

Drought: economic costs and research implications¹

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Drought is a major constraint to rice production in Asia. Drought occurs frequently and is one of the major reasons for wide fluctuations in rainfed production. The economic cost of drought estimated in this study was found to be substantial in rainfed areas of eastern India. The economic cost of drought depends largely on the frequency and coverage of drought, and the importance of rice in total farm income. Farmers deploy various coping strategies but these strategies were found to be largely unable to prevent a reduction in income and consumption in rainfed areas of eastern India. As a result, a large number of people fall back into poverty during drought years. The overall implications of these results for research, technology design, and policy interventions for a long-term mitigation of drought are discussed.

Drought is a recurrent phenomenon and an important constraint to rainfed rice production in Asia. Frequent major shortfalls in rice production—the staple crop of Asia—in this vast drought-prone area threaten food security, human health, and livelihood of millions of poor. At least 23 million ha of rice area (20% of the total rice area) in Asia are subject to drought of different intensities (Table 1). Drought is one of the major factors contributing to low and unstable rice production in the region (Fig. 1).

Drought can cause great harm in terms of human suffering, economic loss, and adverse environmental impact. The effect of drought in terms of production losses and consequent human misery is well publicized during years of crop failure. However, losses to drought of milder intensity, although not so visible, can also be substantial. Agricultural production losses, which are often used as a measure of the impact of drought, are only a part of the overall socioeconomic impact. Severe droughts can result in starvation and even death of the affected population. However, different types of economic impact such as production shortfall, price rise, employment and income fall, food insecurity, poor health, and so on arise before such severe consequences

¹This paper draws heavily from the book *Economic costs of drought and rice farmers' coping mechanisms* edited by S. Pandey, H. Bhandari, and B. Hardy (2007).

Table 1. Drought-prone rice area in Asia (million ha).

Country	Rice area ^a		Drought-prone rice area	
	UR ^c	RL	UR ^b	RL ^c
India	6.3	16	6.3	7.30
Bangladesh	0.9	6	0.9	0.80
Sri Lanka	0.06	0.2	–	na
Nepal	0.1	1.0	0.1	0.27
Myanmar	0.3	2.5	0.3	0.28
Thailand	0.05	8	–	3.1
Laos	0.2	0.4	0.2	0.09
Cambodia	–	1.7	–	0.20
Vietnam	0.5	3	0.5	0.30
Indonesia	1.1	4	1.1	0.14
China	0.6	2	0.6	0.50
Philippines	0.07	1.2	–	0.24
Total	10	46	10	13

^aSource: IRRI (1997). ^bAssuming all upland rice (UR) area as drought-prone. ^cSource: Mackill et al (1996). Rainfed lowland (RL) rice area is classified as drought-prone and drought- and submergence-prone. The numbers represented in the table provide lower-bound estimates as the drought-prone and submergence-prone areas are excluded. na = not available.

occur. Because of market failures, farmers attempt to “self-insure” by making costly adjustments in their production practices and adopting conservative practices to reduce the negative impact during drought years. Although these adjustments reduce direct production losses, they do entail some economic costs in terms of opportunities for income gains lost during good years.

In rural areas where agricultural production is a major source of income and employment, a decrease in agricultural production will set off second-round effects through forward and backward linkages of agriculture with other sectors. A decrease in agricultural income will reduce the demand for products of the agro-processing industries that cater to local markets. This will lead to a reduction in income and employment in this sector. Similarly, the income of rural households engaged in providing agricultural inputs will also decrease. This reduction in household income will set off further “knock-on” effects. By the time these effects have been fully played out, the overall economic loss from drought may turn out to be several times more than what is indicated by the loss in production of agricultural output alone. The loss in household income can result in a loss in consumption of the poor, whose consumption levels are already low. Farmers may attempt to cope with this loss by liquidating productive assets, pulling children out of school, migrating to distant places in search of employment, and going deeper into debt. The economic and social impact of all these consequences can indeed be enormous.

