattening of the curvature of the function would indicate reduced responsiveness to nitrogen fertilizer, which could be due to either a decline in uptake efficiency or internal physiological efficiency. Under nonexperimental conditions, shifts in the level or curvature of the function could be due to a variety of factors, including changes in economic conditions. In such cases, shifts may or may not indicate anything about changes in soil nitrogen supply, uptake efficiency, or internal physiological efficiency.

Production function: *A statistically estimated function that relates the output of a production system (e.g., rice) to the inputs used in its production (e.g., labor, capital, fertilizer, pesticides).*

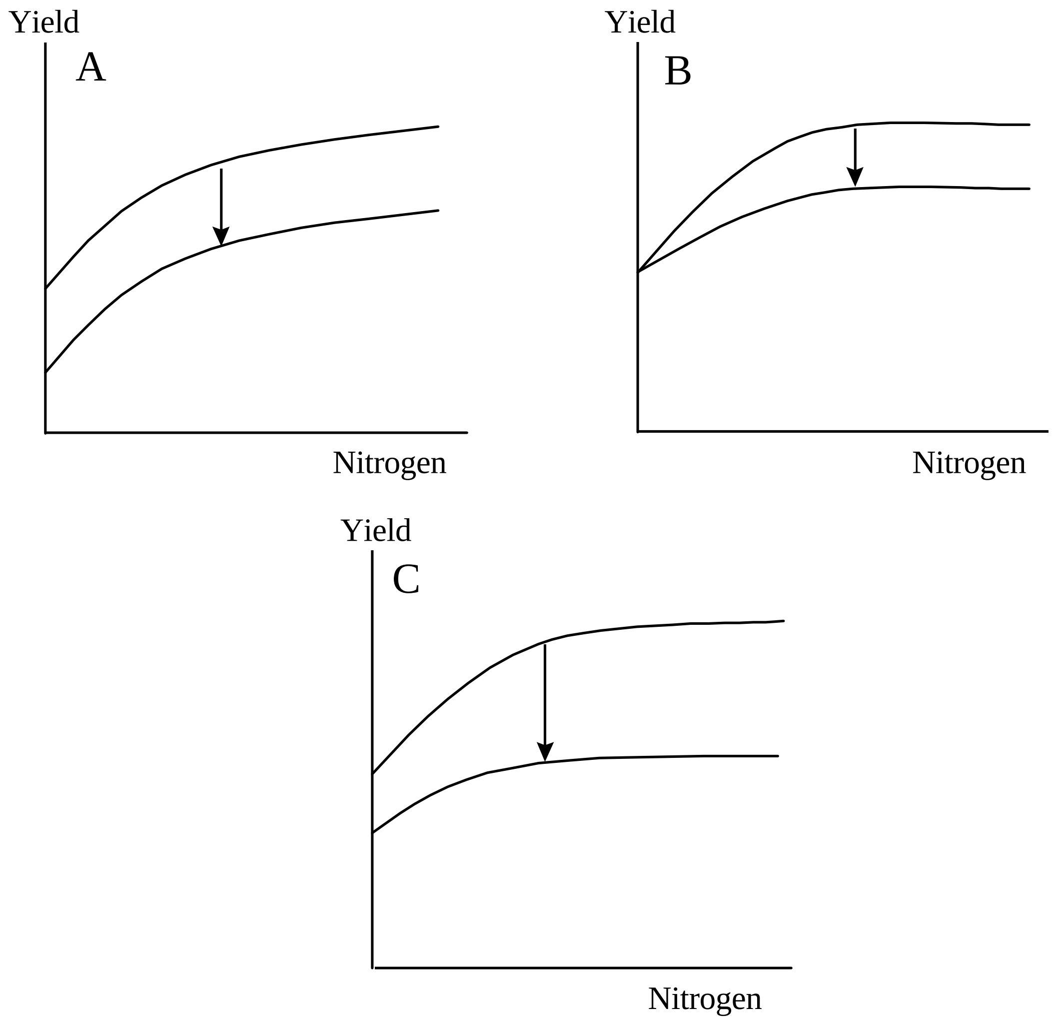

Fig. 2. Hypothetical shift in the level (A), curvature (B), and level and curvature (C) of the fertilizer response function.

