Risk in Agriculture
Proceedings of the Tenth Agriculture Sector Symposium

Dennis Holden, Peter Hazell, and Anthony Pritchard, editors
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FOREWORD

These proceedings are the tenth in a series of records of agricultural symposia presented at the World Bank beginning in 1980. This year's symposium was held January 9 - 10, 1990. The theme, "Risk in Agriculture," directed attention to several key aspects of risk in agricultural development and agricultural policies and how to manage such risk.

The symposium was opened by Barber Conable, president of the World Bank. In his welcoming address, Mr. Conable stated that the challenge facing the Bank's agricultural development effort "is how to bring about greater equity in this sector and how to raise productivity and living conditions among communal farmers, without sacrificing overall agricultural output." He pointed out the following five crucial links between agriculture, rural development, and the Bank's areas of special emphasis: poverty reduction, food security, the environment, forestry, and women in development.

In the first formal presentation of the symposium, John Mellor analyzed risk in agriculture from a macro-economic and low-income consumer perspective. In treating aspects of macro-economic risk in agriculture, he stressed that an agricultural-led growth strategy entails substantial short- and medium-term risks, even though it is the low-risk strategy over the long run.

A paper entitled "Managing Climatic Risk in Agriculture" by J. Ian Stewart used the daily rainfall record from 1905 to 1987 for Niamey, Niger, to develop an illustrative example of a Response Farming program for managing risk associated with variable season rainfall.

The afternoon of the first day of the symposium was devoted to two parallel sessions, each on a different aspect of managing risk in agriculture. The topics examined were: Aspects of Agricultural Research as Aids in Risk Management (J.R. Anderson); Farmer Risk Management Strategies: The Case of the West African Semi-Arid Tropics (P.J. Matlon); Mediterranean Farming Systems and Livestock Management (P.J.M. Cooper and E. Bailey); and Commodity Price Risk Management and Financial Markets (R. Duncan).

The morning of the final day of the symposium was again divided into two parallel sessions. John McIntire's paper, "Managing Risk in African Pastoralism," analyzed policy issues in pastoral systems and noted that pastoral systems have received major investments in pastures, water, and markets in the last 20 years, yet remain poor. Michael Gudger's presentation, "Crop Insurance: Failure of the Public Sector and the Rise of the Private Sector Alternative," pointed out that evidence is accumulating that public sector all-risk crop insurance schemes are a costly failure. The final sessions of the symposium were devoted to discussions of ways of incorporating risk considerations in project design, and to related policy work.

This volume contains papers presented at the opening day plenary session and during the parallel sessions on both days of the symposium. It is designed to be a permanent record to further enhance the knowledge of Bank staff working in agriculture and rural development and as a means of exchanging knowledge with others working in agricultural development, particularly in the area of risk in agriculture.

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OPENING REMARKS

Barber B. Conable

INTRODUCTION

This is the third consecutive year that I have had the honor of addressing the agricultural sector symposium. I would like to begin the session with some of my personal reflections related to my travels in Africa and other nations, where I was able to see first-hand some of the challenges you face in your day-to-day work.

Let me begin by commenting on Madagascar, a country with a population growth rate of over 3 percent annually. If there ever was a classic example of the nexus between rapid population growth, primitive agricultural techniques, damage to the environment, and poverty, Madagascar would be it. I saw upland farmers attempting to eke out a living by planting rice under extremely precarious conditions. Cultivation on steep slopes has contributed to environmental degradation.

Zimbabwe, however, faces a different set of issues in its agricultural sector. Zimbabwe has a small, modern, and efficient commercial farming sector that co-exists with a much larger grouping of poor communal farmers. However, the challenge facing both Zimbabwe and the World Bank is to establish a greater degree of equity in the agricultural sector than currently exists and improve productivity and living conditions among communal farmers, without sacrificing the nation’s overall agricultural output.

These two countries are not isolated cases. In my travels throughout Africa, Latin America, and Asia, I was impressed by the significant number of formidable challenges still remaining before the Bank in agriculture and rural development. Meeting these challenges and ensuring that the agricultural sector will be able to provide the greatest possible contribution to our common struggle against poverty will be a daunting task, but nonetheless a task that is extremely important.

AGENDA FOR THE 1990s

With the new decade now before us, we must maintain a broad perspective in our agricultural development work and seek to integrate our work with that of the entire World Bank development staff. Needless to say, the success of your effort moving forward into this new decade will require a focused agenda encompassing the following critical elements:

• Continued assistance to the countries of Asia, which have fared well during the 1980s in so many ways but which still contain the majority of the world’s absolute poor, including the landless rural poor who are intermittent labor for small-scale agriculture;

Barber B. Conable was president of the World Bank at the time of this address.
• Continued assistance to the highly indebted countries, primarily in Latin America, to help them back on the path to sustained growth. This way they can overcome the high-debt, low-growth downward trend that they have experienced for the past decade. Despite a vibrant private sector in some of these countries, agriculture still must carry a disproportionate burden in the areas of greatest poverty;

• An effort to reverse the economic slide, which has been the lot of much of sub-Saharan Africa. The burden to reverse such a downtrend falls almost exclusively on the agricultural sector;

• New assistance to the emerging market economies of Eastern Europe to help ease their integration into the world economy. The agricultural sector in these nations can be harnessed more efficiently and quickly than their obsolescent and inefficient industrial enterprises; and

• An awareness that there exists a proper balance between economic development and the protection of the environment. Growth achieved at the expense of the environment cannot be sustained and will, over time, exact a terrible price on future generations.

CRUCIAL LINKAGES EXIST

Crucial linkages between the Bank’s agriculture and rural development activities and the Bank’s other areas of special emphasis continue to exist. In this regard, I am referring to the Bank’s emphasis on poverty reduction and food security because most of the world’s desperately poor live in rural areas and are engaged in subsistence agriculture. By advocating policies and financing projects that help farmers to realize fully their economic potential, the World Bank can help improve the quality of life of the poorest in the rural areas.

I am also referring to the Bank’s emphasis on the environment, where environmental protection can only be achieved through the development of agricultural practices that ensure the proper husbanding of natural resources. The challenge in this respect is to build a new set of sustainable values into our daily work. Also, the Bank is placing special emphasis on forestry and is committed to tripling lending in this sector in the coming years.

Finally, the Bank’s continued emphasis on women in development means that the recognition of the role played by women in the developing countries will evolve into an ever-larger element in the agricultural sector during the 1990s. Our policies in the agricultural sector must be designed to take the special needs of women in the developing countries into account.
EMPHASIZING AGRICULTURE IN ECONOMIC DEVELOPMENT
-- IS IT A RISKY BUSINESS?

John W. Mellor

INTRODUCTION

Risk in agriculture is usually examined by agriculturalists from a micro-production economics perspective and includes issues such as the risks faced by individual farmers, the effects of those risks on their production, and how to reduce those risks.

Risk in agriculture also has a macro-economic aspect and a consumer, particularly a low-income consumer, aspect. The latter are the aspects treated in this paper. The following primary principal points are emphasized and will be elaborated in succeeding sections:

- An agriculture-led growth strategy entails large short- and medium-term risks, even though it is the low-risk strategy over the long run;

- Some three-quarters of a billion people in developing countries face the ultimate risk, short of death itself, of falling below an absolute poverty line that provides inadequate income to ensure sufficient calories for an active, healthy life;

- The most effective means of reducing those two risks is to accelerate the agricultural growth rate through technological advances and broad participation in improved rural productivity;

- The second most effective means of reducing those risks requires international agreement to finance food trade -- supplemented by food reserve, supply, and pricing policies in both developed and developing countries; and

- In contrast to the record in the 1950s and 1960s in Asia, the foreign assistance donor community is providing ample rhetoric, but deteriorating leadership, in forwarding these two means of reducing risk to an agriculture-led growth strategy and to poverty reduction.

RISK IN AN AGRICULTURAL-LED GROWTH STRATEGY

Is an agriculture-led growth strategy risky? That would seem a rhetorical question from a long-term exponent of such a strategy, or, an attempt to force a standard statement into the context of a symposium on risk. It is neither.

John W. Mellor was formerly director general of the International Food Policy Research Institute (IFPRI), Washington, D.C.
The inherent risks of an agriculture-led growth strategy are apparent and quantifiable. Perhaps the best way to make that point is by documenting the statistical insignificance of the major acceleration in the agricultural growth rate. In an agriculture-led strategy, a dynamic performance in the basic food sector is growth at half a percentage point more than the population growth rate, or say a 2.5 percent to 3.5 percent growth rate, and for agriculture overall two or three percentage points more than the population growth rate, or say 4 percent to 6 percent overall.

The difference between an agricultural growth rate at these so-called dynamic performance levels and one growing at the population growth rate is of profound economic significance. But such a profound economic difference cannot, within a 10-year period, produce a statistically significant difference. This is because the year-to-year fluctuations in production are large relative to the difference in growth rates. This is not an arcane academic point, but it means there is better than a 30 percent probability that the configuration of weather in a 10-year period will be such as to eliminate the growth that the underlying forces of the strategy would otherwise present. For illustration, in India between 1950 and 1974, while the foodgrain trend growth rate undoubtedly changed by less than half a percentage point, different 10-year periods varied in their growth rates from less than 2 percent to well over 4 percent (Mellor 1976).

While the politician may find this concept difficult to grasp when presented as statistical theory, that same politician has little difficulty in intuitively acting on it. Investment in monuments and steel mills will be able to be photographed in a few years, whereas a bumper crop from investment in agriculture may or may not, depending on the weather.

In addition, the pioneering work of Shakuntala Mehra and Peter Hazell at the International Food Policy Research Institute (IFPRI) has shown that these risks have been increasing in recent decades, with respect to production and even more so for prices. This increased variability is associated with growth accelerating processes (Mehra 1981, Hazell 1982, Anderson and Hazell 1989). The association with improved technology may no doubt be due to certain policies, such as for fertilizer imports or electric supply, but such policies are also a real part of the often imperfect world of development.

Yes, an agriculture-led strategy of development is a risky business. And there is more to come. Accelerated growth in agricultural production benefits the laboring class and the poor, particularly those close to the margin of food sufficiency relatively more than many other groups in society (Mellor and Desai 1986). In poor countries, these groups are large in number, often quiescent politically but liable to massive instability if their expectations are raised and then dashed -- as would happen if an agriculture-led, high-employment strategy proceeded well for a few years and then was cut off by a few years of inclement weather and consequent food shortages.

These risk factors cause governments to, on one hand, be chary of an agriculture-led strategy or the use of food aid to back high-employment oriented development and, on the other hand, to want to control food prices, stocks, and imports. These latter efforts often lead to a diversion of government expenditure inimicable to accelerated rural growth.

In view of the risks involved, why would governments undertake an agriculture-led, high-employment, high-food demand development strategy?

There are basically five alternative reasons. The first one is that a government may recognize that despite the short- and medium-term risks, this strategy gives much higher growth rates than other strategies and may be the only workable strategy. Acceptance of this reason assumes governments are quite sophisticated with respect to judging success, educating the
public, and achieving the complex realities of agricultural growth and its multipliers on overall growth.

Secondly, a government may care about the risks the poor face and opt at least for a strategy that will do the most for the poor over the long run. This assumes a broadly democratic political system as well as some sophistication in understanding the relation between agricultural growth, food prices, and the incidence of poverty.

Thirdly, farm lobbies may push governments toward an agricultural strategy as part of the farmers' effort to promote growth, risk reduction, and a better way of life. That too assumes a broadly democratic political system and sophistication on the part of farmer lobbies.

Fourthly, foreign donors may condition policy toward such a strategy -- in essence, increasing the risks of alternative strategies. The less sophisticated and the less democratic a developing country's government, the more the burden falls on foreign assistance to reduce the relative risks of such a strategy.

Finally, national governments in concert with the international community may devise programs and policies that transfer a portion of the risks inherent in an agriculture-led strategy from the developing country to the larger community. Succeeding sections will address each of these issues.

THE RISK OF POVERTY AND ITS RELATION TO AGRICULTURAL GROWTH

While an agriculture-led growth strategy entails substantial risks, its success greatly reduces one of the most onerous risks humans face -- the risk of dropping below an income line that is inadequate in providing sufficient calories for an active, healthy life. Already, about three-quarters of a billion people fall below such a line, and many more are just above that line and at risk of falling below it. The nominal income of these poor, at-risk people is largely dependent on work closely related to agricultural production. The value of their income is largely determined by the price of food. In India, over the past two decades, the proportion of the rural population falling below the poverty line fluctuated between 40 percent and 60 percent, with changes in per capita agricultural production and food prices explaining the bulk of the fluctuations (Mellor and Desai 1986).

Once we accept Amartya Sen's well-argued position that in poor countries it is absolute poverty that drives equity concerns, not the broad distribution of income, the equity issue is converted into issues of risk and development strategy. For people so close to the margin, risk is an ever-present monstrosity, and the kind of risk that arises from weather and works through agricultural production and prices. Its reduction is most determined by the choice of development strategy. Once we understand those relationships, we elevate and broaden the issue of risk. In this context, there are three basic means of reducing the critical sources of risk to poor people.

The first, and by far the most important means of reducing sources of risk to the mass of poor people, is to raise their incomes well above a defined absolute poverty line. Obviously, with a given amount of variance in income and even with substantial increase in that variance, the probabilities of falling below the absolute poverty line decrease as the average income is raised. An agriculture-led strategy has a high employment content and relatively low food prices -- key elements in poverty reduction. Note that in the four Indian states with the highest growth rates in agriculture, the proportion of rural people falling below the poverty line dropped in half, on a consistent basis, in a two-decade period (Dev 1988).
The second means of reducing risk in this context is to diversify the sources of income -- first, away from agriculture to sectors less dependent on the weather, and second, within agriculture to commodities and production means less adversely affected by weather. Such diversification requires generally higher incomes to provide markets for these more labor-intensive, high-income elastic commodities. As documented below, accelerated agricultural growth accelerates such diversification.

The third means of risk reduction is to abandon intensive, arable agriculture in those areas within which the risks of falling below the poverty line are the greatest. These tend to be the relatively arid areas where population densities are low, incomes average close to the poverty line, and there is a high degree of variability in the weather and thus in production. This requires raising income and opportunities outside agriculture and increased commercialization of agriculture in more favorable areas. Such processes of specialization and intensification are strategies capable of reducing poverty and risk.

RISK REDUCTION THROUGH AGRICULTURAL GROWTH

The three means by which risk to the poor can be reduced also represent the basic means by which agricultural growth itself gradually reduces the risks inherent in an agriculture-led strategy. There are three conundrums in this:

- Accelerated agricultural sector growth hastens decline in the relative size of agriculture (by fostering more rapid growth in the nonagricultural sector).

- Concentration of public investment in agriculture accelerates the diversification of the agriculture sector itself, as well as of the economy totally, and

- Investment in agriculture contributes to the withdrawal from agriculture of the most risky activities, particularly from a poverty risk point of view, with very favorable environmental effects as well.

Accelerated Growth

Agriculture is itself an innately slow-growing sector with one-half to two-thirds the growth rate of other sectors. Its contribution to accelerated overall growth comes from the large initial size of the agricultural sector and from the powerful stimulus it provides to the growth of other sectors. The theory of this is clear (Mellor 1976). Accelerated growth in agriculture generates net additions to national income, the expenditure of which stimulates relatively labor-intensive and typically rural-based nonagricultural activities. Those activities in turn, through the consumption expenditure of the laboring classes which is strongly food-oriented, further stimulate agricultural growth.

We can document this relation very roughly from Asian national cross-section data. With four extreme outliers removed, each percent increase in the rate of agricultural production growth is associated with a 1.5 percent additional to the growth rate of the nonagricultural sector (Figure 1). The R2 for these nine observations is 0.92. The four outliers demonstrate that these relations are not inevitable, rather they depend on appropriate policy. The Philippines and Burma did well in agriculture but had highly unfavorable policies toward nonagricultural growth; Singapore and the Republic of Korea each did very well in nonagriculture, but either lacked a significant agricultural sector or followed ineffective policies toward agriculture.
It is notable that in Africa and Latin America, where national policies favorable to growth have been rare in the past decade, there is little discernible relation between growth in the two sectors. In general, growth in one sector seems to have been a random and isolated event with no impact on the other sector. That is not surprising given the macro and sectoral policy environment.

In an analogous exercise, if we array countries first by the rate of agricultural growth per capita and then by the rate of nonagricultural growth per capita (in each case using *World Development Report* data) and divide each array into a top half and a bottom half, grouping countries into the four classes of (1) high growth rates in both agriculture and nonagriculture, (2) low in both, (3) high on agriculture, low on nonagriculture, and (4) low on agriculture, high on nonagriculture, we find that over twice as many countries fall in the high-high and low-low categories as in the mixed categories of high-low and low-high.

**Accelerated Diversification**

The second conundrum is that concentration of public investment in agriculture tends to accelerate diversification within agriculture as well as in the economy generally. The preceding evidence showing that when agriculture grows fast then the nonagriculture sector grows at an even faster rate is consistent with that observation.

One of the major findings of a World Bank study reported to this same symposium last year was that countries that emphasized their agricultural comparative advantages -- which are typically areas in which they are already substantially specialized within agriculture -- were the countries that diversified most rapidly, not only in agriculture generally but their total economy as well (Lele 1989). For example, in Kenya, which had policies that accelerated growth in smallholder tea and coffee production, the rest of the agricultural sector also grew rapidly and agriculture declined as a percentage of gross national product. Tanzania emphasized capital intensive industry, but it was there that the relative size of agriculture grew, not in Kenya.

Risk reduction through diversification occurs in substantial part because rising incomes cause greatly diversified consumption patterns. Livestock and horticultural products are particularly important because they are labor intensive. Note the rapid growth of small-scale dairy farming in Kenya. Grasping these opportunities requires large investments in rural infrastructure, production technology, and marketing.

**Retreat from High Risk Agricultural Activities**

The greatest risks to family welfare in agriculture are centered in the rural areas, which specialize in annual food crops but which are marginal to the production of those commodities. It is poverty and even worse alternatives which bring about such production emphasis. Such strategies are doubly risky because they are often unsustainable environmentally. In such marginal areas, fluctuations in weather and production are around the critical margin of “profitability,” which in the case of poor countries and people means at the margin of existence.

Agricultural growth has two effects which reduce the extent of such risk. First, by raising incomes and the opportunity to earn higher incomes, agricultural growth makes the farming of high-risk, low-income land unnecessary and undesirable. That land can then be returned to activities that are less intensive and less risky. Second, by broadening consumption patterns and market access, it allows a fine tuning of production to more nearly optimal conditions for production that raises incomes above the margin and will tend to reduce variance. I will return to this point in greater detail below.
As long as farming is a low-income subsistence occupation, consumption patterns will emphasize a small number of commodities which more or less maximize calorie production, and the market for any commodity will be delineated by the local region. The development process allows production of large surpluses of certain commodities, which may not be consumed heavily in the local area but which are best suited to the particular land base. Comparative advantage is, of course, a function of the demand structure as well as a function of the underlying physical resources. Thus, rising incomes, expanding nonfarm job opportunities, increasing demand for livestock and commodities, and improving infrastructure allow semi-arid areas to move out of arable agriculture and into perennial grasses. That not only raises incomes but also reduces the variance in production. The same can be said for the risks in tree crop production as compared to annual crops in the humid low-land tropics and in steeply sloping mountainous areas. These shifts in production patterns are, of course, critical environmental improvements as well. Some environmentalists prefer not to mix environmental objectives with poverty reduction and growth objectives, and as a result they lose focus on the most important means of environmental enhancement.

The Process of Agricultural Growth

How can agriculture be induced to grow in a manner which will reduce risk and increase human well-being? For purposes of this discussion, we need only to outline enough to understand the role of government, the importance of technology, and the immensity of the investment requirements. Simplification of the process focuses on the following three requisites:

- Rapid cost-decreasing technological change in agriculture, which adds substantially to net national income; massive expansion of the physical infrastructure so that the bulk of the agricultural areas can enter into commercial trading and specialization processes with low transaction costs; and widespread participation in a constantly expanding educational system.

- Such a broad activation of the agricultural sector through technological change provides the income and demand structure which will transform the economy gradually into one which is less and less agricultural. Also, such processes will raise real incomes for labor so that people will not have to remain in insecure, low-productivity agricultural activities where the risks of falling below the poverty line are high.

- Technological change in agriculture is complex and requires a wide-ranging institutional structure. Foreign assistance is absolutely vital if such an institutional structure is to be built in a 10- to 20-year time horizon instead of the 60 or so years typical of today's developed countries. Also, the task is never complete because research and other institutions are always expanding to cover increasingly complex issues and a wider range of commodities. The quality of foreign assistance to those critical tasks is deteriorating at an accelerating rate, and this is a major reason why the rate of return on foreign assistance to low-income countries is now abysmally low and dropping.