Yield (t ha⁻¹)

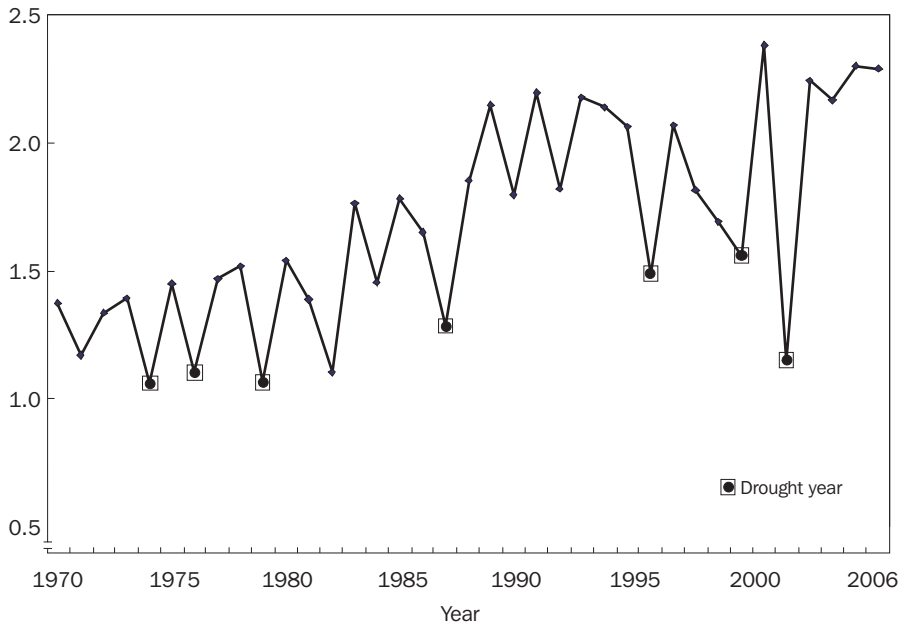


Fig. 1. Trends in rice yield and major drought years, eastern India (Orissa), 1970-2006.

This paper synthesizes the major findings of a recent cross-country comparative study of the impact of drought and farmers' coping mechanisms (see Pandey et al 2007). The countries included in the study were China, India, and Thailand. These countries vary in climatic conditions, level of economic development, rice yields, and institutional and policy contexts of rice farming. The specific regions selected for the study were southern China, eastern India, and northeastern Thailand.

Drought: definition, coping strategies, and consequences²

Conceptually, drought is considered to describe a situation of limited rainfall that is substantially below what has been established to be a "normal" value for the area concerned, leading to adverse consequences on human welfare. Although drought is a climatically induced phenomenon, its impact depends on the social and economic context as well. Hence, in addition to climate, economic and social parameters should also be taken into account in defining drought. This makes developing a universally applicable definition of drought impractical. Three generally used definitions of drought

²Details of different types of drought and farmers' coping mechanisms are presented in Pandey et al (2007).

are based on meteorological, hydrological, and agricultural perspectives (Wilhite and Glantz 1985).

Risk-coping strategies can be classified into *ex ante* and *ex post* depending upon whether they help to reduce risk or reduce the impact of risk after a production shortfall has occurred. Because of a lack of efficient market-based mechanisms for diffusing risk, farmers modify their production practices to provide “self-insurance” so that the likely impact of adverse consequences is reduced to an acceptable level. These *ex ante* strategies help reduce fluctuations in income and are also referred to as income-smoothing strategies. These strategies can, however, be costly in terms of forgone opportunities for income gains as farmers select safer but low-return activities.

Ex ante strategies can be grouped into two categories: those that reduce risk by diversification and those that do so by imparting greater flexibility in decision making. Diversification is simply captured in the principle of not putting “all eggs in one basket.” The risk of income shortfall is reduced by growing several crops that have negatively or weakly correlated returns. This principle is used in different types of diversification common in rural societies. Examples include spatial diversification of farms, diversification of agricultural enterprises, and diversification from farm to nonfarm activities.

Maintaining flexibility is an adaptive strategy that allows farmers to switch between activities as the situation demands. Flexibility in decision making permits farmers not only to reduce the chances of low income but also to capture income-increasing opportunities when they do arise. Examples are using split doses of fertilizers, temporally adjusting input use to crop conditions, and adjusting the area allocated to a crop depending on the climatic conditions. Although postponing agricultural decisions until uncertainties are reduced can help lower potential losses, such a strategy can also be costly in terms of income forgone if operations are delayed beyond the optimal biological window. Other *ex ante* strategies include maintaining stocks of food, fodder, and cash.

Ex post strategies are designed to prevent a shortfall in consumption when the income drops below what is necessary for maintaining consumption at its normal level. *Ex post* strategies are also referred to as consumption-smoothing strategies as they help reduce fluctuations in consumption. These include migration, consumption loans, asset liquidation, and charity. A consumption shortfall can occur despite these *ex post* strategies if the drop in income is substantial.