A production function is a generalized version of a fertilizer response function that incorporates multiple inputs instead of only a single input.[4] An example of such a function would be:

$$Y = 1663 + 19N - 0.06N^2 + 37P - 0.1P^2 + 23K - 0.09K^2 + 2.8L + 7.1T + 2.2S + 292I$$

where all variables are in per hectare terms as follows:

Y = yield in kg of paddy rice
N = fertilizer use in kg of nitrogen

[4] A production function is a multidimensional surface, with yield on one axis and the inputs on all other axes.

P = fertilizer use in kg of phosphorus
K = fertilizer use in kg of potassium
L = labor use in days
T = tractor use in days
S = quantity of seeds in kg
I = insecticide use in kg of active ingredient

A downward (upward) shift in the production function implies that yield will decline (increase) for the same level of inputs. If the production function shifts downward (upward), this represents a decline (increase) in total factor productivity.[5]

Changes in the level of production can occur for one of two reasons: shifts in the production function itself or shifts along the production function. A shift in the function itself represents a change in productivity; a shift along the function does not. For example, if the prices of certain inputs change, farmers will respond by changing the amounts of inputs that are used. This will result in a change in production, but it will be due to a shift *along* the production function and this does not represent a change in productivity (because the production function itself has not changed). Thus, changes in production are not good proxies for changes in productivity because farmers change the level of inputs frequently (i.e., farmers often move along their respective production functions).

Partial factor productivity (PFP): *The average productivity of a single factor, measured by grain output divided by the quantity of the factor applied.*

PFPs can be measured for any factor of production, such as fertilizer, labor, water, pesticide, machinery, etc., with the units of measurement depending on the factor. In the case of fertilizer, agronomists often decompose PFP into several influences, some of which are agronomic efficiency, the uptake efficiency of applied nutrient, and the internal physiological efficiency of the plant (see Cassman et al 1998 for definitions of these concepts).

Measures of PFP for fertilizer can be difficult to interpret for several reasons. First, fertilizer use has increased greatly over the course of the Green Revolution. This increase was not intended to stop yields from declining; the increase occurred because farmers gradually became more comfortable using fertilizer and started to apply larger amounts of it. Because fertilizer response functions are concave in shape, the more fertilizer that is applied, the lower is the average productivity. This natural decline in PFPs of fertilizer as farmers move out *along* a fixed response function will occur unless there are other offsetting factors that tend to shift the response function up, such as a shift to knowledge-intensive nutrient management.

[5] The production function can shift up or down in response to the weather. Data for climatic factors such as solar radiation are being collected in order to try to control for the influence of these variables on the production function, either through the use of statistical techniques or through crop modeling.

Second, PFPs of fertilizer are also influenced by the use of other inputs. If the use of labor declines as wage rates increase, then the intensity of weeding will decline, and yields may fall even if fertilizer use does not change. In that case, the PFP of fertilizer will decline, but, again, this is not necessarily cause for concern.

Third, fertilizer use is also influenced by prices of both rice and fertilizer. For example, if fertilizer prices decline while rice prices stay constant, then farmers will tend to apply more fertilizer. If this occurs, the PFP of fertilizer will decline. Such a decline in PFPs is not cause for concern.

As an example, consider the hypothetical response function specified above in the definition of fertilizer response function. In 1985, fertilizer prices in the Philippines were relatively high, and irrigated rice farmers used an average of about 51 kg N ha^{-1} (averaged across wet and dry seasons for those farmers that used fertilizer). Using the above response function, this would give a yield of 3,756 kg paddy ha^{-1} and a PFP for nitrogen of 74 kg paddy kg^{-1} N. The following year, world oil prices fell dramatically, leading to a large fall in urea prices (the main input in urea production is natural gas, which is a close substitute for oil). The fall in urea prices induced Philippine rice farmers to increase nitrogen use substantially within just one year, to an average of 72 kg N ha^{-1}. Again, using the response function, this would give a yield of 4,000 kg paddy ha^{-1} and a PFP for nitrogen of 56 kg paddy kg^{-1} N. Thus, in this example, the PFP of fertilizer fell significantly, but this is clearly not cause for concern. In fact, for rice farmers it is beneficial because the fall in fertilizer prices led to increased rice production and increased farm profits.

Thus, interpretation of changes in PFP over time is difficult and needs to take into account the learning process of farmers, prices of rice and fertilizer, and use of other inputs. Its advantage over measures of total factor productivity is that it is easier to calculate. Its interpretation, however, is much more ambiguous.