Rural roads and other rural infrastructure as they currently stand are inadequate for modernizing agriculture, and they will require massive investment. Such investment will have profound implications for national political systems. Because agriculture grows relatively slowly, its impact on overall growth rates depends on mass participation in the growth process. In low-income countries only 10 percent to 30 percent of rural areas are covered by infrastructure minimal to supporting a growing, commercializing agriculture, which means that only a small fraction of the agricultural production potential is capable of being utilized. Providing an upgraded infrastructure requires decentralization of the political systems, which will in turn require aid policy
conditioning given the entrenched, centralized systems with which most contemporary developing countries have established. Effective aid policy conditioning in turn requires resources and sectoral policy expertise.

Rural infrastructure development requires special emphasis in the context of risk reduction, because it not only contributes to overall growth -- and hence reduction of risk -- but because it is critical to food security. A sound infrastructure means that food can be brought in during times of bad weather, and it supports a high degree of commercialization, which means that farmers can utilize purchased inputs, rely more upon irrigation, and follow other practices that are risk reducing. Note in particular the close relation between the development of rural infrastructure and the expansion of small-scale tubewell irrigation in Bangladesh (Ahmed and Hossain 1990).

The third leg of risk-reducing agricultural growth is education. Like infrastructure, it is expensive, must be widespread (i.e., be of universal access), and is greatly underrated in importance by development professionals (but not, of course, by ordinary rural people). This is because in part the way education works is ill-understood, it is costly, and there still exist elitist views on the part of urban policymakers. On the latter, note that the urban elite give little emphasis to rural secondary education -- a mistake rural people do not make. Education accrues higher returns and becomes increasingly important to risk reduction as technology advances. In particular, wide participation in education reduces risk. For example, with education farmers can understand the complex processes of fertilizer placement and timing which allow fertilizer to play an increasingly large role in sub-humid and semi-arid areas, lifting incomes, and reducing the variance of production (see the forthcoming work from the IFPRI by Richard Sabot and Amit Ray on these points about education) through better root structure of plants. Increased fertilizer use may increase the variance of production when farmers have low levels of education, and hence of technological application decisions.

Farmer Lobbies, Agricultural Growth, and Risk

The political processes of developing countries tend to be inimicable to the basic decentralization of government and growth of nongovernmental institutions, which are so essential to a broad-based agricultural growth strategy.

Developing countries, in general, come from a tradition of colonialism which was inimicable to the development of decentralized democratic governments and were led to independence by freedom movements which were generally urban-based. Taiwan was an exception to the former because its imperial power was oriented to developing the small farmers' food sector; it was rice exports which Japan particularly wished to extract. Kenya's rural-based independence movement was an exception to the latter. Thus, agricultural growth depends on massive investment in rural physical infrastructure and rural education, which is not only difficult to make and maintain without decentralization of government but is difficult to finance as well. Similarly, complex rural development institutions must be tuned to the highly varying conditions of diverse regions.

Nevertheless, even for those countries initially urban-based, as low-income nations democratize the rural people will increase their political clout. From this inevitably arises farmer lobbies in one form or another. In this context, how do farmer lobbies help control risks in agricultural development?

There are two courses of action that the farm lobbies may take: They may seek to obtain higher prices through subsidies on inputs and outputs, or they may seek to obtain critical public sector investments in technology, infrastructure, and education. Although the former action
is more noted, the latter action is probably more important. Kenya, Cote d'Ivoire, Punjab, and Taiwan all stand out in that respect.

RISK REDUCTION THROUGH FOOD TRADE, STOCKING, AND PRICING POLICY

Agricultural development is a risky business as a strategy. Life for the poor living in low-income countries is inevitably highly dependent on agriculture and hence is necessarily risky. Aside from the longer-term processes of accelerated agricultural growth, is there anything we can do to reduce these risks in the short run? The answer is yes, and it has to do with food trade, developing countries' domestic stocks, and developed countries' production and pricing policies.

In case of analyzing modern transportation costs, which do not yet prevail in much of interior Africa, it is generally cheaper to deal with local production fluctuations by transporting food from distant locations (Valdes 1981, Pinckney 1988/1989, McIntyre 1981). This, however, is also a potentially risky solution for low-income countries with poor access to credit. These are precisely the circumstances for which the International Monetary Fund's cereal facility was designed -- to lend to the poor countries experiencing sudden increases in their food imports (Adams 1983).

Unfortunately, the IMF facility was not initially developed with a sufficiently clear view of the special nature of food in development and of the poor, and it was consequently initially hemmed in with restrictions to its use, which increased over time leading eventually to a moribund facility (Ezekiel 1985). Clearly the failure of this facility is the single most important international policy change detrimental to the poor of the past decade or two, and structural adjustment has been a necessary long-term policy requisite. The cereal facility could have blunted the impact of structural adjustment on the poor, while at the same time it could have helped to reduce risks faced by the poor generally and to an agricultural-led strategy specifically.

However, even a cereal import finance facility cannot do the job of risk reduction without positive and supporting domestic policies in developing and developed countries. Developing countries need national stocking policies to take care of food needs in times of adversities, i.e., for the period between the onset of adversity to the arrival of foreign supplies, which will often be several months. Countries isolated by poor transportation links may need stocks to meet their entire emergency needs, but they should concurrently be working to improve those transport links. Developed countries need to orient their domestic production policies toward a responsible position as supplier, thus quickly relaxing output restrictions in years of bad weather.

Domestic risk-reducing policies require careful, sophisticated analysis of food supply demand, stocking, and trade relations all in the context of a well-articulated national price policy. Foreign assistance has a major opportunity to build those analytical capacities within sound institutional structures. In these days, when we question public interference in market operations, the justification for interference in food price policy, however, is dramatic.

In low-income countries facing a given decline in food supplies, the bottom 20 percent of the income distribution class makes ten times as much reduction in per capita consumption of food as the top 5 percent (Mellor 1978). That aspect of market equation of supply and demand is morally unacceptable to most people. It is a problem no longer faced in developed countries, and it thus tends not to be fully understood.
FOREIGN AID, AGRICULTURAL GROWTH, AND RISK

Given that the most important technique of risk reduction in agricultural growth is to succeed rapidly, foreign assistance has a critical role. Foreign aid in Asia in the 1950s and 1960s clearly emphasized macro, sectoral, and subsectoral policies favorable to agriculture, as demonstrated by its dramatic results. This has been less true in the 1970s and 1980s, particularly in Africa. What are the reasons, and what are the implications to agriculture and risk? And why is it that currently the foreign assistance donor community seems to be turning so much away from an agricultural development strategy so important to growth, environmental enhancement, poverty reduction, and reduction of risk of people falling into poverty?

I see the answer to these questions in the following three sets of forces:

First, in general, the foreign assistance donor communities have large agricultural sectors which played a major role in the early stages of their own development. These sectors are still increasing productivity relatively rapidly through technological change at a time when the domestic demand is growing hardly at all because of the relatively high levels of income and the low propensity for people at higher income levels to spend incremental income on increasing food consumption. Resources are being removed from the agriculture sector of developed countries at a politically and economically uncomfortable speed. Growing agricultural exports reduce the required speed of adjustment.

In this context, it is natural although false to see agricultural development in developing countries as competitive with their own agricultural sector and as a solution to their own agricultural adjustment problems. There is now clear documentation that in fact accelerated agricultural growth of poor countries increases their food imports (Bachman and Paulino 1979, Houck 1986, Kellogg 1988, Mellor 1989, de Janvry and Sadoulet 1988). It is unfortunate that a widespread aversion to food aid has stood in the way of finding a political solution to this complex problem.

Second, we have seen, particularly in the United States but in other countries with foreign assistance agencies as well, a rapid rise of generalists and a decline of technical specialists both in numbers and influence. This change has been both the result of and the cause of faddism in foreign assistance and emphasis on the short-run (or discounted) rate of return. Emphasis on internal rate of return concurrent with high world interest rates militates against activities which provide a return more than five or at most 10 years in the future.

However, agricultural development is dependent on long-term investments in building complex institutions for agricultural research systems, rural infrastructure, and education. At present and of much greater impact, however, is the rapid progression of foreign assistance fads, which have made technical people (with their allegiance to a discipline) inconvenient, at the same time the rise to influence of the generalists makes for quick and ready adaptation to those same fads. In fact, development of agriculture has been fully consistent with each of the half dozen fads that have swept the foreign assistance community over the past two decades. However, the loss of technical capacity has resulted in poorer performance in the agricultural sector on the one hand, while on the other hand technical people have been slow to adopt the rhetoric so essential to carrying the faddists. The result has been a decline in the quality of assistance to agriculture -- a decline which has hit the African countries particularly hard.

The third factor, now just coming into prominence and which is turning attention away from agriculture, is current projections of urban populations and, in particular, projections of concentration of populations in a few major cities in each country. The conclusion that is being
increasingly drawn is that foreign aid of the future must shift to greater emphasis on urbanization and processes that support urbanization.

Just as it is unnatural (but correct) to think that accelerating agricultural growth is critical to the processes which will result in developing countries increasing their imports of agricultural commodities, so it seems unnatural to think that emphasis on agriculture will accelerate growth of urban areas in a healthy, diffused, and structural context. The rise of massive megalopolises is associated with lack of broad-based agricultural growth. Conversely, a broad-based agricultural growth process leads to the development of large numbers of small urban growth centers which, as indicated above, eventually take on a life of their own and lead to accelerated urbanization, one that is a much more dispersed pattern of urbanization which is less expensive and economically healthier.

In this context, a paper of mine published in 1986 titled, "Agriculture on the Road to Industrialization," might more properly be retitled, "Agriculture on the Road to Urbanization." We need to ask why are modern developing countries spawning Mexico City-like urban areas in such sharp contrast to the early pattern in Japan, Taiwan, Western Europe, and North America?

In this section, I imply a comparative advantage of foreign aid in facilitating agricultural growth. Why is that so? Perhaps, most importantly, agricultural growth is particularly dependent on public sector activities -- research, extension, rural credit institutions, roads, education, and so on. Developed countries have large experience and stocks of trained people in these activities. Foreign aid is by definition a public sector activity. One of the consequent problems has been its tendency to inflate the public sector in areas of low priority. Emphasizing agriculture can more easily avoid that problem. Also important is the fact that developed countries have a wealth of experience in developing institutions to support a broad-based, politically active small farm population. The capacity for such activities has generally become under-utilized with the rapid decline of the number of farmers and the geographic area in agriculture. However, they can still be mobilized for foreign assistance.

CONCLUSION

While the success of an agriculture-led development strategy greatly reduces the risks of the population falling below an absolute poverty line, the risks inherent in the strategy itself reduce its probability of acceptance.

Foreign assistance can greatly reduce those latter risks by accelerating agricultural growth with well-thought-out projects for developing the institutions for agricultural technology advances and for improvements in rural infrastructure and education; by finding means to redevelop a high level of intellectual integrity and competence for technical functions; by encouraging policy decisions that decentralize political and administrative systems essential to agricultural growth; by treating the surplus food production capacity of developed countries as a resource that can reduce risk of poor people and back increased employment particularly to foster rural roads and schools; and by rehabilitating and improving the International Monetary Fund's cereal facility to reduce the risk on agriculture-led, high-employment development strategy.

All of these actions require a sophisticated understanding of the favorable effects of broad-based rural development on overall growth rates, employment, poverty reduction, and environmental enhancement. The preceding analysis of the benefits and risks of emphasizing agriculture can be turned around into the following statement of what growth looks like when the agricultural sector is largely left out:
Growth will be relatively slow; urbanization will be concentrated in a few megalopolises; massive environmental degradation will continue at the margin both in the humid and semi-arid tropics; the level of absolute poverty will grow (hence increasing the risk of falling under the poverty line); and the trade component in the growth process will remain at a low level.

**Figure 1.** Growth rates of per capita GDP agriculture and nonagriculture, various Asian countries and years, 1960-1986.


Note: Constant 1980 price GDP at market prices in local economy.

Descriptive variables for simple fit, excluding Burma, the Philippines, South Korea, and Singapore are:

1. R-Square, 0.92.
2. Value of coefficient of agriculture growth rate, 1.56.
4. Standard error of agriculture growth rate, 0.17.
REFERENCES


MANAGING CLIMATIC RISK IN AGRICULTURE

J. Ian Stewart

ABSTRACT

The 1905-87 daily rainfall record for Niamey, Niger, is used to develop an illustrative example of a Response Farming program for managing risk associated with variable season rainfall. Onset relations, i.e., relations between season rainfall parameters (amount, duration, etc) and dates of onset defined for cropping purposes, reveal four distinct periods of rainfall behavior in the record.

The 1905-17 (partial) period was the poorest, with median total season water (TSW) of 315 mm (12.4 in). Total system water (TSW) in the next 30 years (1918-47) shifted upward to 460 mm (18.1 in), then upward further over the next 20 years (1948-67) to 527 mm (20.7 in). A strong downward shift in 1968 began the current period with TSW of 369 mm (14.5 in). It is concluded that the current period record should be the basis for generating farm level cropping strategies and recommendations.

Seasonal risks from rainy period duration, rainfall amount, and the need each season to match soil fertility and plant population to rainfall duration and amount, are assessed in that order. Decisions are that one should select an 80-day maturity millet to grow in early onset seasons (onset before July 14), and a 60-day millet in late seasons. Early seasons, with a 67 percent probability of enough rain to produce for market, should be planted with a high seed rate and low fertilizer rate. If, at germination plus 30 days, the season water supply is 150 mm (~6 in) or more, additional N fertilizer should be added. If less than 150 mm, the plant population should be thinned. All late seasons should be planted with low seed and fertilizer rates for subsistence production. This strategy would have matched fertility and plant population to yield potential in 19 of 20 years.

The reader is cautioned that this paper is an example showing the method of developing a Response Farming program, and the guidance criteria and procedures developed are not intended as recommendations to be transmitted to farmers. Farmer recommendations require more input of localized agronomic information than is utilized in this example.

INTRODUCTION

When his young friend indicated he wanted to avoid trouble, Zorba the Greek said, "life is trouble." We may also say agriculture is risk. But we can lessen the risk and reduce threatened consequences by making enlightened management decisions, based on study of the more critical risk factors and the effects of different management decisions.

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The most damaging climatic risk factor, at least in much of the developing world, is seasonal rainfall variability, which unfortunately is usually greater in zones of lesser mean annual rainfall. That this represents one of the more pervasive challenges to success in development efforts is evident when one reads development project papers. It is not unusual to find a statement in the introductory section to the effect that the greatest constraint to production in the project area is low and variable rainfall. What is unusual is to find any action proposed in the project to gain deeper understanding of the rainfall behavior in order to provide farmers and their advisors with guidance as to how best to meet the situation.

It appears there is broad agreement that we have no means of coping with rainfall variability -- neither control nor prediction. Control no, but prediction is another matter. The purpose of this paper is to stimulate study of rainfall in agriculture and application of the findings in development projects. There is something lacking in policy which states that variable rainfall is the chief constraint, then proceeds to put money into studies of genetics, soils, agronomy, pathology, entomology, economics, social factors, and other aspects of the problem, but little or none to study its root. We really should be more optimistic and venturesome than that.

Rainfall studies to assist agriculture must focus on real problems at the farm or even the individual field level. Problems requiring attention are those for which management decisions make an important difference in the outcome, either for better or worse, depending on how the action taken relates to actual rainfall conditions in that particular season.

Risk posed by variation in rainfall is not related to a single phenomenon, e.g., whether or not rainfall is adequate. Each field level problem which calls for a management decision must be looked at separately. In doing this we find the risks underlying different decisions are emanating from several different aspects of rainfall behavior. When these behavioral factors are studied separately, we find that, with respect to certain management decisions, medium- to long-term policy can be set which will minimize, or in some instances, virtually eliminate those particular risks. Remaining risk factors may be addressed by a flexible plan of action on a season-by-season basis. An "A" versus "B" operational strategy, triggered by early rainfall events, can match key aspects of crop management, e.g., soil fertility and plant population, to actual crop yield potential established by rainfall.

To expand on the above and clarify it, an example will be developed for Niamey, the capital of Niger, representative of much of the semiarid area of the Sahelian zone of West Africa. Over the past two decades the Sahel has been the most troubled part of the world in terms of maintaining satisfactory food production levels in the face of recurring drought and swelling populations. A recent publication covering these and related topics recognizes variable rainfall and low soil fertility as fundamental environmental features influencing development in this area (World Bank 1985).

**Periodicity in Rainfall**

The Niamey rainfall record to be analyzed and discussed covers the 83-year period from 1905-1987 inclusive. It is a daily record missing only the years 1911 and 1920. Data were graciously provided by Drs. E.T. Kanemasu and M.V.K. Sivakumar, respectively, of Kansas State University (presently with the University of Georgia) and ICRISAT’s Niamey Center. Rain in this area is monsoonal, associated with the system which serves most of sub-saharan Africa and the Indian Ocean region. Virtually all rainfall is concentrated in the months May through October as shown in Figure 1.
Figure 1 shows long term (1905-1987) mean monthly rainfall amounts through the potential cropping season at Niamey. The units of measurement are millimeters (mm) and readers are reminded that 25 mm is close to 1 inch, thus, for example, 100 mm equals 4 inches. The figure shows that the rains become greater each month from May, peaking in August, then decline markedly in September and almost disappear in October. The long-term mean for the 6-month period is 541 mm (21.3 in).

Figure 2 is similar to Figure 1, but it divides the 83-year record into four periods which have different monthly and 6-month mean rainfall amounts. The first period, ending in 1917, had a relatively low 6-month mean of 470 mm (18.5 in), similar to the present period which began in 1968 and through 1987 had a 6-month mean of 475 mm (18.7 in). Rainfall remains low today but data after 1987 are not presently in hand. The 50 years from 1918 to 1967 comprise two much wetter periods with a mean of 575 mm (22.6 in) in the 30 years from 1918 to 1947, rising to 602 mm (23.7 in) in the 20 years from 1948 to 1967. Farmer (1989) shows clearly that similar patterns of change in rainfall amount have taken place throughout the Sahelian zone in this century. As we proceed it will be shown that these four periods do not differ simply in rainfall amount, but in several aspects of rainfall behavior. In other words, a number of rainfall attributes change at once, and some of these are important to crop performance and crop management.

Figure 3, like Figure 1, treats the 83-year record as a whole, ignoring differences between time periods indicated in Figure 2. Figure 3 is a simple scatter diagram in which each symbol represents what actually took place in one of the years from 1905 to 1987. However, the data in Figure 3 result from a specialized analysis which estimates for each year the date on which germination of a crop should have occurred, the amount of water stored in the soil from pre-season rains as of the germination date, and the rainfall of consequence for cropping over the succeeding 100 days. The horizontal axis (independent variable) shows the Julian date of crop germination. Note that Julian dates number from January 1 (Day 1) on through the year to Dec 31 (Day 365). Therefore the scale in Figure 3 runs from June 9 (Day 160) through August 28 (Day 240). The vertical axis (dependent variable) shows total season water, i.e., the total of newly stored soil water at germination plus rainfall in the 100-day designated crop season.

Assumptions in the analysis are (1) the farmer waits until 20 mm (0.8 in) of water are collected in the soil before planting, and, in any case will not plant before June 12 (Julian date 163), (2) rainfall loss to runoff in the initial soil water collection period is zero, but normal evaporation takes place, (3) the planting operation takes just three days, whether or not it rains on those days, (4) germination occurs on the first date following planting when accumulated soil water again equals 20 mm or more, and (5) all rainfall in the 100 days following germination is of consequence to the crop until the average daily rainfall intensity in the latter portion of the season falls below 1.0 mm/day. Rains thereafter are not counted. The soil in this and all succeeding analyses is assumed to be sandy, deep and well-drained.

Figure 3 resembles what I have previously termed a "rainfall flag" (Stewart 1988, Figure 12), which results from connecting the outermost data points in the scatter. This has the effect of delineating the boundaries in terms of earliest and latest germination dates, and highest and lowest amounts of total season water applicable on any given germination date. If we imagine the vertical axis is the "flagpole," then the flag droops away from it to the right. In simple terms, rainfall seasons which start earlier in the year tend to produce greater amounts of rain than later starting seasons.

The practical significance of the phenomenon illustrated in Figure 3 is that the historical range of rainfall amounts in seasons beginning on any given date of onset is much narrower than the total historical range -- thus, for the season in question, reducing the
probabilities of many past occurrences to zero -- and actual probabilities within the remaining range of possibilities for that onset date are much different than for the record as a whole.