Farmers who are exposed to risk use these strategies in different combinations. Over a long period of time, some of these strategies are incorporated into the nature of the farming system and are often not easily identifiable as risk-coping mechanisms. Others are deployed only under certain risky situations and are easier to identify as responses to risk.

Opportunity costs associated with the deployment of various coping mechanisms can, however, be large. Climatic uncertainties often compel farmers, particularly those who are more risk-averse, to employ conservative risk management strategies that reduce the negative impact in poor years, but often at the expense of reducing the

average productivity and profitability. For example, by growing drought-hardy but low-yielding traditional rice varieties, farmers may be able to minimize the drought risk but may end up sacrificing a potentially higher income in normal years. Also, poor farmers in high drought-risk environments may be reluctant to invest in seed-fertilizer technologies that could increase profitability in normal years but lead to a loss of capital investment in poor years. In addition to these opportunity costs, poor households that are compelled to sell their productive assets such as bullocks and farm implements will suffer future productivity losses as it can take them several years to reacquire those assets. A cut in medical expenses and children's education will affect future income-earning capacity of the household. Such an impact may linger on into the future generation also. The loss of income and assets can convert transient poverty into chronic poverty, making the possibility of escape from poverty more remote (Morduch 1994, Barrett 2005).

Frequency of drought and economic loss³

An analysis of historical rainfall data indicated that drought is a regular phenomenon in all three regions (eastern India, northeastern Thailand, and southern China). The probability of drought varies in the range of 0.1–0.4, with the probability being higher in eastern India than in southern China and northeast Thailand (Fig. 2). The probability of late-season drought was found to be higher than that of early-season drought generally. Late-season drought was also found to be spatially more covariate than early-season drought. This means that late-season drought tends to cover large areas. As rice yield is more sensitive to drought during flowering/grain-filling stages (i.e., during the late season, according to the definition used here), late-season drought is thus likely to have a larger aggregate production impact than early-season drought.

The temporal instability in rice production as measured by the de-trended coefficient of variation of rice yield was found to be high in eastern India (17%) relative to southern China (4%) and northeast Thailand (9%). The corresponding much lower coefficients of variation for southern China and northeast Thailand indicated that droughts in these regions are not as covariate spatially as in eastern India, with their effects being limited to some pockets. Given the nature of the temporal variability, the aggregate impact of drought on production is also likely to be higher in eastern India than in the other two regions.

The estimated average loss in rice production during drought years for eastern India is 5.4 million tons (Table 2). This is much higher than for northeast Thailand (less than 1 million tons) and southern China (around 1 million tons but not statistically significant). The loss (including any nonrice crops included) during drought years is thus 36% of the average value of production in eastern India. This indeed represents a massive loss during drought years (estimated at US\$856 million).

³Estimation methods for various empirical results presented are described in Pandey et al (2007).

Probability

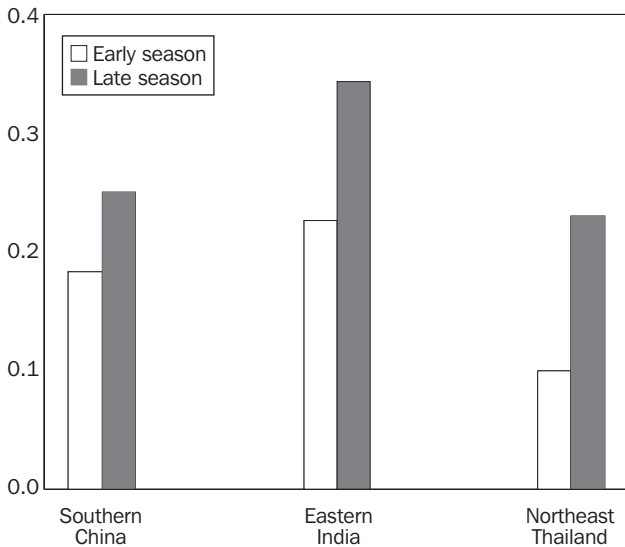


Fig. 2. Estimated probability of early- and late-season drought in southern China (1982-2001), eastern India (1970-2000), and northeast Thailand (1970-2002).

Table 2. Estimated value of crop production losses due to drought using rainfall-based drought years, 1970-2002.