Total factor productivity (TFP): *The productivity of* ***all*** *inputs taken together.*

TFP attempts to measure increases in production that are *not* due to an increased use of economic inputs. In other words, TFP is ultimately a residual, which makes its measurement potentially very sensitive to the exclusion of certain inputs. Thus, to measure TFP, it is important to measure as many inputs into the production process as possible.

A decline (increase) in TFP is equivalent to a decline (increase) in yields when holding the use of *all* economic inputs constant. Alternatively, a decline in TFP can be viewed as the necessity of using more of at least one input without a reduced use of any other input to maintain constant grain yields. For example, suppose that yield had declined over time when holding fertilizer use constant. In this case, the PFP of fertilizer has declined, but this by itself is not necessarily indicative of a fall in TFP. It is possible, for instance, that wages in the economy increased, causing the intensity of weeding to decline, and that this was responsible for the falling yields. Before it can be concluded that TFP has declined, we must be able to show that yield would have declined if the use of *all* economic inputs had been held constant.

TFP is different from PFP in that it is dimensionless. Thus, only *changes* in TFP have any meaning. For example, although a PFP of fertilizer of 50 kg rice kg^{-1} N has meaning, a statement that TFP = 5 is meaningless.

TFP is calculated as a weighted average of the monetary value of various outputs divided by a weighted average of the monetary value of all inputs, including labor, capital, fertilizer, etc., with appropriate adjustments to control for changing prices of inputs and outputs over time. Changes in TFP can then be measured as changes in this index. An alternative method of measuring changes in productivity over time is to estimate a production function and infer changes in productivity from shifts in the production function over time. Productivity measured in this way is not referred to as TFP, which refers to the specific calculation described above, but it is a legitimate measurement of productivity.

Calculation of TFP does not require data on individual farms, a major advantage in many circumstances. If the available data allow us to estimate production functions, however, this technique has two important advantages. One is that the relevant parameters are estimated statistically instead of being calculated mathematically. This allows us to use probability theory to determine whether any changes in parameters over time or across farms are statistically significant. A second advantage is that we can more easily take account of farm-specific influences such as variations in measurable soil properties. Data being collected in Project IR2 will allow us to estimate production functions and calculate TFP.

The final section provides explicit discussion of some (but not all) potential problems with measuring and interpreting TFP (several of these problems also apply to the estimation of production functions).

TFP is a residual. Because TFP is a ratio between outputs and inputs (or the difference if we are using logarithms), small changes in either outputs or inputs can lead to large changes in TFP. For example, small errors in measuring outputs and inputs can have large effects on the measurement of productivity. Excluding one input or output can have the same effect. Thus, it is important to include as many inputs and outputs as possible and to measure them as best we can.

Variability. Because TFP is a residual, it tends to vary substantially from year to year. As a direct consequence, we need many years of data to meaningfully interpret changes in TFP. Otherwise, any trends in TFP may be very sensitive to the inclusion or exclusion of one particular year of data.

Systems approach. TFP calculations made for single crops that are part of larger cropping (or economic) systems can be misleading. For example, TFP for rice might be declining due to a change in transplanting date that lowers rice yields. If this change in transplanting is done to accommodate another crop in the rotation (e.g., wheat), then it may be optimal for farmers to accept lower rice yields in exchange for higher profits with the wheat crop. Thus, in this example, it is better to calculate TFP for the rice-wheat system than for rice and wheat separately.

Quality. Changes in the quality of inputs and outputs over time also create problems for TFP calculations. For example, suppose farmers switch to rice varieties that command higher prices on the market but have slightly lower yields. Such a switch may be optimal from the point of view of both farmers and consumers. At the same time, because TFP calculations hold input and output prices constant, this varietal switch will result in negative TFP growth. It would be wrong to be concerned about the decline in TFP caused by this switch. Similar problems can arise from changes in the quality of inputs, such as fertilizer, seeds, or labor.

The macroeconomic environment and other influences. Increases in TFP over time often occur because of a technological change in the economy, such as mechanization of farm operations. Such technological shifts are more likely in a dynamic economy with rapid economic growth. Conversely, a stagnant economy is more likely to lack such technological change. Thus, a decline in TFP may be more reflective of the general economic environment than of some deterioration of the natural resource base. Similarly, an increase in TFP due to rapid technological change may mask a degradation of the natural resource base. In general, changes in TFP do not necessarily correlate with changes in the resource base. To provide the best interpretation of changes in TFP, it is best if quantitative data on soil characteristics or other features of the environment are also available.

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