Figures 4 to 11 are scatter diagrams similar in kind to Figure 3, but intended to expand on the subject of rainfall behavior periods introduced in Figure 2. The potential importance of rainfall periodicity for improvement of seasonal rainfall prediction has been alluded to in earlier publications (Stewart 1988, 1989) but the example to be developed here goes much further in showing the nature of the periods and, quantitatively, how recognition of rainfall periods can boost our predictive capability.

Figures 4 to 9 have the same scales on the axes as Figure 3, so that changes in the rainfall flags from one period to the next will be clear. Figure 4 shows the scatter diagram and resulting flag for the earliest period which ended in 1917. The first thing one sees is that the correlation between total season water (TSW) and germination date (GD) is much greater than in Figure 3 which combines all periods into a single record. The upper and lower boundaries of the flag are much closer together, such that a relatively small range in possible TSW needs to be considered at any given germination date. The flag in Figure 4 appears to cut right through the middle of the 83-year flag (Figure 3) but in fact there is a great behavioral change in terms of actual germ dates. In the 83-year record, only six years had germ dates as late as August, and fully five of the six were in the short period 1905-17. Further, five more years in this short period had germ dates in July, while only two years were in June. Overall though, 40 of 81 years began in June (Figure 3). Figure 2 shows why onset/germ dates in the 1905-17 period were late. Rainfall in May, June and July was less in this period than in any subsequent period.

In the 30 years from 1918 through 1947 the situation was very different. May and June rains reached the highest levels in the entire record, and rain also increased in all other months except October. The result is seen in Figure 5 which shows 21 of 29 years with germ dates in June, eight others in early to mid-July, and none after July 22. The vertical scale is not tightly compressed, but still provides considerably better prediction than the combined record (Figure 3). The generally higher rainfall in this pattern offers much less risk than in the first period (Figure 4), hence less need for a sharp prediction to guide farm management.

Rainfall behavior in the succeeding 20 years (1948-67) is shown in Figure 6. Figure 2 shows that May and June rains decreased somewhat, but July, August, and September rains strengthened to reach new heights. This resulted in somewhat later onset/germ dates than in the 1918-47 period but much earlier than the 1905-17 period. Season water amounts associated with given germ dates were in the upper portion of the overall range (compare to Figure 3).

In 1968 mean seasonal rainfall amount once again plunged downward, nearly to the level of the 1905-17 period, but with one major difference -- May and June rains are slightly better and July rains are much better. August rains, on the other hand, are much weaker. The result, seen in Figure 7, is relatively early germination dates, but with TSW values in the lower part of the overall range due largely to weakness in August rains.

The contrast between the most recent period (1948-67) and the present period is easily seen in Figure 8 in which both "flags" are displayed together. Each flag contains data for 20 years. Fully 12 years or 60 percent of all years in the earlier pattern are above the best in the present pattern. Conversely, six years (30 percent) of the present pattern fall below the lower boundary of the earlier pattern, and the rest are all in the lower portion of the former pattern.

There are other attributes of rainfall behavior of importance to farm management decision-making, and a key one of these is the duration of the rainy period. Like TSW, it is
correlated with season’s start, i.e. the germ date in our example. Sivakumar (1988) develops considerable information on rainfall duration versus onset dates in the Sahelian-Sudanian Zones. The germ date relationship with duration shows behavioral differences in each of the four time periods discussed above, but the differences are less striking than those in TSW. Figure 9 compares the duration behavior patterns of the 1948-67 period and the current period. The horizontal axis of germ dates in Figure 9 is the same as in Figure 8, while the vertical axis displays the number of days the rains persisted in each cropping season.

Joining the outermost data points to form rainfall duration flags shows that, on average, there is some reduction in the persistence of the rains in the current period. In addition to periodic changes in season duration and TSW, a number of other relevant rainfall parameters have changed in meaningful ways from period to period. These may be seen in Table 1.

Table 1 begins with the dates of the rainfall behavior periods in the 83-year record from 1905-1987. However, only the middle two periods lasting 30 years and 20 years respectively are known to be complete. The table shows median values of eight agriculturally relevant rainfall parameters in the rainfall behavior periods. All show important changes from period-to-period changes sufficient in many instances to force farmers to change crop types and varieties grown and levels of inputs as well as husbandry practices in the field.

The change in rainfall behavior in 1968 was drastic. In the 20 succeeding years (1968-87) only one (1969) provided a total water supply for the 100-day cropping season as great as the median of the 1948-67 period. And, in only one cropping season (1977) did the average rain per rain-day exceed the 1948-67 median. The compounding effects of the 1968 changes on cropping may be seen in columns 8 and 9. Whereas gross May-October rain in the present period is down 21 percent (not shown), TSW declined 30 percent (Column 8). Column 9 shows TSW as a percentage of May-October rain.

In all four periods the percentage increases as May-October rain increases and declines when it lessens. Other changes in the present period are (1) a lessening of season duration, (2) fewer and less frequent rainy days, and (3) considerably less rain per rainy day on average. Day (1989) points out that current crop breeding programs are emphasizing short-cycle varieties. If further research results in greater predictability of periodic changes in rainfall behavior, breeders and other agricultural researchers may be enabled to respond in timely fashion.

This initial technical section of the paper presents evidence for the following:

- Informative relationships of use to agricultural advisors can be found between relevant rainfall parameters and the time of the start of the rainfall season for cropping purposes, i.e., date of onset and/or germination.

- Rainfall behavior at Niamey since 1905 has been episodic, remaining fixed within relatively narrow ranges for substantial periods of time, of the order of 20 or 30 years, then shifting abruptly into different behavior patterns. The different patterns and the years when shifts have occurred are identifiable in patterns of onset relations.

- The patterns of onset relations operating in the current period provide improved predictions of seasonal rainfall expectations, therefore improved cropping strategies and specific recommendations to assist farmers in decision-making. The next section on response farming illustrates how this might work in the area of Niamey.
TABLE 1. Niamey, Niger: Analysis of 1905-1987 rainfall record to determine agriculturally relevant characteristics in each of four distinct rainfall behavior periods.

<table>
<thead>
<tr>
<th>Rain Period</th>
<th>Years</th>
<th>Germ Dates</th>
<th>Duration of Rainy Period</th>
<th>Rainy Days</th>
<th>Frequency of Rainy Days</th>
<th>Average Rainy Day</th>
<th>Total Rain Season Water</th>
<th>TSW/ Rain</th>
</tr>
</thead>
<tbody>
<tr>
<td>1905-17</td>
<td>13</td>
<td>07-27</td>
<td>65</td>
<td>19</td>
<td>3.4</td>
<td>15.0</td>
<td>315</td>
<td>67</td>
</tr>
<tr>
<td>1918-47</td>
<td>30</td>
<td>06-26</td>
<td>90</td>
<td>30</td>
<td>3.0</td>
<td>14.2</td>
<td>460</td>
<td>80</td>
</tr>
<tr>
<td>1948-67</td>
<td>20</td>
<td>07-01</td>
<td>81</td>
<td>36</td>
<td>2.3</td>
<td>13.6</td>
<td>527</td>
<td>87</td>
</tr>
<tr>
<td>1968-87</td>
<td>20</td>
<td>07-04</td>
<td>79</td>
<td>31</td>
<td>2.6</td>
<td>10.8</td>
<td>369</td>
<td>78</td>
</tr>
</tbody>
</table>

Analytical conditions, definitions and assumptions:

- The season considered is that for a 100-day maturity crop.
- Planting is done over the 3-day period immediately following onset of the rainy season, without regard to rainfall amounts on those days.
- Onset date is defined as the first date from June 12 onward when stored soil water from the new rains accumulates to a total of 20 mm or more.
- During the accumulation of soil water for onset, losses to runoff are assumed zero, but losses to normal evaporation are counted.
- Germination date follows the 3-day planting period. The first date when accumulated soil water again totals 20 mm or more.
- The 100-day crop season begins with the germination date.
- The "duration" of the rainy period begins the day following the germ date and ends on the final rain date, defined as the last date in the crop season on which that day's rainfall amount is sufficient to raise average wetness in the preceding dry (or nearly dry) days to 1.0 mm/day or greater.
- The number of rainy days in the crop season is the total number of days having rainfall, regardless of amount, in the period beginning the day following germination and ending on (including) the final rain date.
- Rainfall frequency is the duration divided by the number of rainy days.
- The average rain per rainy day is in-season rainfall (not shown in the table) divided by the number of rainy days.
- The total season water (TSW) amount is the sum of stored soil water as of the date of germination, plus in-season rains.
Developing a Response Farming System for Production of Millet at Niamey, Niger

Response farming is a method of coping with seasonal variation in rainfall through modification of actions taken at the time of land preparation and planting, and in the early season, perhaps 30 days after crop germination. Stewart (1980) and Stewart and Hash (1982) develop the initial examples for response farming of maize in marginal rainfall areas of Kenya, using Bayesian theory to value forecasts. Here it is important to differentiate between decisions and actions. The decisions that certain actions will be taken are made long before the season begins -- even years before in some cases. The decisions are based on results of a specially devised analysis of the historical rainfall record from the locality for which strategies are being formulated. In addition to rainfall data, information which must be input to the analysis includes evaporative conditions of the atmosphere and soil water holding characteristics, plus agronomic information about present and/or proposed cropping systems.

This section describes the methodology one would use to develop recommendations regarding decisions and actions to establish a system to produce a basic food crop such as millet at Niamey, Niger. This exercise is illustrative only. Although based on real data the purpose is only to demonstrate how one would proceed to develop guidance for farmers to cope with rainfall variability. Nothing developed in this paper is intended for direct use in advising farmers.

The development of a response farming system is sequential as follows, and six sets of considerations in the example to be shown are as follows:

1. Determine the applicable rainfall period to analyze.

2. Carry out an agriculturally relevant analysis which determines beginning and ending dates of each season in the pertinent record, then determines stored soil water amount as of germination plus rainfall within the germ to maturity period.

3. Look first at risks due to rainfall ending too early in the season. Relate probabilities of producing crops of different maturity classes at selected yield levels to different dates of onset of the season. Select one or more maturity classes to be recommended, and use these in subsequent simulations to analyze other sources of risk. Risk management in this instance is accomplished through selection of crop maturity classes which minimize risks from premature cessation of the rains.

4. Look next at risks of insufficient water amounts to produce at desired quantity/quality levels. This examination must also assess risks from extended dry or nearly dry spells within the season, particularly for crop quality aspects. Relate the risks for different crops to dates of onset of all the seasons examined. Select one or more crops for which the risks of insufficient water amounts are at acceptable levels.

5. When rainfall is well below normal, yield per hectare is reduced, and if yield per individual plant becomes too small a fraction of the plant's total mass, quality suffers, and in the extreme, yield is extinguished. But crop water requirements, which are calculated for full canopy conditions (Leaf Area Index or LAI > 3), are subject to management. Reducing the plant population to LAI = 1 will reduce the crop water requirement by approximately one-third. The result is fewer plants and a reduced yield per hectare, but each plant is healthy and will yield more grain of higher quality. The trick of course is in anticipating low rainfall early enough in the season to effectively thin the plant population.
6. When rainfall is above normal crop yields will depend on soil fertility, typically low in developing countries with variable rainfall, both because cash is short and the risks are too great for lenders. Without fertilizers yields remain at subsistence levels even in the best rainfall years, and the poverty syndrome is perpetuated. Both credit and fertilizer supplies are needed. Credit will be extended when the risks of loss are reduced to acceptable levels. Fertilizer supplies will become available when there are buyers, but the supply system will have to be a caring one which can buffer stocks through years of low rainfall when fertilizers are not wanted.

Based on the periodicity described earlier for rainfall at Niamey, the period from 1968 is analyzed to establish a response farming program.

Following are inputs to the analytical program selected by the writer:

• Crop -- 80 days maturity; water requirements those of millet.

• ETp (daily grass evapotranspiration rates, held constant for each month). (Hargreaves and Samani 1986).

• Soil water holding capacity -- 70 mm water per 30 cm of depth. This is the total of extractable and non-extractable water. Soil assumed to be sandy in texture, deep and well-drained.

• First accepted date of soil water accumulation May 1.

• First accepted date of onset for cropping, June 12.

• First normal onset date June 12.

• Onset criterion -- 30 mm of water stored in the soil from the new rains. Evaporation assumed to continue throughout the soil water accumulation process. Losses to runoff assumed zero.

• Planting to begin on day following onset and continue three days, without regard to rain in that period.

• Germination criterion -- 20 mm of water stored in the soil to effect germination, usually occurring the first day following planting.

• Last search date for season end rain is the crop maturity date.

• Final rain criterion -- has two parts. First, rainfall is added backward from last search date until it totals 50 mm. Then the program continues forward accepting rains as meaningful to the season provided the sum on the day of each accepted rain averages at least 1.0 mm/day over the prior dry period. The last rain day for which the above is true is taken as the effective end of the rainy period within the maturity period of the crop grown.

Risks from four aspects of variable rainfall are assessed in the analysis described, and, in response, risk management procedures are formulated. In addition to the four, three other risk factors are assessed and found to be at low levels. These are as follows:
• Intense rains, threatening erosion of the basic soil resource. Findings are that in the cropping seasons of the 20 years analyzed, only a single rain day exceeded 75 mm (95 mm in 1977), and on only nine days did rains occur in the range of 50-74 mm. Considering the analysis is for deep, well drained, sandy soils, it was judged that the erosion hazard in present rainfall circumstances is minimal.

• Prolonged heavy rainfall periods threatening crop water-logging, particularly with flat cultivation and such practices as tied ridging. Findings are that heavy rainfall periods in the cropping season, exceeding an average of 10 mm/day for one or more weeks, are infrequent in the current period, with only a single such week since 1979. This is not judged to be a serious risk.

• Prolonged low rainfall periods within the cropping season, threatening untoward yield losses not consistent with the total season water supply. Findings are expressed in terms of weekly or multi-weekly periods, termed dry periods, when rain averaged less than 1.0 mm/day. Single weeks of this nature occur nearly every year. Two-week dry periods have occurred in nine of the 20 years. Seven of the 2-week periods plus the only 3-week dry period have occurred in the 1979-87 time period. The water storage buffering capacity of the soil type assumed is sufficient to handle the 2-week periods, although yield is penalized by reduced rainfall overall in the season. The single 3-week dry period was in 1984, the only year of total failure -- also due to too little rainfall.

Actually, the initial analysis assumed a 100-day millet, but it was found that too many rainy seasons in the current rainfall period do not persist long enough. So the selected analysis is for an 80-day crop. As seen in Figure 10 the risk is minimal if onset is before July 13, with rainfall in 13 years enduring more than 70 days of the 80-day season, and the other two years with durations of 68 and 69 days respectively.

In Figure 10 a line is drawn connecting the lowermost data points, suggesting a lower boundary of expected duration of the rainy period in seasons having a wide variety of onset dates. Additionally, a horizontal line is drawn at 65 days duration dividing market and subsistence level crop yield potential.

Until the onset date of July 13 is exceeded, all data points are in the market level yield zone, but the lower boundary line suggests that duration could be less than 65 days in seasons with onset nearing July 13. Standards for crop yield potentials are in Table 2.

The decision made was to switch to a 60-day cultivar if onset was on July 14 or later. The analysis was rerun for the five late onset seasons and the results are those shown in Figure 10. All subsequent discussion will assume an 80-day millet for early onset and a 60-day millet if onset is after July 13. The figure indicates that a rainfall duration of 45 days or greater is sufficient to permit a 60-day cultivar to yield at the market level. The decisions to utilize 80- and 60-day cultivars in effect eliminate the risk of crop failure due to too short a rainy period, and reduce the probability of subsistence level production due to this cause to one year in 20, or 5 percent.

Following rainfall duration, the next risk faced is that of insufficient water for the crop. Figure 11 illustrates how that may be accomplished.
TABLE 2. Niamey, Niger: Standards for rainfall amount and duration required to achieve crop yields in five categories, considering millet cultivars in three maturity classes.

<table>
<thead>
<tr>
<th>CROP YIELD LEVEL EXPECTED</th>
<th>MILLET MATURITY CLASS</th>
<th>100-DAYS</th>
<th>80 DAYS</th>
<th>60 DAYS</th>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TOTAL CROP SEASON WATER SUPPLY, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market Level</td>
<td>(415-500 +)</td>
<td>(330-400 +)</td>
<td>(250-300 +)</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>500 +</td>
<td>400 +</td>
<td>300 +</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>415-499</td>
<td>330-399</td>
<td>250-299</td>
<td></td>
</tr>
<tr>
<td>Subsistence Level</td>
<td>(250-414)</td>
<td>(200-329)</td>
<td>(150-249)</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>330-414</td>
<td>265-329</td>
<td>200-249</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>250-329</td>
<td>200-264</td>
<td>150-199</td>
<td></td>
</tr>
<tr>
<td>Failure</td>
<td>(0-249)</td>
<td>(0-199)</td>
<td>(0-149)</td>
<td></td>
</tr>
</tbody>
</table>

- - - - - - - - - - DURATION OF THE RAINY PERIOD, days - - - - - - -

| Market Level              | (85-100)              | (65-80)   | (45-60) |
| High                      | 90-100                | 70-80     | 50-60   |
| Low                       | 85-89                 | 65-69     | 45-49   |
| Subsistence Level         | (70-84)               | (50-64)   | (30-44) |
| High                      | 80-84                 | 60-64     | 40-44   |
| Low                       | 70-79                 | 50-59     | 30-39   |
| Failure                   | (0-69)                | (0-49)    | (0-29)  |

The vertical axis in Figure 11 is now an expression of average "wetness" of the crop growing season. This is computed simply by dividing TSW by the length of the growing period (80 days for early seasons, or 60 days for late seasons).

Figure 11 shows that average season wetness at Niamey ranges from just above 2 mm/day to just below 7 mm/day. This is where the selection of types of crops to be grown enters the picture. What is feasible depends mostly on four factors in addition to rainfall rates as displayed in the picture. The factors are (1) atmospheric evaporation rates expressed as ETp rates in the crop growth period, (2) crop physiological characteristics affecting evapotranspiration rates, (3) crop leaf canopy cover which influences degree of interception of light and advective energy, and (4) the efficiency with which rainfall is stored in the root zone of the crop versus being lost to surface runoff or deep percolation.

The listed factors sound abstract, so some brief practical comments are in order. ETp rates, like rainfall rates, are what they are, so it is management's job to select a crop type with optimal physiological characteristics and then manipulate the canopy cover (seed rates, row spacing, thinning) so that available rain fulfills a "satisfactory" degree of the (managed) crop water requirement. Management must also strive, when water is short, to minimize losses to runoff or deep percolation. In Niger the practice of "tied ridges" which turns the field into tiny basins is one of the means used to minimize runoff.
Millet is the selected crop due to a lesser daily water requirement than corn or many other crops. Millet canopy cover is easily manipulated by row spacing and seed rates, or by thinning. Millet also roots densely and deeply in sandy soils which some other crops cannot do; therefore, it exploits the extractable water and nutrients to the fullest.

Lines denoting levels of potential production of millet have been drawn across Figure 11, based on the above and related considerations. The maximum production line is drawn at 5 mm/day, deemed sufficient (in this illustrative example) to fulfill the crop water requirement under "full canopy" conditions. Note that 5 mm/day equals 400 mm total season water supply for an 80-day crop and 300 mm for a 60-day crop. Season water supply averaging at or above 5 mm/day should be capable of producing maximum yields of millet providing that fertility is not lacking; competing weeds, pests, and diseases are controlled; and water losses are minimal, not to exceed approximately 10 percent assumed in the standards set up in Figure 11.

When average daily water supply falls below 5 mm/day, the plant numbers can be reduced so that each plant still produces near the maximum. If anticipated at planting time this is accomplished by wider row spacings and reduced seed rates. If determined after planting, plant numbers are reduced by thinning. Figure 11 assumes production is at market level until the average daily water supply falls to about 4.15 mm/day, after which subsistence level production is attainable until the daily water level falls below 2.5 mm/day, when failure is assumed.

Figures 10 and 11 combined illustrate a method of determining probabilities of achieving five levels of crop yields of millet in the rainfall conditions at Niamey since 1968. If the potential yield category assigned to a given year differs in the two figures, it is considered a limiting factor situation and the lower category is assumed correct.

Also incorporated into the categorizations in Figures 10 and 11 are assumptions that soil fertility and plant numbers per hectare are being controlled at levels commensurate with actual seasonal rainfall. This is really the crux of the problem. These are two of the most important management factors for coping with variable season rainfall.