Country ^a	Drought years			Annual	
	Quantity of rice production loss (million t)	Value of crop production loss ^b (million \$)	Ratio of loss to average value of production (%)	Value of crop production loss ^b (million \$)	Ratio of loss to average value of production (%)
Southern China	1.2	133	3	16	0.4
Eastern India	5.4	856 ***	36	162	7.0
Northeast Thailand	0.7	85 *	10	10	1.2

^aThe values are estimated based on secondary data of study provinces/states. ^bThe value of production losses is estimated using both rice and nonrice crops for India while only the rice crop is used for China and Thailand. * = $P < 0.1$ and *** = $P < 0.01$.

Table 3. Percentage change in rice area, yield, and production among sample farm households in drought years compared with normal years.

Rice	Southern China	Eastern India	Northeast Thailand
Area	-19	-36	-21
Yield	-31	-54	-45
Production	-44	-71	-56

As droughts do not occur every year, the above estimate of production loss needs to be averaged over a run of drought and nondrought years to get the annual average loss estimate. Again for eastern India, this represents an annual average loss of \$162 million (or 7.0% of the average value of output). For northeast Thailand and southern China, the losses were found to be much smaller and averaged less than \$20 million per year (or less than 1.5% of the value of output).

The estimates thus indicate that, at the aggregate level, the production losses are much higher for eastern India than for the other two regions. Lower probability of drought, a smaller magnitude of loss during drought years, and less covariate nature of drought together have reduced production losses at the aggregate level in the other two regions relative to eastern India.

The overall economic cost of drought includes the value of production losses, the costs farmers incur in making adjustments in production systems during drought years, opportunities for gains forgone during good years by adopting ex ante coping strategies that reduce losses during drought years, the generally lower productivity of drought-prone areas due to moisture deficiency, and the costs of government programs aimed at long-term drought mitigation. The average annual cost for eastern India is in the neighborhood of \$400 million (Pandey et al 2007). Overall, the cost of drought is a substantial proportion of the agricultural value added in eastern India.

Household-level consequences of drought

A detailed analysis of the household-level impact of drought was conducted using farm survey data. Drought-affected households suffered rice production losses of 44–71% (Table 3). Even in southern China and northeast Thailand, where aggregate production losses were small, production losses for the households affected by drought were substantial. Production losses resulted from both yield loss and area loss. The loss in yield, however, accounted for the major share of production losses. Across the toposequence, production losses were higher in upper fields that drain quickly than in bottom lands, which tend to have more favorable hydrological conditions.

Drought resulted in an overall income loss of 24% to 58%.⁴ The drop in rice income was the main factor contributing to the total income loss. Earnings from farm labor also dropped substantially because of reduced labor demand. Farmers attempted to reduce loss in agricultural income during drought years by seeking additional employment in the nonfarm sector. This mainly included employment as wage labor in the construction sector, for which farmers often migrated to distant places. The additional earnings from nonfarm employment were clearly inadequate, however, to compensate for the loss in agricultural income.

Farmers relied on three main mechanisms to recoup this loss in total income: the sale of livestock, sale of other assets, and borrowing. These adjustment mechanisms helped recover only 6–13% of the loss in total income. Compared with normal years, households still ended up with a substantially lower level of income despite all these adjustments. Thus, all the different coping mechanisms farmers deployed were found to be inadequate to prevent a shortfall in income during drought years.

The incidence of poverty increased substantially during drought years. Almost 13 million additional people “fell back” into poverty as a result of drought (Fig. 3). This is a substantial increase in the incidence of poverty and translates into an increase in rural poverty at the national level by 1.8 percentage points. Some of the increase in poverty may be transitory, with households being able to climb out of poverty on their own. However, other households whose income and assets fall below certain threshold levels may end up joining the ranks of the chronically poor (Barrett 2005). The data collected, however, did not permit the estimation of the proportion of these two categories of households. Households with small farm sizes, with proportionately more area under drought-prone upland fields, and with a smaller number of economically active members, are more vulnerable to such adverse income consequences of drought.

In terms of crop management practices, farmers seem to have less flexibility in making management adjustments in rice cropping in relation to drought. Other than delaying crop establishment if the rains are late, replanting and resowing when suitable opportunities arise, and some reduction in fertilizer use, farmers mostly follow a standard set of practices irrespective of the occurrence of drought. This could partly be because drought mostly occurs during the late season, by which time opportunities for crop management adjustments to reduce losses are no longer available. The timing of drought (mostly late rather than early) and the lack of suitable technological options probably has limited flexibility in making tactical adjustments in crop management practices to reduce losses.