Figure 12 derives from the same analysis of 1968-87 rainfall as Figures 10 and 11. The horizontal axis of onset dates and the July 13/14 division between 80 and 60-day cultivars are the same. However, the vertical axis is now the known season water as of 30 days after germination. This includes stored soil water at germination plus 30-day rainfall.

Figure 12 recognizes the fact that farmers get a second chance at deciding the important questions of fertilizer rates and plant populations. The figure addresses the question of how well season total rainfall is reflected in early season rainfall -- in this case the first 30 days after germination. The method used is to color each symbol representing one of the past 20 years, according to its expected yield category, as developed in Figures 10 and 11.

When this is done, an interesting picture emerges. First we see that only subsistence level production can be expected if onset is after July 13. The same is true if the 30-day water supply does not total at least 150 mm. Nine of the 20 years suffered one of these problems. Eight of these are categorized as subsistence level production and the other a complete failure. The remaining 11 years had early onset (by July 13) and a 30-day water supply totalling at least 150 mm. Of those, six should have produced at the highest level and four more at a lower market level. Only one year would have fallen into the subsistence level production category.

A picture like Figure 12 can be used as a management decision tool for an "A" versus "B" type of strategy. Both plan A and plan B are clearly defined and known to the farmer.
from the time the analysis is made onward and apply in the same way to every season thereafter until the rainfall shifts into a new behavior pattern. For example, plans for fertilizer usage might be that phosphorus requirements are supplied every season at planting time, on the basis that maintaining even subsistence level production requires it. Nitrogen might be added to achieve market level production in early onset years, provided the 30-day water supply was at least 150 mm. Plant numbers could also be controlled at two levels, say to achieve LAI = 3 for market level production or LAI = 1 for subsistence production. With early onset, seeding would be for LAI = 3. At the 30-day decision point, if water supply were at or above 150 mm, nitrogen fertilizer would be added, but if below 150 mm, no nitrogen would be added and the plants would be thinned to LAI = 1. With late onset, seeding would be to achieve LAI = 1 and the 30-day decision point would not apply.

**SUMMARY**

The 1905-87 daily rainfall record for Niamey, Niger, an important center in the Sahelian zone of West Africa, is used to develop an illustrative example of a response farming program for managing risk associated with variable season rainfall. Response farming is a flexible farming system in which some predetermined actions are modified each season on the basis of (1) the date onset of the rains actually occurs, and (2) the amount of rain actually received as of 30 days (for example) after crop germination. Three principal steps for program establishment follow:

1. Identify the relevant portion of the rainfall record to serve as a basis for developing guidance criteria for current season use. Utilize onset relations for this purpose, and when identified, use only the relevant record for the steps below.

2. Quantify risks from the following aspects of rainfall behavior, in the sequence given:

   a. Rainfall intensity -- threat of erosion of the basic soil resource.

   b. Prolonged heavy rainfall -- threat of waterlogging and crop loss.

   c. Prolonged low rainfall periods within the rainfall season -- threat of inordinate crop yield reduction, not solely attributable to gross water deficit - crop growth stage effects.

   d. Too early cessation of the rains in the crop growth period -- inadequate rainy period duration.

   e. Insufficient crop water supply -- inadequate rainfall amount.

3. In each case, decide on management strategies and actions for (1) reducing the level of risk and (2) minimizing the impact of the remaining risk. For actions which are variable in accordance with early season rainfall activity, quantify criteria and timing for executing plan "A" versus plan "B".

Onset relations -- i.e. relations between season rainfall parameters (amount and duration) and dates of onset defined for cropping purposes -- are used to delineate four markedly different periods of rainfall behavior in the record. Until 1917 total season water (TSW) had a median value of 315 mm (12.4 in). Seasons started late and were short, with infrequent but heavy rains. The next 30 years (1918-47) had early onset, long seasons, and more frequent rains but less heavy. TSW was much increased at 460 mm (18.1 in). The next 20 years (1947-67) were
still wetter (TSW of 527 mm or 20.7 in). Onset was moderately early, seasons of medium length and rains frequent, but a bit lighter than previously. The current period of relatively poor rainfall conditions began in 1968. TSW has fallen to 369 mm (14.5 in), with somewhat shortened seasons, intermediate dates of onset and fairly frequent but light rains. Due to marked differences between periods and the persistence of each period once established, it is concluded that the current period record should be the basis for generating farm level cropping strategies and recommendations.

Key sources of risk to crop yield levels or cost overruns were assessed in logical sequence. The initial goal was risk avoidance through selection of (a) crop maturity classes, and (b) crop type(s) to grow, in that order. The first minimizes risk from rainfall cessation too early in the growing period, and the second optimizes the fit between average daily water supply and average daily crop water requirements of different crops of possible interest. Conclusions are that an 80-day millet should be grown if onset is "early," i.e. by July 13. Probability of early onset is 75 percent or three of four years. In early onset seasons, the probability of sufficient rainfall and season duration to attain market level crop yields is 67 percent, or two years in three. Remaining early onset years will yield at subsistence level (27 percent), with a small probability (6 percent) of complete failure.

In late onset seasons (one year in four), only subsistence yields are attainable and these require a 60-day millet. One advantage is that the situation is clarified as of July 14 and planting may proceed. Costs are low with recommended minimal seed and fertilizer rates. An alternative is to fallow the land for a year and pursue a different means of livelihood.

Seasonal risk management strategy in early onset years is concerned primarily with matching soil fertility and plant population to anticipated (potential) yield level. Too little of either can spoil a market crop opportunity, while too much, when rainfall is limiting at the subsistence level, incurs wasted cost (fertilizer), and can result in total crop failure with too many plants, none of which are healthy.

A plan "A" versus plan "B" strategy is formulated for early onset seasons, based on the fact that soil fertility and plant population do not require finalization until there is more information about the rainfall season -- in this instance perhaps 30 days following germination. Immediately following onset, an 80-day millet is planted at a high seed rate (sufficient for full leaf canopy achievement), but with initial fertility limiting at subsistence level. At day germ + 30, if soil water at germ + 30-day rain is 150 mm (~6 in) or more, add sufficient nitrogen fertilizer for a market yield. But if under 150 mm, thin plant population to optimize subsistence production and do not augment fertility.

Had the above decisions been enacted at Niamey over the 1968-87 period (20 years), indications are that all 10 of the early onset market potential yields would have been realized. A single year with only subsistence potential would have been overfertilized and left with too high a plant population. The other nine low potential years would have been managed correctly.

CONCLUSIONS

(1) Seasonal variation in rainfall poses the greatest climatic risk to agricultural production in the developing world.

(2) Periodicity in seasonal rainfall behavior at Niamey, Niger, is confirmed by a specialized analysis which, based on patterns of onset relations of agriculturally relevant rainfall
parameters, differentiates four periods in the 1905-87 record. New behavior patterns began in 1918, 1948, and 1968. Until 1917 median crop season water was only 315 mm, rising to 460 mm in 1918, up still further to 527 mm in 1948, then downward to 369 mm in 1968.

(3) In view of the finding that seasonal rainfall behavior occurs in discreet and identifiable patterns which persist for periods like 20 or 30 years, it is concluded that criteria for guidance of response farming should be based on the current pattern only.

(4) In variable rainfall zones at least five aspects of seasonal rainfall behavior need to be evaluated in terms of risk to agricultural production. These are intense rains threatening erosion, prolonged heavy rains threatening waterlogging, prolonged low rainfall periods within the cropping season, cessation of the rains too long before crop maturity, or too little rainfall in relation to crop water requirements.

(5) Cursory examination of the Niamey rainfall data indicates risk from intense or prolonged heavy rains is not much in the present low rainfall period, particularly on the deep, sandy, well-drained soils of this example.

(6) Present low rainfall at Niamey is due to smaller (on average) daily rains, but nevertheless rains are rather frequent within the season and long spells of dryness or exceedingly low rainfall do not pose extra risk, i.e. risk not accounted for by low total rainfall in relation to crop requirements.

(7) Early cessation of the rains threatens short duration of the rainy period with respect to crop maturity. Duration is very much correlated with the date the season begins (onset or germination), hence is the key factor in selecting maturities of crops (cultivars) to be grown. Relating duration to onset dates provides season-by-season guidance. The present example shows an 80-day cultivar is optimal at Niamey, provided onset occurs by July 13. If later, a 60-day cultivar is indicated.

(8) Following determination of cultivar maturities to be grown, the next selection is the type(s) of crops themselves. This is done by relating average water supply (rain plus soil water at onset) per day to daily water requirements of crops of interest. For example rice water requirements are greater than corn which are greater than millet. Millet was selected to fit water supply at Niamey.

(9) The crux of the management problem with variable rainfall is to adapt soil fertility and plant populations to actual rainfall conditions in the season at hand. Fortunately, farmers can delay final decisions on these questions until about 30 days after germination. This paper concludes that season water supply to that point in time is adequate to provide low risk guidance on whether to add additional fertilizer for high rain conditions, or to thin and reduce the plant population for low rain conditions. The example here indicated 19 of 20 years at Niamey would be correctly managed using the indicated information.

(10) It is concluded that response farming programs of the type described here are ready for field application in development projects, and that rainfall studies to improve risk management procedures should receive strong financial and policy support.
FIGURE 1  NIAMEY, NIGER: MEAN MONTHLY RAINFALL
1905-1987 MAY-OCT MEAN = 541 MM

FIGURE 2  NIAMEY, NIGER: PERIODICITY IN RAINFALL
83-YEAR MAY-OCT MEAN = 541 MM
FIGURE 3  NIAMEY, NIGER: RAIN FOR 100-DAY CROP
ENTIRE RECORD: 1905-1987

FIGURE 4  NIAMEY, NIGER: RAIN FOR 100-DAY CROP
RAINFALL PERIOD: 1905-1917
FIGURE 5  NIAMEY, NIGER: RAIN FOR 100-DAY CROP
RAINFALL PERIOD: 1918-1947

FIGURE 6  NIAMEY, NIGER: RAIN FOR 100-DAY CROP
RAINFALL PERIOD: 1948-1967
FIGURE 7  NIAMEY, NIGER: RAIN FOR 100-DAY CROP
RAINFALL PERIOD: 1968-1987

FIGURE 8  NIAMEY, NIGER: RAIN FOR 100-DAY CROP
RAINFALL PERIOD: 1948-1987
FIGURE 9 NIAMEY, NIGER: RAIN FOR 100-DAY CROP
RAINFALL PERIOD: 1948-1987

FIGURE 10 PRE-SEASON DECISION: 80-DAY/60-DAY CROPS
NIAMEY, NIGER: CURRENT PERIOD (1968 ON)
FIGURE 11  PRE-SEASON: DECIDE INIT FERT/SEED RATES
NIAMEY, NIGER: CURRENT PERIOD (1968 ON)

AVERAGE CROP SEASON WETNESS, mm/day

80-DAY CROP

60-DAY CROP

PRODUCTION LEVEL
MARKET, HIGH
FULFILLS CROP WATER REQUIREMENT

MARKET, LOW

(4.5)

(4)

3.5

SUBSISTENCE, HIGH

3

SUBSISTENCE, LOW

2.5

FAIL

13/14 JUL

25 , 13/14 JUL

150 - 160 170 180 190 200 210 220
(JUN 9) ONSET - Julian Date

(AUG 8)

FIGURE 12  GERM+30DAYS: DECIDE FERT LEVEL/PLANT POP
NIAMEY, NIGER: CURRENT PERIOD (1968 ON)

GERM WATER + 30-DAY RAIN, mm

250

PLANT HIGH SEED RATE & FERTILIZE W/PHOSPHORUS

PLANT LOW SEED RATE & FERTILIZE W/PHOSPHORUS

150

RECOMMEND: ADD N-FERT IF WATER TO DATE > 150 mm

125

RECOMMEND: REDUCE PLANT POPULATION

100

160 170 180 190 200 210 220
(JUN 9) ONSET - Julian Date

(AUG 8)
REFERENCES


ASPECTS OF AGRICULTURAL RESEARCH AS AIDS IN RISK MANAGEMENT

Jock R. Anderson

ABSTRACT
Farmers are first and foremost risk managers. Agricultural research has much to offer by way of innovations that can ease the burdens of risk with which farmers must cope in their environments. Attention in this necessarily partial review is focused on the contributions that have been made and must continue to be made through plant breeding for resistance to pests and diseases, and to stresses arising from soils and climate. Animal breeding and a range of agronomic management techniques are also considered for their potential roles in dealing with risk. The review is closed by noting that farm management research also has an important part to play.

INTRODUCTION
There is nothing new about the existence of risk in the agricultural sectors of poor countries. Farmers have dealt with risk since the dawn of agriculture and have been responding creatively to changing adversities for centuries. The approaches taken have often involved selecting plants and animals that seem best able to cope with perils and pestilence, and managing what control farmers do have over the conditions in which plants and animals are grown.

With the development of science-based agriculture, farmers have received new forms of assistance for coping with their traditional risk-management responsibilities. The primary purpose in this review of selected aspects of agricultural research is to examine the considerable potential for modern approaches to breeding and agronomy in managing the manifold risks that beset agriculture in developing countries. For small-scale, resource-poor farmers in many areas, the immediate emphasis must be on low-input technologies for improving productivity and the stability of agricultural production. This is not to imply at all that research thus directed is "low-tech." Indeed, such research is most demanding, even though it is sometimes frustratingly slow. But exciting progress is being made. The international agricultural research centers, for instance, are now applying major efforts to such activities in food-crop based systems (see, e.g., the syntheses by Anderson, Hazell, and Evans 1987; and the Consultative Group on International Agricultural Research [CGIAR] 1988).

PLANT BREEDING
Contemporary plant breeding is addressed to many objectives including maintenance of and improvement in average yield potential, improved quality characteristics for particular crop
products, and, most relevant to the present review, the resistance to and tolerance of stresses from the biotic, edaphic, and climatic environments. In fact, some of the early major achievements during the past 100 years of crop improvement work were in breeding for resistance to fungal diseases and for tolerance of drought, as exemplified by the pioneering efforts of wheat breeders, such as William Farrer (1898). The work by H.H. Storey in the 1930s at Amani in Tanzania in crossing cassava with related wild species to produce mosaic resistance was similarly notable and indeed won for him the first Fellowship of the Royal Society given to an agricultural scientist (S.J. Carr, personal communication).

There may be important differences in priorities accorded to stability and risk-reduction between developing and industrial countries, especially among those that face risky rainfed regimes. Marshall (1987), for instance, argues that stability has much greater intrinsic merit in subsistence-oriented agricultures with thin markets and weak infrastructure than it has, for example, in Australia where the emphasis has mostly been on increasing average yields. Risk aversion thus plays a minimal role in such cases of well-developed export infrastructure and credit markets, which together enable farmers to benefit by smoothing consumption over variable eventualities. The converse is true in most developing countries, which means that it is important, if not imperative, for plant breeders to feature stability in their breeding objectives. Indeed, Simmonds (1988), in the context of wheat breeding for rust resistance, goes so far as to insist that breeders adopt strategies that are ultimately less risky for the clientele of poor farmers than those traditionally used. In particular, he advocates use of the more durable "horizontal" resistance (i.e., polygenic pathotype-nonspecific [Simmonds 1985]) rather than what has been the more popular "vertical" resistance (i.e., major-gene, pathotype-specific) in order to make the developing world a safer place.

Breeding for resistance to the onslaught of particular insects and fungal, bacterial, and viral pathogens is a continuing activity because of the facility that such organisms have for mutation and adaptation to the changing genetic composition of their host. Thus, it is that most plant breeding programs consist importantly of a maintenance research function that is intended to keep at least one step ahead of the adapting micro-organisms and insects. The situation with which rice breeders must deal is illustrative of that encountered for many crops. Intensification of production based on modern varieties means that large areas are sown asynchronously to similar materials grown under similar conditions, and thus insect and disease pressures are -- in historical terms and relative to yet unintensified situations -- high indeed (Coffman and Hargrove 1989). Thus, maintenance research to defend yields has breeding for multiple insect and disease resistance at its core. The speed with which IR26 rice and its relatives were released in response to the brown planthopper outbreaks of the early 1970s, for instance, speaks much for the hard-won modern capacities of maintenance breeding programs to "do the needful."

Modern techniques of biotechnology, especially RFLP (restriction fragment length polymorphism) methods for gene mapping, enable a better appreciation of the genetic makeup of resistance. If plant breeders can know exactly how many genes are involved and where these are located on particular chromosomes, breeding programs can be much more efficiently oriented to specific resistance objectives. In spite of the many exciting possibilities offered by contemporary molecular biology, it behooves contemporary observers to be realistically patient in awaiting concrete contributions (e.g., Marshall 1987, Riley 1988, Parsley 1989). In the meanwhile, other more conventional biological techniques are continuing to be refined and used to accelerate progress in producing cultivars resistant to diseases and pests and for innumerable pathogen-crop combinations (e.g., smut resistance in pearl millet [Thakur and King 1988], resistance to the spotted stem borer in sorghum [ICRISAT 1988], and multiple-borer resistance in maize [CIMMYT 1989]).
Many recent plant breeding endeavors have been addressed to selecting materials that can cope with environmental stresses, in addition to those associated with invading organisms. The difficulty here is that -- in contrast to the former when only a few major genes may be involved in the resistance -- tolerances to stresses such as drought, frost, and adverse soil conditions (such as those associated with high levels of aluminum and manganese ions) are typically controlled by many genetic factors. These necessitate complex breeding programs directed at exploiting relevant sources of resistance which tend to have yield heritabilities lower than found in traits that are more significant in less stressed environments.

Accordingly, progress in this type of plant breeding is inevitably slow as the breeding work relies on traditional methods of selecting under "appropriate" growing conditions (Austin 1987). The strategy pursued by plant breeders varies greatly according to their perception of how advances might best be made. For instance, selecting for plants that are tolerant of drought might seem most naturally approached through selection under particularly droughty conditions. At one extreme, a drought may cause total crop failure and thus an inability for plants to reproduce successfully. Assuming the most extreme conditions, progress would be essentially zero in terms of plant breeding objectives. Equally, were selection for such drought resistance to be made only in crops grown under favorable soil and moisture conditions, progress would also necessarily be rather coincidental and surely slow. Clearly a compromise is needed, and would encompass deciding on the most appropriate degree of adversity which is at the heart of strategic decision-making among stress-oriented plant breeders.

In practice, plant breeders are obliged to make tradeoffs among several considerations. Great progress was made in the 1950s through the 1970s by concentrating on comparisons of diverse materials grown in many diverse locations, and using selection based on multi-location performance. Technically, breeders were thus selecting, among other things, for adaptability rather than for stability per se, since the latter term refers to reliable performance over time at a given site. The regression framework developed over several decades by Mooers, Yates and Cochrane, Finlay and Wilkinson, and Eberhart and Russell for aiding such selection has been criticized by many, including Anderson (1974) and Arnold and Austin (1989). Fortunately, as Evenson et al. (1979), Binswanger and Barah (1980), and Flinn and Garrity (1989) have found, there is a positive association between adaptability and stability and so, somewhat through good fortune rather than necessarily good management, most of the widely grown modern cultivars have proved to be quite stable. This is exemplified by the Veery "S" wheat developed at CIMMYT which is adaptable as to outyield competitors in almost every tested environment (Osmanzai, Rajaram, and Knapp 1987, Pfeiffer and Braun 1989). To take an example driven more by disease than climatic stresses, an exception is illustrated by pearl millet hybrids in India, which have succumbed to new pathotypes of downy mildew in many important producing areas (Witcombe 1989).

Methodologically speaking, the fact that observations over space do not substitute perfectly for observations over time at a site (Watson and Anderson 1977) means that the quest for stability must eventually take place at specific locations over time. It is especially in this case that innovations from modern biology, engineering (Portmann 1983), and operations research (Brennan 1988, 1989) can be so valuable in reducing the time taken to identify and incorporate genetic resistances to environmental stresses. Other considerations can also significantly influence the pace and efficiency of breeding efforts, such as defining and mapping the environment and its stresses and collecting cogent information on environmental variables in order to facilitate the interpretation of yield responses (Harris, Goebel, and Cooper 1987). Similarly, identification of novel resistances in wild relatives (Evans and Dunstone 1970, Srivastava 1987) and recognizing and using physiological and morphological traits (Clarke 1987, Richards 1987) must feature more actively in breeding programs.
The environments in which plant breeders are working are indeed risky, and there are many essentially random elements in the game of genetic roulette they play. The choice of tactics and strategies for stress-related plant breeding is a risky matter itself and there is assuredly no universal truth awaiting discovery. Breeding for positive genetic response to drought, for instance, has been uniformly difficult across all species as illustrated, for example, by the reviews for wheat, sorghum, cotton, and maize assembled by J.R. Welsh in Stone and Willis (1983) and by Blum (1983). As in all risky situations there is an element of luck in what progress is achieved. For the administrators of plant breeding programs, it is a matter of setting the scene so that luck can play its expected role and genetic gains can be made in the most timely and economically efficient manner possible. While much progress has been made for many crops in recent decades, many weaknesses remain. See, for example, the priorities listed by Carr (1989) for urgent African breeding work on cassava, maize, sorghum, cowpeas (especially for striga resistance), groundnuts (especially for Cercospera and rosette resistance), and rice. There are other potential hazards that require continued vigilance, especially those that stem from erosion of genetic diversity in the materials available to breeders. Several of the international agricultural research centers, along with several national germplasm centers, are actively working to reduce these hazards.

Wider institutional issues must also be addressed in contemplating research policy concerned with risk-reducing innovations for farmers of the developing world. These naturally relate to the development and sustenance of effective, relevant research capacity within national and regional agricultural research systems. As Cantrell (1989) observes in the context of national maize breeding programs’ ability to employ effectively special-purpose pools carrying host-plant resistance to insects, programs do differ greatly; special attention and interventions will be necessary if farmers in countries with weak systems are to benefit at all. And such farmers are among those in greatest need of such low-cost innovations if they are not to fall further behind those developing nations with more advanced capabilities. Bank-assisted projects in the agricultural research and development arena need to reflect these changing needs and emerging opportunities and to consider the possible role of private sector initiatives in the field.

ANIMAL BREEDING

There are many obvious differences between animal and plant breeding programs. The populations involved in most animal breeding programs are much smaller and the crosses typically much more expensive per cross. A further difference advanced here is that it is somewhat more challenging to select animals that are more stress-resistant than it is for their plant counterparts because farmers in their informal role as animal breeders (mainly selecting among indigenous populations) have been very purposefully involved in such selections for countless generations. Selection in animal populations has, it is hypothesized, been more overtly directed at risk-management objectives than has been the case for plant breeding, where the technology of crossing was not always known to farmers in their role as crop improvers.

Plant breeders have long recognized tradeoffs between stability and productivity in crop germplasm (Lawn 1988) and such recognition has led ICARDA, for instance, to differentiate its cereal breeding approaches between medium-potential and low-potential areas of its mandate regions (Srivastava 1987). Analogous tradeoffs are also encountered in livestock breeding (Franklin 1985, p.53), who cites especially the physiological antagonism between adaptation and production reported by Frisch and Vercoe, 1982. Perhaps the exemplification of this -- where it has the widest geographical and probably the greatest economic significance -- is the low economic productivity of cattle in Africa that are tolerant of trypanosomiasis infections (Trail 1985). Attempts at cross breeding N'Dama and other trypano-tolerant cattle with inherently more productive (for traction, milk, and beef) European and Asian breeds have thus far been
disappointing outside atypically favorable environments, but, as Trail and Gregory (1984) describe, the opportunities for improved productivity in the more favored zones are considerable.

Somewhat similar challenges have been faced in the long-running endeavors to produce dairy and dual-purpose cattle breeds well adapted to the tropics. It seems that ability to withstand high temperatures and the tropical disease and parasite challenge has thus far proved to be at odds with high levels of milk productivity and reproductive performance (Jarvis 1986). While it would be valuable, especially for resource-poor farmers, to have access to "drought-proof" sheep, cattle that better prospered on poor-quality forages, and poultry naturally immune to their traditional major diseases, for instance, progress in such breeding objectives is bound to be slow, notwithstanding contemporary and prospective biotechnology.

On the other hand, as Bhat (1984), Franklin (1985), and others have stressed, the application of modern animal selection techniques to developing new breeds that perform in a superior way in the challenging and variable tropical environments is really just beginning. While implementation of such techniques will not be easy, and while progress takes time, investment in such techniques will eventually lead to considerable productivity gains. In the meantime, in many parts of the developing world it is likely that nutritional constraints are the most binding and must be overcome before benefits to genetic improvement (and veterinary inputs) can be more fully realized (Falvey 1985, and McIntire, Bourzat, and Pingali 1989).

AGRONOMIC INTERVENTIONS

As the number of inputs used in crop and livestock production increases, so too does the range of options for managing the risks of production. Some inputs are overtly risk reducing in their effects, such as fungicides and pesticides. If such inputs are used wisely and in timely fashion, production will usually be less risky than it would be otherwise. If the timeliness of application is not ideal, however, perhaps because of an inability to acquire input supplies because of weak and unreliable distribution systems, the effect on riskiness of production may be obscured. Misuse of agricultural chemicals, particularly at very high and unintended rates, can lead to a range of effects, including accelerated adaptation of organisms in developing resistance to pesticides (Carlson 1989) and serious impairment of the user's health. Unsophisticated users, who may be unable to read warning labels, can face considerable risk to their personal safety through exposure to some agricultural chemicals. The benefits attributable to genetic resistance to diseases and pests in this regard go beyond merely saving expenditures on pesticides, they extend to environmental and health dimensions as well.

The above-noted observation that crop protection chemicals are usually (but not necessarily) risk-reducing agents derives from the fact that outlays for the chemicals in terms of cash and scarce labor to apply them will not be recouped in the event that the protection was not required. This can arise either because conditions do not favor development of the pest or disease or because the crop fails for other reasons, such as drought. While such crop-protection measures may reduce the overall variability of production, there is still an element of risk in their use that for some risk-averse farmers is unacceptable (Anderson 1974). The lack of clear advantage over the complete range of circumstances, which would amount to universal preference by all risk-averse agents, may explain why many resource-poor farmers choose not to adopt such "safety enhancing" technologies.

Nick Wallis, in discussing this presentation, noted that tropical tree crops have been underemphasized and yet provide instructive examples of agricultural research yielding low-cost biological manipulations of cropping systems (often inter- or multi-cropped) that reduce farmers' risks. Illustrative in this regard is the late 1930s work of A.R. Melville wherein predators of the
coffee mealy bug were collected from Uganda and released in Kenya. One of these, a small wasp (Anagyrus kivuensis), has for the most part controlled this particular pest effectively ever since.

For many inputs it is something of an empirical question as to whether they increase risk, decrease it, or leave it unchanged. Fertilizer provides one such example. Some nutrients, such as phosphorus applied early in the growth of a crop, generally tend to reduce subsequent yield variation through the production of a more robust plant. Others, particularly nitrogen applied at various times through the cycle of crop growth, may increase the instability of production. Lush growth of foliage may predispose high crop-yield potential but can work against stable production if moisture supplies are insufficient to service the physiological demands of a larger plant. Also, especially lush growth may foster the development of micro-organisms such as fungi. In most of the rather few cases where appropriate data have been available to permit an assessment, it has been found that nitrogen generally leads to small increases in yield variability, at least as measured by the coefficient of variation (Roumasset et al. 1989).

Water as a factor in crop production provides further illustration of the potentially ambiguous effects. Irrigation is usually thought of as a risk-reducing input, but if water supplies are unreliable the converse may well be true. Water-use time patterns, as Pandey (1989) elaborates, contribute to the range of risk effects observed with irrigation. These are often found to vary systematically with the place a farm occupies in an irrigation system. More generally, the lack of clear resolution of such empirical questions arises from the inherent complexity of the effects on risk of interactions among productive inputs (Anderson and Hazell 1989).

The manipulation of labor and capital inputs provides substantial scope for modifying the riskiness of the natural environment of crops and animals. Ready availability of labor for weeding and crop tillage operations can make better use of moisture and reduce the riskiness of production. The contrary applies when such labor is in short supply as it is, for example, in many parts of Africa for some key crop-management operations. Mechanization generally provides much opportunity for useful risk-reducing interventions but at the same time perhaps exposes owners of machines to increased financial risk. The development of relatively large-scale efficient tillage equipment, for instance, can assist farmers to make much better use of limited and unreliable rainfall events. Other practices, perhaps the most advocated being mulching, may seem to be able to improve water-use efficiency at much lower cost (at least for capital but probably not labor) but often are judged by farmers to be unprofitable. In similar vein, techniques for surface water trapping and for water harvesting in general (Anderson 1988) continue to be so seemingly under used that they are deserving of more penetrating research in order to understand better the full costs of their implementation, and other possible obstacles to greater use.

To summarize, there are no clear and simple conclusions that can be reached regarding the effect of inputs on the riskiness and the variability of crop and livestock production. The possible exceptions to this are the relatively straightforward cases of low-cost risk-reducing inputs, such as vaccines for animal diseases and some crop-protection inputs.

At the most general level, the issue is one of information and the timeliness of its availability to decision makers. If the farmer knows the nature and timing of the phenomena that may lead to damage of a biological enterprise, an informed approach can then be taken to managing the use of applicable inputs. The difficulty for the present and the foreseeable future is that such information is all too often not at hand, and the enterprise is consequently one that is intrinsically risky. With development, improved information systems can be implemented which ease the farmer’s management challenge.
Modern approaches to integrated pest management, for instance, depend on effective pooling of information on the biology of major pests, and on the effectiveness of interventions that greatly diminish the chances of organisms developing resistance. This has possibly reached its zenith with the integrated cotton pest management schemes operative in some industrial countries.

CONCLUSION

The topic of what agricultural research can do to assist farmers in their risk management is a broad one that can hardly be dealt justice in a review of this brevity. Confining attention to the three major themes of crop improvement, animal breeding, and agronomy has meant that many other areas of agricultural research undertakings have been bypassed. Attaching importance to those neglected is a rather subjective task and different experience will lead to different priorities. An anonymous reviewer, for instance, nominated as essential aspects (a) the analysis of climatic variability for crop assessment and early warning systems for pest and disease attacks, and (b) market intelligence research. For the author’s attempt at seeking belated balance, just two neglected aspects are mentioned as being suggestive of other themes that could usefully be pursued. First, heritable inbuilt resistance to storage pests in traditionally grown grain has seemingly been prized by northern Malian farmers, for example, as a key to managing intertemporal food security through long storage of grains from "good" years (Bunting and Kassam 1988 citing work by Gillman). Such resistance has not been a feature of the modern "improved" varieties so far made available to these farmers, and so it is easy to guess what varieties they choose to grow. More generally, research on storability and storage methods and strategies may be valuable for its contribution to risk management per se.

In choosing a second omitted research theme, the opportunity to select one close to the heart -- e.g., Anderson, Dillon and Hardaker (1977), Anderson and Hardaker (1979), Dillon and Hardaker (1987), Heady and Candler (1958), Hazell (1971), Hazell and Norton (1986), and Sanders (1989) -- cannot be passed up. This is the broad field of farm management research in its particular manifestation of farm planning under risk. It might be thought of as a special case of information management wherein technical information on the options open to farmers is blended with that pertaining to their resource constraints and socioeconomic environment. In my view, all this falls naturally within the sphere of agricultural research but is an aspect that is severely underplayed in most developing-country institutions.

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INTRODUCTION

Purpose and Approach

Farming in marginal agroclimatic environments that lack major infrastructural safeguards can be a highly stochastic process. Important production risks are posed by periodic drought, flooding, pest and disease infestation, and unanticipated interruptions in labor supply. The West African semi-arid tropics (WASAT) is in many respects typical of such a risky environment.

Over time farmers in this sub-region have developed an array of methods to protect their household food consumption against stochastic production shocks. Any particular combination of risk-reducing methods can be defined as a risk management strategy. These strategies tend to be interwoven as key elements in the farming systems developed in particular environments. We observe that strategies typically involve overlapping methods designed to provide fallback protection against the occurrence of major food deficits. Some methods focus on reducing downside yield risk directly, while others are designed to generate compensatory income (consumption purchasing power) in the event that production shortfalls nevertheless occur.

As these strategies condition farmers’ behavior in responding to new options, an understanding of farmers’ risk management strategies can be crucial both for effective policy formulation and technology development. To optimize impact, technologies and policies should be consistent with and, most desirably, reinforce these strategies. Conversely, if new interventions undermine key components of such strategies, broad adoption and impact will be blocked and/or farmer welfare reduced.

This paper sets out a conceptual framework within which to identify and analyze the main risk management practices employed by WASAT farmers. To illustrate that framework, the paper examines three sets of methods by presenting comparative farm-level evidence of their application in the major agroclimatic zones of the sub-region. The discussion draws on primary data collected by means of a weekly household survey conducted by ICRISAT in Burkina Faso during the period 1981 through 1985. The survey included some 150 farming households located in six villages that were selected as being broadly representative of the three principal agroclimatic zones found in the subregion (Matlon 1988).

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The Environment

The zones included in the survey -- Sahel, Sudan savanna, and North Guinea savanna -- represent striking contrasts in production potential and risk. Climatic constraints are most limiting in the Sahel and decline in importance in the Sudanian and Guinean zones. These constraints include limited total precipitation, a short unimodal rainy season, high intra-seasonal rainfall variability, high rainfall intensity, and high evapotranspiration demands (which peak at seedling and grain-filling stages thereby increasing the risk of drought-induced yield loss).

The highly weathered soils of semi-arid West Africa reinforce these climatic constraints. Loamy sands of the Sahel zone and sandy loams of the Sudanian and Guinean zones are generally low in phosphorous, nitrogen, and organic matter; are structurally inert; tend to cap; and are susceptible to compaction. These features combined with the soils' generally shallow depth, result in low water holding capacity, poor fertilizer use efficiency, and high risk of periodic moisture stress.

Because the climatic and edaphic constraints tend to be closely correlated across agroclimatic zones, the lowest technical potential is located in the Sahel, and the highest in the Sudan and North Guinean zones. Cropping patterns correlated closely with these zonal differences in production potential:

- Millet, cowpea (intercropped with millet), fonio, and groundnut are the major upland crops in the Sahel zone. Sorghum cultivation is of secondary importance, grown primarily in lowland portions of the toposequence and in increasing shares even on upland soils in the more southern margin of the zone.

- The Sudan zone is an area of transition between millet and sorghum based systems. Maize, concentrated on the most fertile soils, groundnut, cowpea, and cotton are also cultivated, but these minor crops generally represent less than 25 percent of total cultivated area.

- The North Guinea zone is characterized by the greatest overall production potential and has the most diversified production patterns. Important shares of the cultivated area are sown to market oriented crops such as cotton, maize, rice, cowpea, groundnut, and vegetables. Sorghum is gradually replaced by maize as the dominant food staple in the southern portion of this zone. Millet is of secondary importance limited primarily to poorer land types, to the drier northern half of the zone, and (short-cycle millet) as a component of cereal/cereal relay cropping systems in the southern portion.

Several climatic characteristics and a measure of grain yield variation across the three zones are shown in Table 1.

A Conceptual Framework for Understanding Farmer Risk Management

Empirical evidence strongly suggests that food security is the overriding objective of household production and employment among the vast majority of WASAT farmers (Norman, Newman and Ouedraogo 1981). Food security can be defined as the satisfaction of domestic consumption requirements during all periods of the year, irrespective of food source. It follows that methods to ensure food security can focus on each major food source: own-production, purchases, and transfers.

Risk management methods, moreover, are applied at several levels of operation: (1) plant, (2) plot, (3) farm, (4) whole household, (5) village, and (6) region. Methods to ensure
own-production involves actions at levels (1) through (3); purchases are secured at levels (3) through (6); and transfers are secured at levels (5) and (6). (Table 2.)

Risk management methods also differ according to when they are applied relative to the occurrence of production shocks. **Ex ante** methods are designed to place households in a less vulnerable position before the occurrence of a shock. Interactive methods involve the reallocation of resources at the time a shock occurs with the goal of minimizing its ultimate production impact. **Ex post** methods involve actions taken after a shock has already reduced production and aim to minimize the subsequent impact on consumption.

Table 3 uses the level X time-frame classification to inventory the principal risk management methods employed by farmers in the WASAT. Even a casual review of this inventory reveals the difficulty in attributing practices exclusively to risk-reduction objectives. Several of the methods listed are known to achieve both lower variance in returns as well as higher average returns compared to alternative practices. An example of this is intercropping compared to solecropping in low-input systems.

Moreover, although some practices reduce production risk without necessarily improving expected returns, they may be implemented by particular farmers for reasons not explicitly related to risk. Examples of this latter include: the practice of crop diversification that farmers may pursue to meet consumption objectives in the face of product market inefficiencies; and plot fragmentation caused by customary rules of land inheritance.

**EX ANTE RISK MANAGEMENT METHODS AT THE PLOT AND FARM LEVELS**

**Crop Diversification**

Diversification -- of crops, cultivars, and plot locations -- is one of the most common means by which farmers attempt to stabilize agricultural income.

Crop diversification is practiced through cropping different enterprises across dispersed plot areas as well as through the planting of crops in mixtures on the same plots. The following objectives of crop diversification are well-known (Matlin and Fafchamps 1988):

* To make more complete and efficient use of production factors by spreading their use across enterprises with different temporal profiles;

* To increase aggregate productivity by matching physiological requirements of crops to specific micro-environments;

* To meet domestic household consumption requirements in a context of multiple failures in both product and factor markets;

* In the case of intercropping, to exploit morphological complementarities and compensatory behavior of crop components to improve and stabilize plot level productivity; and

* To reduce aggregate production and income risk.

Diversified cropping patterns can reduce aggregate farm-level income across years (Walker 1986, Lang *et al.* 1984). Indeed we observe that cross time yield variance differs importantly across the major crops of the region. Millet generally displays the greatest yield stability, with groundnut, white sorghum, red sorghum, and maize showing increasing yield risk in
that order. Moreover, in a study of farmers’ perception of yield risks in the Sudan zone of Burkina Faso, Lang et al. (1984) observed that yields are not highly correlated across crops over time. They measured simple correlation coefficients between 0.30 and 0.55 for the majority of crop pairings using 10-year yield recall data adjusted for interfarm variation (Table 4).

As one form of crop diversification, intercropping further improves stability at the plot level to the extent that crop mixtures: yield better than sole equivalents in stress conditions; reduce the incidence and buildup of pests and diseases; or manifest compensatory yield behavior due to differences in crop structure, physiology, or phenology (Norman 1974, Abalu 1976, Willey 1981, Stainer 1982).

ICRISAT survey data revealed significant differences in the degree of crop diversification across study zones. Due to agroclimatic constraints, farmer cropping patterns in Burkina Faso are least diversified in the riskier, lower potential zones surveyed. Millet-based crop enterprises dominate Sahelian cropping systems in which they occupy 93 percent of total cultivated area. White sorghum-based enterprises displace millet as the major crop in the Sudan savanna occupying 55 percent of cropped area, with millet’s share in that transition zone falling to 27 percent. Cropping patterns in the high-potential and relatively low-risk Northern Guinea zone are most diversified with no single crop-based enterprise occupying more than one-third of cultivated area. At 29 percent, cotton is the largest enterprise set -- followed by white sorghum, millet, red sorghum, maize, and groundnut at 27, 22, 10, 5, and 1 percent, respectively. A total of 156 distinct crop enterprises were identified in the Northern Guinea zone compared to 65 and 56, respectively, in the Sahel and Sudan zones.

We measured the degree of crop enterprise diversification across agroclimatic zones by means of the Simpson index (bounded between zero and one, with lower values indicating greater diversity; Patil and Taillie 1982). The results shown in Table 5 confirm the crop share analysis, that diversification is lowest in the Sahel and increases directly with zonal production potential. These patterns reflect the fact that higher rainfall and a longer growing period in the higher potential zones permit farmers to grow a wider range of crops sole, mixed, or in relay cropping systems.

**Varietal Diversification**

Farmers also select and maintain a diversified set of varieties for the major crops as part of their *ex ante* risk management strategy to achieve several objectives. Cultivating varieties with varying maturities permit staggered first plantings which spread the risk of loss due to period-specific stresses, such as brief periods of drought or insect population peaks, both of which may occur during critical crop growth stages. (Varietal differences in maturity are also employed in farmers’ "interactive" management methods discussed below.) Varietal diversification can also reduce the risk of pest and disease losses where there is genetic variability in resistance or tolerance to biotic stresses.

Management of local varieties can also be highly dynamic as varieties are substituted in response to changing environmental stresses. Farmers in the ICRISAT survey villages, for example, distinguished an average of between four and seven local varieties of millet, and between six and eight local varieties of white sorghum across the six study villages. Adoption histories often showed rapid and broad spread of new varieties and suggested that the pace of varietal change and diversification has probably accelerated during the last 20 years. In one of the Sahel study villages, for example, six of the seven millet cultivars in current use were all adopted during the last 15 years; and of the six new cultivars, five were locals which had been introduced by farmers acting independently of the agricultural extension system.
relatively shorter maturity than the varieties they replaced, reflecting adaptation to reductions in precipitation and growing periods experienced throughout the region during the last 20 years (Matlon 1987). Similar patterns were found in the Sudan and North Guinean zones.