Since rice is the staple food, a loss in its production can be expected to result in major adjustments in consumption. Such adjustments could involve a reduced sale of rice, reduced quantity retained as seeds for the following year, increased amounts purchased, substitution of other crops for rice, supplementation of food deficit by other

⁴The household-level impact of drought presented here is based mainly on the study in eastern India. Relative to eastern India, impact in northeast Thailand and southern China was found to be quite small and, hence, is not discussed here.

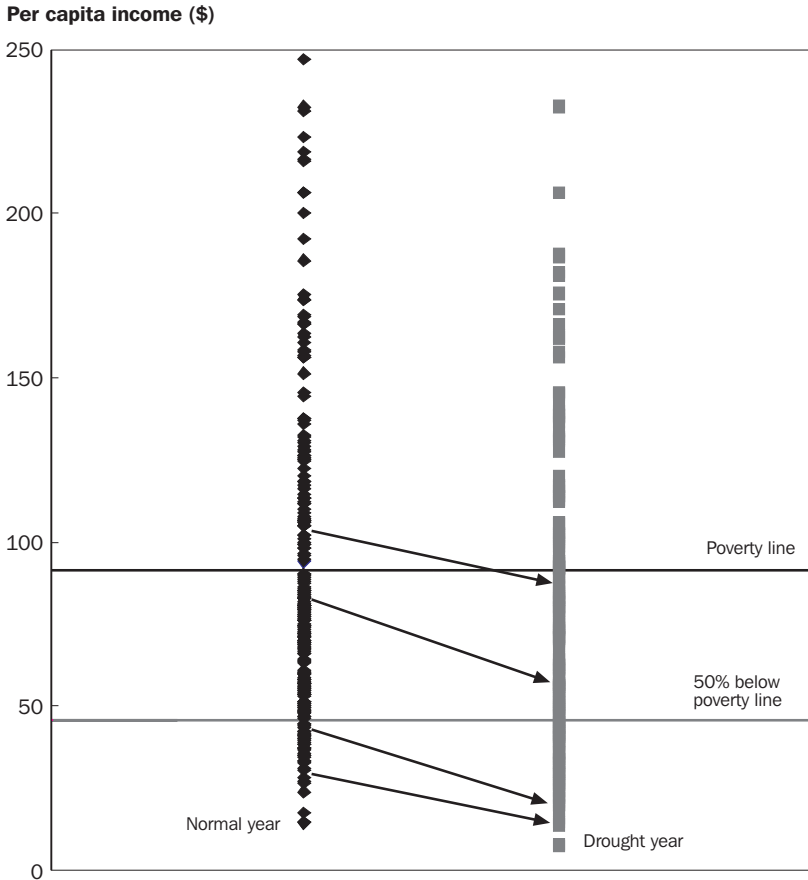


Fig. 3. Effect of drought on incidence and severity of poverty, Jharkhand, India (each dot refers to a household).

types of food not normally consumed, and, in the worst-case scenario, a reduction in consumption.

Farmers made all these types of adjustments to a varying degree. Despite these various adjustments, most farmers were unable to maintain consumption at the pre-drought level. They reduced both the number of meals eaten per day and the quantity consumed per meal. As a result, the average number of meals eaten per day dropped from close to three to close to two, with 10–30% of the households reducing their frequency of food intake to one meal per day. A large proportion (60–70%) of the households also reduced the quantity of food consumed per meal. In addition, households consumed other “inferior” food items that were not normally consumed.

The interruption and/or discontinuation of children’s education is a disinvestment in human capital, which will most definitely reduce their future earning potential

in most cases. An important pathway for escape from poverty may be foreclosed as a result of drought. More than 50% of the farmers reported curtailing children's education.

Relative to eastern India, the economic costs in southern China and northeast Thailand were found to be small, in both absolute and relative terms. Production losses at the aggregate level in these two regions were relatively small because of a lower frequency and less covariate nature of drought. In addition, rice accounted for a smaller proportion of household income because of a more diversified income structure. The differences in rice production systems, the level of income diversification, and the nature of drought in these latter two regions are hence the major factors determining the relative magnitudes of economic losses.

Implications

Agricultural research

Improved rice technologies that help reduce losses to drought can play an important role in long-term drought mitigation. Important scientific progress is being made in understanding the physiological mechanisms that impart tolerance of drought (Blum 2005, Lafitte et al 2006). Similarly, progress is being made in developing drought-tolerant rice germplasm through conventional breeding and the use of molecular tools (Bennett 1995, Atlin et al 2006, Serraj 2005). The probability of success in developing rice germplasm that is tolerant of drought is likely to be substantially higher now than what it was a decade ago. Complementary crop management research to manipulate crop establishment, fertilization, and general crop care for avoiding drought stress, better use of available soil moisture, and enhancing the plant's ability to recover rapidly from drought can similarly help reduce losses.