The numbers of varieties identified by farmers did not vary systematically between agroclimatic zone, although the extent to which farmers actually planted different varieties as major shares in the cropping patterns did show important interzonal diversification. The lowest degree of varietal diversification was observed in the Sahel zone (see below).

At first sight, the results of these interzonal comparisons of both crop and varietal diversification are counterintuitive. Although it is in the Sahel that the risk of crop failure is highest and the apparent need for crop and varietal diversification greatest, actual diversification is least. The particularly harsh environment of that zone severely limits the number and types of crops that can be economically grown. Moreover, because drought stress is the major cause of crop losses, the likely high correlation between bad outcomes on different crops also reduces the usefulness of crop diversification as a hedge against extreme downside risk in that zone. The shortness of the growing period in the Sahel further reduces the viability of employing cultivars of different duration as a risk escape method.

Land-Type Diversification

Over the gently undulating landscape of the WASAT, soil physical and chemical properties vary systematically with location on the toposequence (Van Stavern and Stoop 1985). Soils on the plateau and upper slopes are frequently located on lateritic caps remaining from the old weathered landscape and thus tend to be shallow with sandy, gravelly top soils. With a low kaolinitic clay fraction and low organic matter content, these soils tend to be droughty with low soil-water holding capacity. Soils on the mid-to-lower slopes tend to be deeper with higher fractions of swelling clays and organic matter. These factors combine to result in better water holding capacity, less risk of soil moisture stress, and larger and more assured fertilizer response. Soils on the extreme lower portions of the toposequence tend to be hydromorphic and experience periodic flooding which limit their exploitation to crops physiologically suited to those conditions.

The principal yield-loss factors differ according to land type. Moreover, the impact of particular factors, such as periodic drought, are poorly correlated across land types. As such, by diversifying plot locations across various toposequence positions farmers are able to reduce plot yield covariation and thus aggregate production variability. To the extent that plots are highly dispersed spatially, farmers are also able to reduce aggregate yield variability caused by location specific impacts; for example, pest and disease losses and highly localized drought. Finally, farmers match crops to the micro-environments in which they best fit agronomically, thus reducing the risk of crop losses due to stresses associated with particular land types.

Despite the lack of a monetized formal land market, the ability of a household to diversify their land holdings does not depend upon land inheritance alone. Means of accessing land of different types include inheritance, clearing from unclaimed bush, and various forms of borrowing. An analysis of transfers of different types of land in the study villages showed that farmers who had inherited limited amounts of land on lower portions of the toposequence -- i.e. preferred, lower-risk land -- borrowed such plots extensively in an effort to diversify their cultivated holdings (Matlon 1989). This had the double effect of increasing their expected returns, as the most profitable crop enterprises can be grown on such land, as well as reducing aggregate production variability through diversification of holdings and, in particular, by protecting yields from losses due to drought.
Farmers in the Burkina study cultivate a large number of plots in highly fragmented and dispersed patterns. But once again the interzonal patterns are at first counterintuitive with respect to the need for risk-avoidance measures. Plot fragmentation is lowest in the Sahel with an average of 10 plots per farming unit, highest in the Sudan (23 plots), and intermediate in the North Guinea zone (15 plots). More importantly, Simpson indexes calculated on land types for each zone in Table 5 show that land type diversification is lowest in the Sahel and increases directly with zonal production potential.

Differences in agroclimatic factors again help explain why farmers in the Sahel zone made less use of this particular ex ante risk-management method. More favorable climate and soils allow farmers to cultivate a wider range of land types in the higher-potential environments. Low rainfall and the poor water-holding capacity of the Sahel's sandy soils limit cultivation primarily to pearl millet for which moisture requirements are least. And because low rainfall constrains farmers from exploiting large portions of land located on the upper slopes of the toposequence, both plot and land type diversification are relatively less important in the Sahel zone than elsewhere.

These points are clearly reflected in Table 6 which summarizes the distribution of crop enterprises across toposequence positions in each zone. Plateau portions of the toposequence are extensively used only in the Northern Guinea zone where higher and more assured rainfall allow extensive cultivation of those shallower soils. In both the Sahel and Sudan zones, farmers avoid plateau portions with less than 3 percent of cultivated area located on these marginal land types. These land use patterns reflect an agronomically logical fitting of crops to land type potentials, and reflect the effort of farmers to avoid risks of moisture stress. However, the more limited options for land type diversification in the Sahel and Sudan zones also mean that crop yields are likely to be more highly correlated in those zones, contributing to greater aggregate production variability.

Conclusions

We conclude that options for ex ante diversification of crops, cultivars, and land types within farmers' traditional cropping patterns can be of only limited effectiveness in the most marginal agroclimatic zones. Low rainfall and shallow droughty soils strictly limit farmers' choices in crop and cultivar selection as well as in allocating plots to land types. As such ex ante methods at the plot and farm levels are relatively inefficient components in the risk strategies of farmers in the riskiest cropping environments.

"Interactive" Methods at the Plot Level -- Sequential Decision Making

At the beginning of each cropping season farmers have subjective expectations developed from past experience concerning: the probable onset, amount, distribution, and duration of rains; the possibilities of pest and disease incidence; and the possibilities of inadequate labor at key points in the cropping cycle. As the season progresses these expectations are revised and farmers sequentially adjust their cropping patterns and cultivation practices to correspond to the occurrence of exogenous shocks. Reducing predetermined commitments and maintaining a high degree of flexibility during this period, such that cropping patterns can be subsequently adjusted as conditions dictate, is crucial for the success of sequential adaptation methods.

Stages in Sequential Decision Making

We can distinguish between four stages of crop management that occur at the beginning of the rainy season (Kristjanson 1987). To simplify, the discussion concentrates on risks induced by variability in precipitation.
The Preliminary Rainfall Stage

Rains are infrequent during this stage and, because they are not viewed by farmers as the onset of assured rainfall, planting does not occur. Nevertheless, rains during this period compared to previous years begin to shape farmers’ expectations for the season and cropping plans are formulated, though subject to subsequent adjustments. This period tends to be very short in the Sahel, of short duration in the Sudan zone, and somewhat longer (up to a month) and more assured in the Northern Guinea zone.

Soil preparation in the Sahel and Sudan zones at this time is negligible due to its brevity, but plowing by hand and animal traction can take place in the Northern Guinea zone if the amounts and duration of rainfall before expected planting dates are sufficient.

The Planting Stage

Major plantings begin immediately with the first adequate rainfall that occurs after what farmers consider “safe” threshold planting dates. Even though long-term probabilities of assured rainfall increase with later dates, farmers intuitively realize that the conditional probabilities of establishing a crop through early planting and subsequent replantings are greater than if they were to wait for a later date and plant only once. Low opportunity cost of labor during this period, and normally adequate seed stocks further support this strategy.

Time-consuming hand planting and the irregular distribution of rainfall during this stage combine to extend major first plantings from over 50 days in the Sahel to over 100 days in the North Guinean zone (Matlon 1987). On soils with low water retention capacity, planting can only be done within two to three days following an adequate rainfall (10 mm approximately), after which farmers must await the next rain to resume safe planting. Delays of 10 days or more between rainfalls during this period are not unusual, particularly in the more arid zones. For these reasons, some farmers begin planting on more humid plots located lower on the toposequence in order to avoid the risk of drought stress at germination and seedling stages.

Direct seeding without plowing is the rule in all but the North Guinea zone. Although research station trials demonstrate that yields can be maximized if plowing and incorporation of a basal dose of fertilizer are executed at the beginning of the rainy season, farmers in each zone rarely use the early rains for plowing (Table 7), and generally delay fertilizer application until first weeding (Matlon and Fafchamps 1988). Preplanting plowing would conflict with farmers’ early planting and reseeding strategy that maximizes their flexibility to adjust to early season rainfall and labor availability. Instead, the most common use of the plow observed in the study areas was to clear weeds from those fields which are sown latest in the season. This provides farmers with greater flexibility by extending their “planting windows” and by staggering the need for early first weeding on late planted areas thereby reducing the risk of labor shortage at the crucial first weeding stage.

Farmers avoid early application of chemical fertilizer for similar reasons. They know early fertilization would encourage greater weed infestation, risk loss of purchased nutrients to weed growth and run-off, and accentuate labor demands at first weeding. They prefer to wait until the pattern of rainfall is better known and seedlings are well-established. This method not only ensures maximum availability of the fertilizer to the crop, but maximum complementarity between soil moisture and fertility increments.

Farmers can adjust cropping patterns throughout this extended first planting stage in response to emerging rainfall patterns by shifting crops to “safer” portions of the toposequence
(e.g. planting upland crops on lower and more humid portions when early rainfall is deficient); changing "intended" crops and/or varieties during late first plantings (e.g. toward those with earlier maturity and/or lower soil moisture requirements -- such as shifting from maize or sorghum to millet or groundnut); and adjusting plant densities positively through late first planting of the main crop or intercrop, or negatively through thinning.

Although the ICRISAT survey did not determine the extent to which farmers modified their original cropping plans by first planting different crops than intended at later planting dates, the survey did identify how they changed varieties as planting dates advanced. Significantly, it was only in the Sudan Savanna and North Guinean study villages that farmers changed to relatively short-duration millet cultivars for late plantings (Matlon 1987). Employing an analysis of variance, highly significant differences were found in first planting dates among the local varieties within individual villages in these two zones. In contrast, because of the much shorter rainfall period in the Sahel there were no significant differences in mean date of planting between varieties. This indicates that genetic variability in maturity periods for the local varieties of millet was too limited relative to the length of the growing season in that zone. As a result, unlike the other two zones, very little varietal diversification was observed as the vast majority of millet area was first sown to a single variety (Kristjanson 1987).

Farmers set their hill densities and seed rates with several risk related goals: to conform to the expected soil moisture regime of the agroclimatic zone and land type; to ensure seedling emergence and survival; and to create flexibility for subsequent changes in plant density.

Survey results show that hill densities are far lower in more arid zones and on more drought-prone land types within each zone. Typical hill densities for millet in the Sahel are between 7,500 and 15,000 hills ha\(^{-1}\), in the Sudan zone this increases to 15,000 - 25,000 hills ha\(^{-1}\), and in the North Guinea zone hill densities vary between 20,000 - 40,000 hills ha\(^{-1}\). Though well below recommended plant population densities based on yield maximizing experiment station conditions, these levels ensure greater probability of crop survival (through decreased competition) during periods of drought, and thus are a means of reducing downside risk.

In contrast, seed rates per hill vary inversely with agroclimatic potential. Typical seed rates for millet in the Sahel are 20 to 60 seeds per hill, in the Sudan 8 to 12, and in the North Guinea zone rates vary between 4 to 10 seeds per hill. The extremely high rates in the more risky arid zone reflect farmers' efforts to ensure adequate germination and seedling emergence in order to obtain full hill stand. Farmers in that zone indicate that high seed rates provide security from both low seed viability and termite damage, as well as providing sufficient mechanical power to ensure seed emergence through capped soils. Farmers also indicated that high seed rates in the Sahel also represent a self-selection method whereby the most vigorous seedlings survive early competition and grow into more robust mature plants.

Low hill densities and high hill seed rates also provide farmers low cost flexibility to change final population densities in response to subsequent rainfall patterns through later thinning and transplanting operations. As such, these planting patterns set the stage for several crop management decisions taken later as part of farmers' sequential decision making.

**Seedling Establishment and Reseeding Stage**

With information on the extent of germination and seedling establishment, farmers form more definitive expectations as to their final cropping patterns. If seedling establishment is poor in early plantings, farmers will reseed up to three times. Reseeding can be to the same variety, or to a different variety or crop if the period becomes too late to fit the maturity period of
the earlier planted materials. In this way shorter-maturing varieties or crops may replace earlier planted long-cycle materials, and/or more drought-tolerant crops may substitute for more susceptible crops. Intercropping with very short cycle crops (e.g., cowpea) also occurs as a form of reseeding during this stage as well as subsequently when major weedings begin.

Kristjanson (1987) examined the frequency with which farmers changed varieties and crops during reseeding and found them to vary widely across agroclimatic zones and years with few consistent interzonal patterns. Table 8 summarizes the degree to which farmers reseeded millet and sorghum to the same and to different varieties. Table 9 shows the frequency with which crops were substituted through reseeding due to the failure of first plantings. Reseeding of major cereals was consistently high in the Sudan zone (ranging between 10 percent and 50 percent of sown area during 1981-83) but reached levels as high as 30 percent in the Sahel and 80 percent in the North Guinean zone in particular years. Varietal substitution was also highest in the Sudan zone. Crop substitution at replanting reached its highest level (approaching 20 percent for white sorghum in 1981) in the North Guinea zone, representing in part replacement through intercrops as well as the shifting of crops along the toposequence.

Kristjanson concluded that while the need for adjustments was greater and more frequent in the Sahel, the flexibility to execute them was again more limited, particularly due to the brevity of the cropping season. The opposite was true of the North Guinea zone. The greater frequency of reseeding in the Sudan zone reflected the coincidence of need (frequent failure of earlier plantings) with greater flexibility (a longer season than in the Sahel).

The Weeding, Thinning, and Late Replanting and Transportation Stage

Farmers also adjust the coverage, timing, and intensity of weeding and thinning to fit evolving conditions in any given year. It was observed that a major share of farmers often plant larger areas than they ultimately weed and harvest (Matlon and Fafchamps 1988). This practice reflects an effort to maximize production during good years while reducing downside risks in bad years. Due to considerable micro-variation in soil depth, the effects of drought are often expressed unevenly over even relatively small plots. With adequate rainfall, even the shallower portions of fields produce sufficient grain to justify the planting costs and cultivation. However, during periods of moisture deficit, seedling survival on such marginal portions can be very low. These areas are often abandoned, with weeding concentrated on those areas where plant growth is better in an effort to further reduce competition for scarce moisture.

A second reason that farmers tend to weed smaller areas than they first plant is that in a poor year weed infestation tends to be less. Thus, if the seedlings survive, contrary to the case just described, it may be possible that the full planted area can be cultivated and brought to harvest. In contrast, during a year of above average rainfall, weed infestation may be higher and thereby demanding greater weeding intensity which may not permit the entire area to be cultivated and harvested. The net result is that the offsetting area and yield effects tend to reduce inter-annual production variability.

It is also during the weeding period that farmers thin plant stands to reduce intra-hill competition for moisture and nutrients. In addition, thinning also provides a source of seedlings for transplanting to fill gaps in empty hills where seedlings have not survived during bad years, or to increase hill density during good years. Providing this kind of flexibility to adjust the plant population with the emerging rainfall pattern is one of the principal reasons that farmers employ the high per hill seed rates observed earlier.
The effort of farmers in more arid environments to preserve plant population flexibility well into the season can be seen when comparing differences in the timing of thinning across zones. Farmers in the Sahel attempt to maintain flexibility as long as possible -- only 30 percent of millet area is thinned at first weeding, and 95 percent of area is thinned at second weeding, on average 65 days after planting (Matlon and Fafchamps 1988). In the less arid Sudan zone, these reverse as farmers thin approximately 77 percent of their millet and sorghum areas at first weeding (approximately 33 days after planting), and only 5 percent (millet) to 19 percent (sorghum) of area at second weeding. Because farmers in the less risky North Guinea zone employ lower hill seeding rates, thinning is performed on less than 20 percent of millet and less than 3 percent of sorghum areas. Moreover, when it is performed, thinning is carried out either as a separate operation soon after planting, or during first weeding. Flexibility to change plant densities is clearly less important in the strategies of farmers in this relatively low risk zone.

The Value of Flexibility

It is evident that flexibility is greatest at the beginning of the season before commitments are made, and declines continuously as decisions are taken on the basis of new information. Kristjanson measured the effect of several management practices on increasing or reducing farmers’ flexibility through an econometric analysis. She divided the production season into the periods noted above and used multi-stage production function techniques to approximate input-use decisions being taken sequentially based on new state of nature information (Antle and Hatchett 1986).

Her results confirmed that earlier planting consistently improved flexibility and reduced risk by allowing farmers to take advantage of early rains while giving them sufficient time to reseed when rains at seedling stage failed. Access to shorter-cycle varieties of millet and sorghum also gave farmers more options as to the timing of plantings and replantings. Chemical fertilizer use (though not manuring) was positively associated with greater flexibility such that estimated optimum doses were greater when decisions to apply fertilizer were taken in a sequential fashion, than when taken on the basis of pre-season information alone. Fertilizer use also allowed farmers some scope to reduce losses due to late plantings by accelerating vegetative growth. Finally, although the small number of observations rendered the plowing terms insignificant, the signs suggested that animal traction plowing reduced flexibility. Because farmers in each study zone generally plant sorghum and millet without soil preparation this probably reflects early season labor conflicts between plowing and timely planting as described above. (More on this in the last section.)

Kristjanson’s analysis also estimated the value of maintaining flexibility for millet and sorghum systems in each zone. This was represented by the production value of employing new information which became available as the season progressed. The estimated value of information was derived from regression coefficients, including higher order interaction terms for period specific rainfall and input-use parameters.

Results showed that the value of maintaining flexibility to employ new information was large and significant in the Sudan and North Guinea zones but not in the Sahel. Traditional farming practices simply offer little flexibility in the tightly constrained Sahelian environment. Across crops and zones the value of flexibility was greatest for sorghum cultivation in the Sudan reflecting the greater sensitivity of sorghum to drought stress (compared to millet) and the greater climatic risks of the Sudan (compared to the North Guinea) zone.
COMPENSATORY *EX POST* RISK MANAGEMENT METHODS

When crop failure occurs despite the application of *ex ante* and *interactive* risk management practices, farmers have recourse to several *ex post* methods to obtain income to protect household consumption. Listed in order of decreasing positive covariance with crop production, these include (Reardon, Matlon, and Delgado 1988):

- Agricultural wage income.
- Inter-household transfers (e.g., gifts in cash or kind).
- Local non-farm income (e.g., trading and artisanal activities).
- Sales of fixed and moveable assets (e.g., livestock).
- Non-local off-farm income (e.g., migratory labor).
- Official food aid.

The success of these components in protecting consumption against major production shortfalls depends on the degree to which their respective income streams are covariant with local cropping outcomes. Because annual rainfall patterns are the major determinant of inter-annual crop yield variation in the sub-region, production is subject to a high degree of intra-regional covariation. Income-earning activities that depend upon incomes generated through input, output, or demand linkages to local cropping are not effective means of stabilizing aggregate incomes by offsetting poor crop yields. For these reasons farm wage employment, receipt of gifts from other farming households, and non-farm employment (which relies upon local demand for goods and services) are relatively ineffective insurance elements when general production shocks occur. Conversely, employment driven by demand in other sectors and particularly in other (less affected) regions is more effective. At the extreme, if properly targeted, official food relief is negatively correlated with cropping outcomes and thus most effective if information, adequacy, and access conditions are met.

Protecting average annual consumption alone, however, is inadequate. Strict seasonal limits to cropping in the WASAT mean that farmers must manage or supplement household cereal stocks and/or income streams throughout the period between annual harvests (Reardon and Matlon 1989). Following a poor harvest, the timing with which farmers allocate their consumption, sales, and purchases can be crucial to ensure adequate calorie intake during the next cropping season when labor demands and energy expenditure peak. Failure to achieve this can be devastating on welfare and subsequent productivity. Severe and sustained calorie deficits that occur during the next cropping season can force households into a poverty cycle not easily resolved by most market-oriented policy instruments.

Severe drought in the Sahel and Sudan zones of Burkina Faso during 1984 provide an example of how farmers employ the major *ex post* methods when crops fail. Low and poorly distributed rainfall that year reduced cereal yields to 42 percent of their average 1981-1983 levels (which were already 10 percent below long-term averages) in both zones. (Household production in the North Guinea zone was relatively unaffected that year with farm incomes actually increasing due to higher crop prices.) As a result, domestic food production from the 1984 harvest met only 29 percent of annual energy requirements among sample households in both affected zones (using the World Health Organization standard of 11.9 kilojoules per day — 2850 calories — for an adult male equivalent).
Average consumption levels, however, differed significantly between sample households in the two zones. Despite identical production deficits, consumption in the Sahel households actually exceeded requirements during the 12 months following harvest, with an average daily intake of 12.2 kilojoules, whereas average consumption among Sudan zone households fell 18 percent below requirement standards at only 9.3 kilojoules per man equivalent per day (Reardon and Matlon 1989).

Seasonal consumption showed similar patterns. Table 10 presents average seasonal energy consumption levels achieved by households in three wealth strata in each zone. Three related features of these seasonal caloric patterns should be noted.