Despite the potential role of improved technologies in drought mitigation, the level of agricultural research in developing countries is generally low. Although industrialized countries invest about 2.6% of their agricultural GDP in research, the research intensity (or the ratio of research expenditure to agricultural GDP) for developing countries has been estimated to be around 0.62% (Pal and Byerlee 2003). For China and India, research intensities are only 0.43% and 0.29%, respectively. Clearly, agricultural research in the developing countries of Asia remains underinvested. The total agricultural research investment in India in 1998-99 was about \$430 million (Pal and Byerlee 2003). The economic losses from drought alone as estimated in this study by considering just rainfed rice-growing areas are close to this figure.

The allocation of research resources to rainfed areas and specifically to address abiotic constraints such as drought and submergence is even lower relative to the size of losses resulting from these constraints. A recent study from India illustrates the case in point. It has been found that the allocation of rice research resources to rainfed areas in India is disproportionately small relative to the potential contribution of these areas in making efficiency and equity impacts (Pandey and Pal 2007). The share of even this limited amount of resources targeted to address abiotic constraints such as drought and submergence is less than 10%.

It has been established that the marginal productivity of research resources may now be higher in rainfed environments than in irrigated environments and that agricultural research in unfavorable (rainfed) environments can generate a substantial poverty impact (Fan et al 2005). There is a strong justification for increasing research intensity in agriculture and allocating a larger proportionate share to rainfed areas to address drought and submergence, which are the dominant constraints to productivity growth.

Technology design considerations

Several design features need to be considered when developing improved technologies for effective drought mitigation. An important design criterion is that the technologies should improve flexibility in the decision regarding crop choices, the timing and method of crop establishment, and the timing and quantity of various inputs to be used. Flexibility in agricultural technologies permits farmers not only to reduce the chances of low income but also to adaptively capture income-increasing opportunities when they do arise. Technologies that lock farmers into a fixed set of practices and timetables do not permit effective management of risk in agriculture. In fact, the empirical analyses presented in this report indicate that farmers do not seem to have much flexibility in making management adjustments in rice cropping in relation to drought. Other than delaying crop establishment if rains are late, replanting and resowing when suitable opportunities arise, and some reduction in fertilizer use, farmers mostly follow a standard set of practices irrespective of the occurrence of drought. The timing of drought (mostly late rather than early) and the lack of suitable technological options have probably limited flexibility in making tactical adjustments in crop management practices to reduce losses. Examples of technologies that provide greater flexibility are varieties that are not adversely affected by delayed transplanting caused by early-season drought, varieties that perform equally well under both direct seeding and transplanting, and crop management practices that can be implemented over a wider time window.

Losses in agricultural production and income are important factors that contribute to increases in poverty during drought years. Technologies that reduce yield losses during drought years can avoid such adverse impacts on poverty even if there may be some associated trade-offs in yield during favorable years. Hence, in terms of poverty impact, higher priority should be accorded to research focused on lopping off the lower tail of the yield distribution than to raising average yield by improving performance during normal years, if there are trade-offs involved in achieving both simultaneously.

Late-season drought is more frequent and tends to have more serious economic consequences for poor farmers than early-season drought. In addition to having to deal with the consequences of low or no harvest, farmers also lose their investments in seed, fertilizer, and labor if the crop is damaged by late-season drought. Although early-season drought may prevent planting completely, farmers can switch early to other coping strategies such as wage labor and migration to reduce income losses in such years. Thus, the poverty impact of technology is likely to be higher if research

focuses on late-season drought if tolerance of early- and late-season drought cannot be achieved simultaneously.

In rainfed areas, the land endowment of farmers typically consists of fields across the toposequence that have different hydrological conditions. Fields in the upper part of the toposequence are typically more drought-prone than those in the lower part. Farmers use such a hydrologically diversified portfolio of land by growing different varieties of rice that match field hydrological features. In addition, farmers grow a range of varieties for other reasons such as staggering of labor demand, grain quality, taste, and suitability to various uses. Breeding programs that produce a wider choice of plant materials with different characteristics and varying responses to drought that correspond with field hydrological features can play an important role in effective protection from drought.