First, consumption levels were not only substantially lower but also more equitably distributed among the Sudan village households. That is, this zone reflects a pattern of shared chronic poverty as nearly all strata were below caloric adequacy throughout the year. In the Sahel zone, however, consumption deficits were largely concentrated among the poorer strata of households. Second, cross-seasonal variation in consumption was considerably higher in the Sudan compared to the Sahel zone, reflecting greater capacity of Sahelian farmers to avoid large seasonal consumption shortfalls by supplementing own cereal stocks.

And third, the likely consequences of caloric shortfalls in the Sudan zone were more serious since the seasonal pattern of consumption and labor demands were countercyclical with energy intake consistently lowest during the following cropping period when energy demands again peaked. Average energy consumption in the Sudan zone was only 75 percent of required levels during the 1985 cropping season. A deficit of this level is likely to have significantly reduced labor capacity, particularly in view of consistently large consumption deficits during each of the preceding nine months. This pattern is in sharp contrast to the Sahel case where average energy intake during the cropping period was 95 percent of requirement, a level fully adequate to meet that period’s labor demands. These comparative results suggest that the frequently cited hungry season hypothesis may be true only in cases of extremely poor production outcomes when households are unable to reduce consumption during earlier low labor demand periods as a means of rationing food stocks for peak demands in the cropping season.

Structure of Income and Assets

Interzonal differences in the structure of assets, income, and food sources underlie these distinct aggregate and seasonal consumption patterns. The success of Sahel households reflected the priority given ex post methods to generate purchasing power in their overall risk management strategies. Earlier discussion has shown how climatic conditions chronically limit the ability of Sahelian farmers to protect total crop production through ex ante diversification methods as well as through interactive management flexibility. As a result, Sahelian households had invested proportionately more in insurance substitutes, such as livestock, which could be easily liquidated to generate cash. The value of livestock herds was nearly three-and-a-half times larger among the Sahelian compared to the Sudanian households surveyed (US$125 versus US$38 per adult male equivalent at 1984 prices).

Sahelian farmers had also diversified their options for non-farm employment across sectors and regions considerably more than had farmers in the Sudan zone. Analysis of income structures shows that the agricultural sector (crop production plus farm wage labor) accounted for only 23 percent of income in the Sahel sample during 1984, but fully 55 percent in the Sudan (Table 11) (Reardon et al. 1988). Alternative income sources included livestock trading and extra-regional employment linked to well-established migration labor networks. Together these provided more than double the absolute income for sample households in the Sahel compared to
those in the Sudan. Since income from both of these sectors is largely determined by economic conditions in national urban centers as well as in coastal countries of West Africa, such earnings have relatively low covariation with local cropping outcomes, and serve to buffer household consumption from the effects of localized production shocks.

**Food Sources**

Tables 12 and 13 show the percentage of calories consumed by source and wealth stratum according to season in the Sahel and Sudan, respectively. In both zones, asset-poor households tended to consume a higher percentage of purchased food as well as food received through transfers. As such their vulnerability to market fluctuations and uncertainties in access to relief assistance was greater. Between 60 percent and 70 percent of all calories consumed by households in the poor and middle asset strata immediately preceding and during the cropping season were obtained through purchases, indicating that dependence on the market was greatest for all but the most asset-rich households precisely during the periods when cereal prices are reaching their maxima.

A brief mention should be made as to the impact of food relief as observed in the present case study, particularly its effectiveness as an component of farmers’ risk management strategies. Donors responded quickly to the poor 1984 harvest and began providing substantial flows within three months. Reliance on food relief was greatest for poor Sahelian households during the immediate post harvest period when it represented 45 percent of calories consumed by that stratum. The share of calories from donor relief remained at about 20 percent for the poor through the cropping season -- or roughly double the share consumed by middle and rich asset households. These patterns indicate that interpersonal targeting of relief supplies was highly efficient at the village level.

Interzonal relief targeting, however, was considerably less efficient. Despite nearly identical production outcomes, donors and government officials essentially bypassed the Sudan zone by directing the vast majority to the Sahel where a greater need was incorrectly perceived. Food relief was more than 10 times greater, in fact, in the Sahel than in the Sudan (298 calories per adult equivalent compared to 23). Ignoring differences in purchasing power, policy makers perceived that emergency assistance was most needed where absolute rainfall and yields were lowest, and the greater actual need of the Sudan zone was not accurately ascertained.

**SYNTHESIS AND IMPLICATIONS**

This overview of farmers’ risk management strategies in the WASAT carry several implications for methods of risk analysis, for policy formulation, and for technology design.

**Analysis of Risk Behavior**

Because the choice and application of most risk management methods are interdependent, it is evident that their analysis poses important problems of simultaneity. The decision to implement any one practice (such as investing in livestock as an insurance substitute) is partially a function of the feasibility, costs, and relative protection afforded by methods applied at other levels and in other time frames (such as crop and plot diversification or access to non-farm employment and income). Dynamic systems approaches, which include multiple sectors and inter-seasonal time frames and linkages, may be necessary to obtain unbiased results in even rudimentary positive or normative analyses of farmer risk behavior.
Policy Formulation

It was stated at the outset that to effectively serve the welfare interests of the rural population, agricultural policies should be consistent with and, if possible, reinforce the risk management strategies enumerated above. It should be clear that policy instruments have greatest potential impact on the *ex ante* and *ex post* components of farmers’ strategies.

Policies which have the effect of improving purchasing power at the farm level serve to reinforce risk management strategies and derive particular importance in those regions where diversification and cropping flexibility are most limited by environmental constraints. Relevant policy actions include:

- Investments in market infrastructure to reduce inter-regional margins for cereals and livestock.
- Increasing counter-season employment opportunities both in the farm sector, through investments in dry-season cropping alternatives, and, in the non-farm sector, through punctual food-for-work projects and through longer-term incentives to non-farm enterprises.
- Concessional sales of cereals to limit post-drought price increases.

Development of Market Infrastructure

Because important components of farmers’ risk management strategies rely upon generating supplementary food purchasing power, market dependence and vulnerability to market inefficiencies tend to be extremely high for low-income producers, as well as for those in the most marginal and risky production environments. While cereal sales are an insignificant part of farmers’ income in bad years, cereal purchases do represent a major share of the diet for the most affected populations. As such, investments that reduce marketing and information costs and that improve the efficiency of inter-regional cereal transfers are highly complementary with farmers’ efforts for self-insurance through market interaction. It is evident that such investments not only have substantial efficiency effects but important equity benefits as well by disproportionately improving the real incomes of the poorest and most affected.

A corollary to this finding is that policies which assist the development of greater and more diversified noncropping income generation opportunities for farmers in low potential areas serve to reinforce their *ex post* risk management strategies. The most effective market oriented options are those types of employment least closely associated with local cropping outcomes through input or output linkages. Policies to facilitate extra-regional income generation, through seasonal labor migration or through sales of farm produced goods linked to demand in coastal or urban areas, may be highly effective from a risk reduction perspective. In the absence of such sectoral developments, punctual food-for-work projects may also be an extremely effective means of generating and targeting purchasing power in immediate post-drought periods with the added benefit of infrastructural spin-offs.

Targeting Relief Assistance

Food relief, either through grants or concessional food sales, is the last and probably least secure element in farmers’ risk management strategies. In any given year and location, however, its impact can be decisive as a means of increasing food availability at the local level while reducing prices and thereby increasing real incomes more generally. However, the case
study of the 1984 drought reviewed earlier demonstrates that gross measures such as crop yields or rainfall deficits may not adequately reflect the need for such emergency food assistance where there are substantial regional differences in production structures and in household purchasing power.

Systematic variation in land/man ratios, in the ownership of moveable assets such as livestock, and in the establishment of links to extra-regional seasonal employment opportunities explain why the risk of severe food insecurity was substantially greater and more widespread in the Sudan savanna study areas, despite identical production deficits. Broader more holistic measures of food insecurity which explicitly include the non-crop sector should be employed to achieve more efficient targeting of emergency assistance. This is most true and implementable at the level of the region, rather than at inter-household levels.

IMPLICATIONS FOR TECHNOLOGY GENERATION

Changes in production technology can affect farmers' risk management strategies in several ways: by increasing farmers' uncertainty of production expectations at early stages of new technology adoption; by directly increasing or decreasing variance in yields depending on the nature of so-called "technology x" environment/management interactions; and by affecting farmers' ability to apply their traditional interactive methods for managing risk.

The first aspect reflects inadequacy of farmers' information on new production techniques and thus is of primary interest in the design of extension approaches. The second aspect constitutes the most common object for most analyses of the risks attendant to technical change and will not be dealt with here. The third aspect forms our focus: that is, how new technical options facilitate or restrict the ability of farmers to execute the risk management methods described earlier. The discussion concentrates on the interactive methods and derives from the recent work of Fafchamps (1989).

Estimating a stochastic dynamic model of farmer behavior fit to the ICRISAT Burkina Faso survey data, Fafchamps analyzed how different types of technical change affect the ability of WASAT farmers to manage production risk through sequential decision-making. The model was designed to include: failure in the farm labor market, precommitments (the commitment of resources to production before the occurrence of certain random factors and thus without "certain" knowledge of marginal productivities), flexibility (the converse of precommitments), and risk aversion.

In a series of simulations using this model, Fafchamps explored the effects on welfare gain and adoption potential for three types of technology:

- Labor saving during the early planting period (e.g. mechanized land preparation equipment);
- Labor saving during the late planting/early weeding period (e.g. mechanized weeding and/or herbicides); and
- Land-saving technology (e.g. high-yielding varieties and fertilizer).

Without entering into the details of his analysis, Fafchamps's principal findings are consistent with the earlier discussion that new technologies must preserve farmer flexibility in order to enable broad adoption and to maximize improvement of farmer welfare. He found that the absence of a labor market and the presence of uncertainty in stochastic production systems
dramatically reduce the response of farm families, both to market incentives and to most technical change options. Although the ability to shift human labor inputs in response to random shocks in nature is the main source of flexibility in WASAT farming systems, the lack of an operating labor market imposes strict limits on the degree of flexibility.

**Flexible Versus Inflexible Technologies**

Fafchamps's modeling also showed that not all random shocks are necessarily bad, and that some can be exploited positively if adequate system flexibility is maintained. Shocks for which no flexibility exists are the most damaging -- for example drought or pest attacks late in the season. It follows that in technology design more emphasis should be placed on increasing system resistance to late season shocks while increasing system responsiveness to early- and mid-season shocks. Technologies that provide farmers with additional flexibility have greater "system" value in a stochastic farming environment than simple average or marginal returns calculations would suggest. The development of earlier maturing varieties are an example. Such materials broaden the "planting window" and thereby give farmers the ability to plant and reseed more often and later into the season, while at the same time escaping late season drought if the rains end early. Other examples are mechanized weeding equipment, herbicides, and late season tied ridging to ensure adequate soil moisture for grain filling.

Simulation runs testing technology alternatives in each of the three zones showed that the lack of labor flexibility reduces the attractiveness of most land saving technologies more than the labor-saving technologies. This is because the greater labor intensity of land-saving technologies (in the face of extremely inelastic family labor supply) can lead to temporary labor shortages; the generally greater precision required in the timing of operations reduces farmers' ability to shift labor within and across periods; and such packages generally require precommitments (e.g. cash outlays, capital investments in equipment, and land improvements) which create not only reduced flexibility but greater potential losses-vulnerability.

**Package Versus Component Approaches**

The common observation that farmers tend to disaggregate packages and adopt single components and/or adjust components to fit different labor profiles can be explained in large part by this analysis. Late animal traction plowing and the delayed timing of fertilizer application, as noted earlier, are cases in point.

The tendency for farmers to adopt individual components, in part as a risk-reduction method, does not mean that the potential technical complementarities need to be lost. Rather, the extension of improved production packages could itself be based on a sequential strategy. In such an approach, extension agents could guide farmers to adopt components incrementally in such a way that earlier components increase the return to and reduce the risks associated with the adoption of later components. An example of this might be the adoption of techniques to reduce soil moisture stress before the promotion of moderate levels of fertilizer so as to improve fertilizer use efficiency and reduce the risk of loss. Both of these components could in turn precede the promotion of input responsive cultivars that yield poorer than local cultivars under soil water and fertility stress conditions, but substantially greater when these constraints are relaxed.

**Precommitments and the Role of Non-farm Income**

Fafchamps used the model to conduct sensitivity analyses on: the cost of technologies (as precommitments); expected returns; and availability or non-availability of non-farm sources of income that are uncorrelated to cropping outcomes. Results showed that in the
absence of substantial non-farm income sources, farmers were generally averse to technologies with high precommitted costs except at extremely profitable rates of return. Simulations showed that farmers generally preferred low-cost technologies even if it meant only modest returns. These results give an additional rationale for the divisibility of technical innovations to make them more attractive to risk-averse farmers.

Non-farm incomes were observed to serve as an essential self-insurance mechanism to avoid bankruptcy when crop failure follows costly precommitments. This result is consistent with several other West African village studies which found that farmers who have invested in animal traction technology are also those households most involved in non-farm (often migrant) employment, despite the fact that the proceeds from such employment are rarely used to purchase the equipment and animals. In short, non-farm income is not only a valuable ex ante method for stabilizing aggregate income and insuring consumption following crop failure, but it (or other self-insurance mechanisms) may also be an essential enabling factor for the adoption of costly technologies.

FOOTNOTES

1/ Crop enterprises were defined as unique combinations of one to three crops grown on the same plot in a given season.

2/ Plots were defined as a contiguous piece of land sown to the same crop or crop mixture and under the management of a single household member.

3/ Wealth strata were defined by ranking households according to the total value of crops and livestock at the end of the 1984 harvest, divided by the number of adult equivalents in the household. Households were then grouped into terciles (Reardon and Matlon 1989, pg. 123).

4/ See, for example, Barrett et al. (1982).
Table 1. Measures of climate and grain yield variation in three agroclimatic zones of Burkina Faso.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Sahel</th>
<th>Sudan Savanna</th>
<th>North Guinea Savanna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual rainfall (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981-1985</td>
<td>380</td>
<td>550</td>
<td>775</td>
</tr>
<tr>
<td>Long-term¹</td>
<td>480</td>
<td>720</td>
<td>940</td>
</tr>
<tr>
<td>Length of growing period (days)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>110-140</td>
<td>130-160</td>
<td>150-190</td>
</tr>
<tr>
<td>Coefficient of variation for annual rainfall (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981-1985</td>
<td>24</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Long-term²</td>
<td>34</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>Coefficient of variation for millet and sorghum yields (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981-1985</td>
<td>71</td>
<td>34</td>
<td>24</td>
</tr>
</tbody>
</table>

¹ Source: Sivakumar, M.V.K. and Gnounon, F. 1987. Agroclimatology of West Africa: Burkina Faso. Information Bulletin No. 23. Patancheru A.P. 502 324 India. ICRISAT. Data are from ORSTOM and from the National Meteorological Service of the Government of Burkina Faso. Data are through 1983 and include 29 years for the Sudan savanna villages, and 58 years for the northern Guinea savanna villages.

² Data are from the ICRISAT farm-level survey for 1981-83.
Table 2. Levels of intervention at which food from different sources are secured in farmers risk management strategies.

<table>
<thead>
<tr>
<th>Level of Intervention</th>
<th>Own Production</th>
<th>Purchases</th>
<th>Transfers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Plant</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Plot</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Farm</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4. Household</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5. Village</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>6. Region</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Table 3. An inventory of risk management methods used by farmers in semi-arid West Africa.

<table>
<thead>
<tr>
<th>Time frame</th>
<th>Scale</th>
<th>Ex ante</th>
<th>Interactive</th>
<th>Ex post</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plant</td>
<td>Varietal selection for stress resistance/tolerance</td>
<td>Replanting with earlier maturing varieties</td>
<td>Grazing of failed plots for animal maintenance</td>
</tr>
<tr>
<td></td>
<td>Plot</td>
<td>Early/staggered planting dates</td>
<td>Changing crops with replanting</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low hill density</td>
<td>Changing plant density through thinning or replanting</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>High seed rates</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intercropping</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Run-off management</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delayed fertilizer application</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farm</td>
<td></td>
<td>Diversified cropping pattern</td>
<td>Shifting crops between land types</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Land type diversification</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plot fragmentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Household,</td>
<td>Cereal stocks</td>
<td>Farm wage labor</td>
<td>Cereal rationing</td>
</tr>
<tr>
<td></td>
<td>village,</td>
<td></td>
<td></td>
<td>Asset sales for food purchases</td>
</tr>
<tr>
<td></td>
<td>region</td>
<td>Livestock/assets</td>
<td></td>
<td>Migration employment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Social networks</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Non-farm employment networks</td>
<td></td>
<td>Food transfers</td>
</tr>
</tbody>
</table>
### Table 4

Correlation matrix for yield estimates based upon subjective yield recall, adjusted for inter-farm variation.

<table>
<thead>
<tr>
<th></th>
<th>White Sorghum</th>
<th>Red Sorghum</th>
<th>Millet</th>
<th>Maize</th>
<th>Peanuts</th>
<th>Cowpeas</th>
<th>Rice</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White Sorghum</strong></td>
<td>1.000</td>
<td>0.6476</td>
<td>0.4779</td>
<td>0.5322</td>
<td>0.4177</td>
<td>0.5497</td>
<td>0.4344</td>
</tr>
<tr>
<td><strong>n</strong></td>
<td>220</td>
<td>120</td>
<td>200</td>
<td>220</td>
<td>180</td>
<td>170</td>
<td>30</td>
</tr>
<tr>
<td><strong>p</strong></td>
<td>0.001</td>
<td>0.001</td>
<td>0.008</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.084</td>
</tr>
</tbody>
</table>

Source: Lang et al., 1984.
Table 5. Simpson diversification indexes for crops, plots, and land types in three agroclimatic zones of Burkina Faso, 1981-85.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Crop</th>
<th>Plot</th>
<th>Land Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sahel</td>
<td>.50</td>
<td>.25</td>
<td>.60</td>
</tr>
<tr>
<td>Sudan Savanna</td>
<td>.42</td>
<td>.13</td>
<td>.54</td>
</tr>
<tr>
<td>North Guinea Savanna</td>
<td>.21</td>
<td>.11</td>
<td>.47</td>
</tr>
</tbody>
</table>

1 Crop enterprises are defined as unique combinations of between one and three crops grown simultaneously on the same plot.

2 Plots are defined as contiguous portions of land sown to the same crop mixture, and under the management of a given household member.

3 Five land types were distinguished based on toposequence postion: plateau, upper slope, mid-slope, lower slope, swamp.
Table 6. The spatial distribution of crop enterprise areas (%) according to toposequence position in three agroclimatic zones of Burkina Faso, 1981-83.

<table>
<thead>
<tr>
<th>Toposequence position b</th>
<th>Savel Sua</th>
<th>Sudan Savanna</th>
<th>North Guinea Savanna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise</td>
<td>1 2 3 4 5</td>
<td>Enterprise</td>
<td>1 2 3 4 5</td>
</tr>
<tr>
<td>Maize</td>
<td>16 44 38 2 0</td>
<td>Millet+Couma</td>
<td>2 32 59 8 1</td>
</tr>
<tr>
<td>Earthnens</td>
<td>8 45 53 2 5</td>
<td>N. Sorgnue+Couma</td>
<td>3 29 54 13 1</td>
</tr>
<tr>
<td>Fento</td>
<td>4 31 60 5 0</td>
<td>Groundnut</td>
<td>1 28 63 10 0</td>
</tr>
<tr>
<td>Millet+Couma</td>
<td>0 38 44 18 0</td>
<td>Sweet Potato</td>
<td>0 15 50 5 0</td>
</tr>
<tr>
<td>Groundnut</td>
<td>0 25 60 15 0</td>
<td>Millet</td>
<td>0 9 22 3 0</td>
</tr>
<tr>
<td>Okra</td>
<td>2 5 73 20 0</td>
<td>Eggplant</td>
<td>0 8 63 19 0</td>
</tr>
<tr>
<td>N. Sorgntum</td>
<td>0 0 5 63 35</td>
<td>Millet+Lima</td>
<td>0 20 51 27 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maize+Lima</td>
<td>0 10 71 17 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Okra</td>
<td>3 12 61 22 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N. Sorgntum</td>
<td>0 12 68 20 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yam</td>
<td>0 1 84 16 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R. Sorgntum</td>
<td>0 10 54 38 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maize+Tobacco</td>
<td>0 10 49 38 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A. Sorgnue+Couma</td>
<td>0 10 52 32 6</td>
</tr>
</tbody>
</table>

Total 3 30 54 11 1 2 26 56 14 2 24 18 20 6 1

a Enterprises are ordered by degree of concentration on upper portions of the toposequence


c Less than 0.5 percent.
### Table 7.
Percentage areas mechanically plowed before planting in three agroclimatic zones of Burkina Faso, 1981-83.