Crop diversification is an important drought-coping mechanism of farmers. Rice technologies that promote but do not constrain such diversification are therefore needed. In rainfed areas, shorter-duration rice varieties can facilitate planting of a second crop using residual moisture. Similarly, rice technologies that increase not just yield but also labor productivity will facilitate crop and income diversification. Higher labor productivity in rice production will help relax any labor constraint to diversification that may exist. Examples of such technologies are selective mechanization, direct seeding, and chemical weed control.

Complementary options

The development of water resources is an important area that is emphasized in all three countries for providing protection against drought. Opportunities for large-scale development of irrigation schemes that were the hallmark of the Green Revolution are limited now because of high costs and increasing environmental concerns (Rosegrant et al 2002). However, there are still substantial opportunities to provide some protection from drought through small and minor irrigation schemes and through land-use approaches that generally enhance soil moisture and water retention (Shah 2001, Moench 2002). Similarly, watershed-based approaches that are implemented in drought-prone areas of India provide opportunities for achieving long-term drought proofing by improving overall moisture retention within the watersheds (Rao 2000).

In all three countries studied, a major response to drought has been to provide relief to the affected population. Although the provision of relief is essential to reduce the incidence of hunger and starvation, the major problems with relief programs are slow response, poor targeting of beneficiaries, and limited coverage due to budgetary constraints. A “fire-fighting” approach that underlies the provision of drought relief cannot provide long-term drought proofing despite the large amount spent during drought years (Rao 2000, Hirway 2001). It is important that the provision of relief during drought years be complemented by a long-term strategy of investing in soil and water conservation and use, policy support, and infrastructure development to promote crop and income diversification in drought-prone areas (Rao 2000).

The scientific advances in meteorology and informatics have made it possible now to forecast drought with reasonable degrees of accuracy and reliability. Various

indicators such as the Southern Oscillation Index (SOI) are now routinely used in several countries to make drought forecasts (Wilhite et al 2000, Meinke and Stone 2005). Suitable refinements and adaptations of these forecasting systems are needed to enhance drought preparedness at the national level as well as to assist farmers in making more efficient decisions regarding the choice of crops and cropping practices (Abedullah and Pandey 1998). Improvements in drought forecasting systems, the identification of efficient agricultural management practices to reduce the impact of drought, and the provision of timely advice to farmers are activities that can help reduce the overall economic costs of drought and improve preparedness to manage drought risk effectively.

Although technological interventions can be critical in some cases, this is not the only option for improving the management of drought. A whole gamut of policy interventions can improve farmers' capacity to manage drought through more effective income- and consumption-smoothing mechanisms. Improvements in rural infrastructure and marketing that allow farmers to diversify their income sources can play an important role in reducing overall income risk. Investment in rural education can similarly help diversify income. In addition, such investments contribute directly to income growth that will further increase farmers' capacity to cope with various forms of agricultural risks. Widening and deepening of rural financial markets will also be a critical factor for reducing fluctuations in both income and consumption over time (Barrett 2005). Although the conventional forms of crop insurance are unlikely to be successful because of problems such as moral hazard and adverse selection (Hazell et al 1986), innovative approaches such as rainfall derivatives and international re-insurance of agricultural risks can provide promising opportunities (Skees et al 2001, Glauber 2004). However, these alternative schemes have not yet been adequately evaluated. More work is needed for developing and pilot testing new types of insurance products and schemes suited to hundreds of millions of small farmers of Asia who grow rice primarily for subsistence.

Concluding remarks

The socioeconomic impacts of drought are enormous even in subhumid rice-growing areas. Drought causes huge economic costs, in terms of both actual economic losses during drought years and losses arising from the opportunities for economic gains forgone. The provision of relief has been the main form of drought management of the government. Although important in reducing the hunger and hardship of the affected people, the provision of relief alone is clearly inadequate and may even be an inefficient response for achieving longer-term drought mitigation. Given the clear linkage between drought and poverty, it is critically important to include drought mitigation as an integral part of a rural development strategy. Policies that in general increase income growth and encourage income diversification also serve to protect farmers from the adverse consequences of risk, including that of drought.

The scientific progress made in understanding the physiology of drought and in the development of biotechnology tools has opened up promising opportunities

for making a significant impact on drought mitigation through improved technology. However, agricultural research in general remains grossly underinvested in the developing countries of Asia. This is a cause for concern, not only for drought mitigation but also for promoting overall agricultural development.

References

- Abedullah, Pandey S. 1998. Risk and the value of rainfall forecast for rainfed rice in the Philippines. *Philipp. J. Crop Sci.* 23(3):159-165.
- Atlin GN, Lafitte HR, Tao D, Laza M, Amante M, Courtois B. 2006. Developing rice cultivars for high-fertility upland systems in the Asian tropics. *Field Crops Res.* 97(1):43-52.
- Barrett CB. 2005. Rural poverty dynamics: development policy implications. *Agric. Econ.* 32(1):45-60.
- Bennett J. 1995. Biotechnology and the future of rice production. *GeoJournal* 35(3):335-337.
- Blum A. 2005. Drought resistance, water-use efficiency, and yield potential: are they compatible, dissonant, or mutually exclusive? *Aust. J. Agric. Res.* 56(11):1159-1168.
- Fan S, Chan-Kang C, Qian K, Krishnaiah K. 2005. National and international agricultural research and rural poverty: the case of rice research in India and China. *Agric. Econ.* 33(3):369-379.
- Glauber JW. 2004. Crop insurance reconsidered. *Am. J. Agric. Econ.* 86(5):1179-1195.
- Hazell P, Pomerada C, Valdes A. 1986. *Crop insurance for agricultural development*. Baltimore, Md. (USA): Johns Hopkins University Press.
- Hirway I. 2001. Vicious circle of droughts and scarcity works: why not break it? *Ind. J. Agric. Econ.* 56(4):708-721.
- Lafitte HR, Yongsheng G, Yan S, Li ZK. 2006. Whole plant responses, key processes, and adaptation to drought stress: the case of rice. *J. Exp. Bot.* 58(2):169-175.
- Mackill DJ, Coffman WR, Garrity DP. 1996. *Rainfed lowland rice improvement*. Manila (Philippines): International Rice Research Institute. 242 p.
- Meinke H, Stone RC. 2005. Seasonal and inter-annual climate forecasting: the new tool for increasing preparedness to climate variability and change in agricultural planning and operations. *Climatic Change* 70(1-2):221-253.
- Moench M. 2002. Groundwater and poverty: exploring the connections. In: Llamas R, Custodio E, editors. *Intensive use of groundwater: challenges and opportunities*. Abingdon, UK.
- Morduch J. 1994. Poverty and vulnerability. *Am. Econ. Rev.* 84(2):221-225.
- Pal S, Byerlee D. 2003. The funding and organization of agricultural research in India: evolution and emerging policy issues. National Center for Agricultural Economics and Policy Research (NCAP) Policy Paper 16. New Delhi (India): Indian Council for Agricultural Research (ICAR). 53 p.
- Pandey S, Bhandari H, Hardy B, editors. 2007. *Economic costs of drought and rice farmers' coping mechanisms: a cross-country comparative analysis from Asia*. Los Baños (Philippines): International Rice Research Institute. 203 p.
- Pandey S, Pal S. 2007. Are less-favored environments over-invested? The case of rice research in India. *Food Policy* 32(5-6):606-623.
- Rao CHH. 2000. Watershed development in India: recent experiences and emerging issues. *Econ. Polit. Weekly*, 4 November 2004.

- Rosegrant MW, Cai X, Cline S. 2002. World water and food to 2025: dealing with scarcity. Washington, D.C. (USA): International Food Policy Research Institute and Colombo (Sri Lanka): International Water Management Institute.
- Serraj R. 2005. Genetic and management options to enhance drought resistance and water use efficiency in dryland agriculture. Selected talk. Interdrought-II: coping with drought. The 2nd International Conference on Integrated Approaches to Sustain and Improve Plant Production under Drought Stress. Rome, Italy, 24-28 September 2005. University of Rome La Sapienza, Rome, Italy. Online at www.plantstress.com.
- Shah T. 2001. Wells and welfare in the Ganga basin: public policy and private initiative in eastern Uttar Pradesh, India. Research Report 54. Colombo (Sri Lanka): International Water Management Institute.
- Skees JR, Gober S, Varangis P, Lester R, Kalavakonda V. 2001. Developing rainfall-based index insurance in Morocco. World Bank Policy Research Working Paper 2577. Washington, D.C. (USA): The World Bank.
- Wilhite DA, Glantz MH. 1985. Understanding the drought phenomenon: the role of definitions. *Water Int.* 10:111-120.
- Wilhite DA, Shivakumar MKV, Wood DA, editors. 2000. Early warning systems for drought preparedness and drought management. Proceedings of an expert Group Meeting in Lisbon, Portugal, 5-7 September. Geneva (Switzerland): World Meteorological Organization.

Notes

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