<table>
<thead>
<tr>
<th>Crop Enterprise</th>
<th>Sahel</th>
<th>Sudan Savanna</th>
<th>North Guinea Savanna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Millet</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Millet and cowpea</td>
<td>5</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Sorghum</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Sorghum and cowpea</td>
<td>NA</td>
<td>2</td>
<td>14</td>
</tr>
<tr>
<td>Maize</td>
<td>4</td>
<td>1</td>
<td>40</td>
</tr>
<tr>
<td>Cotton</td>
<td>NA</td>
<td>NA</td>
<td>18</td>
</tr>
<tr>
<td>Cotton and maize</td>
<td>NA</td>
<td>NA</td>
<td>47</td>
</tr>
</tbody>
</table>

Source: ICRISAT survey data.

### Table 8.
Percentage of total area reseeded.

Percentage of millet and sorghum areas reseeded to same variety, and (percentage of areas reseeded to a different variety).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Silggy</td>
<td>9 (0)</td>
<td>10 (0)</td>
<td>13</td>
<td>0 (0)</td>
<td>17 (1)</td>
<td>2 (0)</td>
</tr>
<tr>
<td>Worue</td>
<td>11 (3)</td>
<td>7 (5)</td>
<td>16 (2)</td>
<td>57 (0)</td>
<td>29 (1)</td>
<td>15 (0)</td>
</tr>
<tr>
<td>Kolbila</td>
<td>57 (2)</td>
<td>60 (7)</td>
<td>38 (19)</td>
<td>34 (0)</td>
<td>10 (0)</td>
<td>13 (7)</td>
</tr>
<tr>
<td>Ouounon</td>
<td>18 (0)</td>
<td>43 (28)</td>
<td>37 (0)</td>
<td>28 (6)</td>
<td>13 (0)</td>
<td>19 (2)</td>
</tr>
<tr>
<td>Koho</td>
<td>-</td>
<td>-</td>
<td>1 (0)</td>
<td>8 (0)</td>
<td>35 (5)</td>
<td>36 (2)</td>
</tr>
<tr>
<td>Sayero</td>
<td>18 (0)</td>
<td>82 (0)</td>
<td>7 (0)</td>
<td>13 (0)</td>
<td>40 (0)</td>
<td>53 (0)</td>
</tr>
</tbody>
</table>

Table 9. Crop substitution with replanting.

(%) of area re-seeded to a different crop > 10 days after initial planting.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Millet</td>
<td>W.S.</td>
<td>Millet</td>
</tr>
<tr>
<td>Silgey</td>
<td>17</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Woure</td>
<td>56</td>
<td>11</td>
<td>25</td>
</tr>
<tr>
<td>Kolbila</td>
<td>1</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Ouonon</td>
<td>0</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>Koho</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Sayero</td>
<td>4</td>
<td>18</td>
<td>-</td>
</tr>
</tbody>
</table>


Table 10. Average daily energy intake per adult equivalent by season and startum, Sahel and Sudan village samples (kilocalories).

<table>
<thead>
<tr>
<th>Season</th>
<th>Sahel village sample</th>
<th>Sudan village sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poor</td>
<td>Middle</td>
</tr>
<tr>
<td>Sep-Nov</td>
<td>Oct-Nov</td>
<td>Dec-Feb</td>
</tr>
<tr>
<td>1984</td>
<td>2,595</td>
<td>3,926</td>
</tr>
<tr>
<td>1985</td>
<td>2,335</td>
<td>3,165</td>
</tr>
<tr>
<td></td>
<td>CV</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2,506</td>
</tr>
</tbody>
</table>

Source: Reardon and Matlon, 1989.
Table 11. Household income sources (level) in the Sahel and Sudan samples.

(In Francs CFA per adult equivalent per annum).

<table>
<thead>
<tr>
<th>Sector</th>
<th>Subsector</th>
<th>Sahel</th>
<th>Sudan</th>
<th>(2)/(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(9,090)</td>
<td>(17,130)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Agriculture</td>
<td>Crop Prod.</td>
<td>8,500</td>
<td>9,010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agric. Wages</td>
<td>590</td>
<td>8,120</td>
</tr>
<tr>
<td></td>
<td>Livestock husbandry</td>
<td>8,370</td>
<td>1,930</td>
<td>23%</td>
</tr>
<tr>
<td></td>
<td>Local non-farm</td>
<td>Construction</td>
<td>640</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Commerce</td>
<td>2,510</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Artisanal</td>
<td>5,420</td>
<td>1,370</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Gathering</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Service</td>
<td>980</td>
<td>2,640</td>
</tr>
<tr>
<td></td>
<td>(Subtotal)</td>
<td>(9,580)</td>
<td>(4,250)</td>
<td>44%</td>
</tr>
<tr>
<td></td>
<td>Non-local non-farm</td>
<td>Food aid</td>
<td>8,760</td>
<td>5,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intra-village</td>
<td>1,630</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>From abroad</td>
<td>650</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>(Subtotal)</td>
<td>(3,020)</td>
<td>(2,360)</td>
<td>78%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>38,810</td>
<td>30,880</td>
<td>80%</td>
</tr>
</tbody>
</table>

Source: Reardon et al., 1988.
### Table 12. Breakdown by food item and source of caloric intake per season, Sahel village sample (percent).

<table>
<thead>
<tr>
<th>Asset strata</th>
<th>Sep-Nov</th>
<th>Dec-Feb</th>
<th>Mar-May</th>
<th>Jun-Aug</th>
<th>Sept-Nov</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produced</td>
<td>72</td>
<td>37</td>
<td>46</td>
<td>10</td>
<td>66</td>
<td>51</td>
</tr>
<tr>
<td>Purchased</td>
<td>25</td>
<td>17</td>
<td>54</td>
<td>69</td>
<td>14</td>
<td>32</td>
</tr>
<tr>
<td>Food aid/gift</td>
<td>1</td>
<td>45</td>
<td>0</td>
<td>21</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produced</td>
<td>82</td>
<td>27</td>
<td>22</td>
<td>25</td>
<td>66</td>
<td>49</td>
</tr>
<tr>
<td>Purchased</td>
<td>16</td>
<td>50</td>
<td>78</td>
<td>70</td>
<td>21</td>
<td>42</td>
</tr>
<tr>
<td>Food aid/gift</td>
<td>2</td>
<td>23</td>
<td>0</td>
<td>4</td>
<td>13</td>
<td>8</td>
</tr>
<tr>
<td>Rich</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produced</td>
<td>86</td>
<td>47</td>
<td>43</td>
<td>59</td>
<td>73</td>
<td>63</td>
</tr>
<tr>
<td>Purchased</td>
<td>10</td>
<td>33</td>
<td>57</td>
<td>34</td>
<td>19</td>
<td>28</td>
</tr>
<tr>
<td>Food aid/gift</td>
<td>4</td>
<td>20</td>
<td>0</td>
<td>6</td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

Source: Reardon and Matlon, 1989.

### Table 13. Breakdown by food item and source of caloric intake per season, Sudano-Sahel village sample (percent).

<table>
<thead>
<tr>
<th>Asset strata</th>
<th>Sep-Nov</th>
<th>Dec-Feb</th>
<th>Mar-May</th>
<th>Jun-Aug</th>
<th>Sept-Nov</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produced</td>
<td>69</td>
<td>76</td>
<td>25</td>
<td>40</td>
<td>89</td>
<td>61</td>
</tr>
<tr>
<td>Purchased</td>
<td>29</td>
<td>23</td>
<td>74</td>
<td>58</td>
<td>10</td>
<td>38</td>
</tr>
<tr>
<td>Food aid/gift</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Middle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produced</td>
<td>86</td>
<td>72</td>
<td>38</td>
<td>24</td>
<td>88</td>
<td>62</td>
</tr>
<tr>
<td>Purchased</td>
<td>13</td>
<td>27</td>
<td>61</td>
<td>72</td>
<td>11</td>
<td>37</td>
</tr>
<tr>
<td>Food aid/gift</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Rich</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Produced</td>
<td>83</td>
<td>91</td>
<td>77</td>
<td>53</td>
<td>95</td>
<td>80</td>
</tr>
<tr>
<td>Purchased</td>
<td>17</td>
<td>10</td>
<td>22</td>
<td>43</td>
<td>4</td>
<td>19</td>
</tr>
<tr>
<td>Food aid/gift</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Source: Reardon and Matlon, 1989.
REFERENCES


LIVESTOCK IN MEDITERRANEAN FARMING SYSTEMS:  
A TRADITIONAL BUFFER AGAINST UNCERTAINTY IS NOW  
A THREAT TO THE AGRICULTURAL RESOURCE BASE

Peter J.M. Cooper and Elizabeth Bailey

ABSTRACT

Rainfed farming in West Asia and North Africa has evolved against a background of highly variable rainfall and temperature conditions. Traditional systems developed strategies to buffer against climatically induced uncertainty of production, a prime example being the close integration of crop and livestock enterprises. In this paper, climate, as the basis of uncertainty and risk, is discussed, and a broad overview of the evolution of different farming systems is presented. The integration and role of livestock, principally sheep, in these systems is highlighted together with an assessment of regional trends in livestock numbers and feed supplies.

Syria is taken as a case study and examined in significant detail. Rising demand for livestock products has resulted in a dramatic increase in national sheep flock size (3.1 to 13.3 million) in the last 35 years. The derived demand for barley, grain, and straw has caused an equally dramatic increase in the area sown to barley, which has risen from 0.75 million ha. in 1960 to 2.9 million ha. in 1988/89, but yields per hectare have largely stagnated. Analysis of secondary data of area, yield, and production in terms of sheep feed equivalents (SFE) showed that 30 years ago, Syria would have expected a sheep feed equivalent deficit of 3.0 million SFE only once in ten years. Whereas, today it would be expected that this deficit would exceed 4.0 million SFE nine out of 10 years. This is reflected in our analysis of barley trade figures which indicate that Syria has moved from being a frequent exporter to a frequent importer of barley in the last 25 years.

The data indicate that the rapid expanse of the area under barley has been achieved by expanding cultivation into more and more marginal environments, and through the adoption of barley monoculture. National average yields have not increased, but clear indications of increased yield variability are present. Currently, barley cultivation occupies two-thirds of the arable land in Zones 2 to 5. The implications of this apparent strategy on sustainable production and resource conservation are discussed.

Other possible strategies are examined through the utilization of our research results on improved barley production practices and improved cropping systems. The analyses indicate that alternative strategies are possible. Reducing the area under barley in the marginal areas of Zones 4 and 5 and improving production on the remaining area through the introduction of simple,
improved practices -- such as seed dressing, drill sowing, the use of nitrogen and phosphorus fertilizer, and the maintenance of the barley/fallow rotation -- has the potential to meet national flock feed requirements in 75 percent of years and, at the same time, will increase the stability of production over time. In addition, the introduction of forage legumes would further enhance the national feed supply in all but the driest years.

INTRODUCTION

Agricultural systems first evolved in the Mediterranean basin over 10,000 years ago in the fertile crescent of West Asia. These systems have been the center of origin of many major cereal and legume crops and of the early domestication of sheep and goats.

The development of agriculture from these early times, through the period of Roman administration, the subsequent periods of Arab and Turkish domination, and the more recent colonial period of the 19th and 20th centuries has been reviewed elsewhere (White 1963, 1970; Watson 1974) and the evolution and characteristics of existing farming systems have been described in some detail (Grigg 1974, Aschmann 1977, Oram 1979, Gibbon 1981, and Tully 1986).

McWilliam (1981) notes that the problem facing farmers throughout this period of evolution has remained the same, namely that of farming in an environment characterized by highly variable and often chronically deficient rainfall. Many of the strategies developed as "buffers" against this uncertainty of rainfall are still common features of current farming systems. These are, however, becoming increasingly threatened as radical changes in food and feed demand place greater pressure on the region's land resources.

While the climate, soils, crops, and livestock which form the essential edaphic and biological components of the farming systems have probably changed little over time, both the social and economic environments in which farmers operate are today radically different. National policies emphasizing industrialization, pricing policies favoring urban populations, and neglect of both basic services and farming in rural areas have led to stagnation of agriculture and emigration of the farming community.

Throughout the region the relative importance of agriculture has declined in recent decades, and, in most countries, food production per capita has also declined; yet the population is increasing (Tully 1989). It has been estimated that by 1990 the countries within the Mediterranean basin will face an annual 30 million to 34 million ton food deficit.

Such predictions highlight recent trends of increased demand for livestock products and the associated derived demand for increased supplies of coarse grain feed, principally barley (Khalidi 1984; Food and Agricultural Organization [FAO] 1987). Substantial regional deficits in barley production already exist and are predicted to rise sharply by the year 2000.

The FAO suggests that the nations of West Asia and North Africa can help alleviate these deficits in three principal ways. Twenty percent of possible increases may come through fallow replacement, 7 percent could come from expanding the area under production, but over 70 percent must come from increasing production per hectare.

In the context of increasing sheep feed supply to meet the demands of expanding national flocks, the nations of the region will continue to rely heavily on barley production as a major source of feed through the consumption of grain and straw and often through green grazing of immature crops. In addition, they will also continue to depend on the natural pastures which are
seasonally available on marginal lands. Such lands are unsuitable for cultivation, either due to
topographical features or because they occur in areas too dry for sustainable agriculture. Since
barley is also largely produced in the drier and lower potential agricultural systems of the region, it
is clear that much of the projected increase in sheep feed supply must come from the region’s most
fragile and vulnerable environments. Both the challenges involved and the potential threat to the
agricultural resource base are very real.

Climatic Variability: The Basis of Uncertainty and Risk in Rainfed Mediterranean Farming Systems

Rainfall

In the Mediterranean region of West Asia and North Africa (WANA), the rainy season
begins about October and ends in May or June. Most rain occurs during the cool or cold winter
months of December, January, and February. At the beginning and end of the season, rains are
less reliable. Summers are hot and arid.

The quantity of rainfall is determined by proximity to the coast or to significant
topographical features such as mountains. There are steep gradients in precipitation across short
distances, and changes as great as 3-to-4 mm/km are common; the Syrian isohyet map illustrates
this (Figure 1). In general, coastal areas are wettest, and they support intensive horticulture and
agriculture. Declining rainfall with distance inland leads to systems dominated first by wheat then
by barley, before arable land gives way to large expanses of steppe grazing lands and desert in the
interior of land masses. These systems are described in more detail in subsequent sections.

Rainfall varies not only in space, but, even more importantly, in time. At any one
location large differences are recorded, not only in the total seasonal amounts (Figure 2a), but also
in its distribution through the season (Figure 2b). Kassam (1981) pointed to a general relationship
between seasonal rainfall totals, the length of potential growing season, and crop yields. Smith
and Harris (1981) also discussed the implications of variable rainfall on soil moisture dynamics and
crop yields. They correctly emphasized the importance of analyzing long-term rainfall records in
terms of probability when assessing the implication of improved production practices.

The direct effects of rainfall amounts and distribution on crop water use, growth, and
yield have been extensively documented and reviewed (e.g. Cooper et al. 1987). In the
Mediterranean environment, the spatial and temporal variability of rainfall is the single most
important factor associated with the uncertainty of crop production (and hence risk), which typifies
the region.

Temperature

Variation in temperature, both in space and time, is also an important factor and causes
unpredictable hazards to crop production. In general, winter months are cool or cold, and
temperatures are sub-optimal for plant growth. A strong continental influence causes winters in
West Asia to be quite cold, and plateau areas experience severe frost and prolonged snow cover.
Milder conditions prevail in North Africa, except for small areas in the Atlas Mountains (Figure 3).

In the spring, temperatures rise rapidly; super-optimal temperatures and large vapor
pressure deficits occur widely in late spring and early summer when crops are maturing.

As with rainfall, temperatures vary from year-to-year, causing the length of the growing
season to vary by as much as 3 weeks to 4 weeks. Extreme low temperatures due to radiation
frosts are an unpredictable hazard in much of the region’s lowlands.
Climatic Uncertainty and Pest Development

A plant disease problem results from the interaction of at least two organisms -- the host plant and the disease (or insect) pest. Both are influenced by the environment. Humidity is often considered the key environmental parameter in the development of pathogens. High moisture is needed for the pathogen to penetrate the plant and often for the reproduction of leaf diseases. The relationship between moisture and root diseases is more complex with certain pathogens requiring high soil moisture while others are favored by dry conditions (i.e., dryland root rots caused by Cochliobolus and Fusarium). The development rate of a fungus within the plant is temperature-dependent and differs greatly between pathogens. Diseases that can develop at relatively low temperatures, like barley scald (Rhynchosporium secalis) or yellow rust (Puccinia striiformis) are often more severe in regions of West Asia where periods of rainfall are often associated with low temperatures. Powdery mildew (Erysiphe graminis) and leaf blotches like Septoria and Pyrenophora are more serious in the mild winter areas of North Africa.

Like diseases, the size of insect pest populations is dependent on factors affecting birth, death, immigration, and emigration of individuals in the population. These factors include within-species and among-species competition effects, predation and parasitism, interactions with the host plant, and weather conditions which directly affect the insect or influence the quality of its host plant.

Insect pest problems in West Asia and North Africa are diverse in nature and are rather localized, as are the environmental conditions of each region. Wheat stem sawflies are serious pests of wheat and barley in the 250 mm to 350 mm rainfall zones of Syria and Morocco, but they are relatively unimportant elsewhere.

The effect of plant stress on the insect population is not clear, although it appears that mild stress in some cases enhances the attractiveness of the host plant to the insect. Ground pears, Porphyrophora, rapidly become serious pests of wheat and barley monocultures along the drought-stressed desert fringes of Syria and Turkey but are insignificant, though present, in higher rainfall areas. During high-rainfall years in these areas, such as at Breda and Boudier in Syria, ground pearl populations decrease while other pests, such as sawflies, spread from their normal ranges into these zones. In general, highly stressed plants are neither acceptable to the farmer or to the insect pests that would otherwise infest them.

The complex interaction between environment, pest, and host plant makes prediction of the development of diseases and pest populations dependent on the prediction of key meteorological factors that set the level of interaction between pests and hosts. Prediction of pest outbreaks also depends on a thorough knowledge of the host-pest system. Presently neither of these fundamental necessities are realized for the low rainfall areas of West Asia and North Africa. Thus unpredictable and climatically associated outbreaks of pest and disease problems will continue to contribute to the uncertainty of crop production.

EVOLUTION OF BROADLY DEFINED AGRICULTURAL SYSTEMS

Four broadly defined agricultural systems have evolved in response to the prevailing climatic and soil conditions:

1. Steppeland and native pastures.
2. Systems dominated by livestock and barley production.
3. Systems dominated by wheat, food legume, and summer crop production.
4. Irrigated systems.
Steppeland and Native Pastures

Native pasture is used primarily for the grazing of small ruminants. Where rainfall exceeds 250 mm, native pasture encompasses land that is too steep or stony, or where the soil is too shallow, for arable agriculture. In West Asia such pastures usually occur on the foothills and slopes of mountain ranges, while in North Africa they may also be found on sandy soils of low-water holding capacity. The vegetation is dominated by annual grasses, legumes, and herbs, and the perennial vegetation is severely degraded.

Where rainfall is below 200 mm, native pastures cover most of the land surface -- although at the wetter margin areas barley cultivation is encroaching. Communal ownership of and open access to land is increasing, replacing the old tribal control which broke down earlier this century. Originally a shrub steppe or even savanna woodland, the land is now characterized by ephemeral vegetation of very low productivity.

Stocking rates are difficult to estimate but probably reach one sheep/ha in areas of higher rainfall. Native pastures rarely support livestock on a year-round basis and are grazed mainly in winter (low-rainfall areas) or spring (high-rainfall areas). For that reason, the use of native pastures is to a greater or lesser extent integrated with the wheat-based and barley/livestock systems which are described below.

Barley/Livestock Farming Systems

Adjacent to the dry steppe (between approximately 200 mm and 350 mm rainfall), the production of livestock, principally sheep and goats, continues to be the dominant enterprise and provides the bulk of farmers’ income through sales of dairy products, meat, and wool. Barley, by far the most common crop, is grown without inputs. Both grain and straw are used as livestock feed. Throughout the region, a barley/fallow rotation still predominates, but increasingly, fallow is being regarded by farmers as an inefficient use of land. With greater availability of mechanization for tillage operations, continuous barley production is becoming more common despite being detrimental to yield. Such yield reductions are associated with a range of factors including reduced moisture supply, lower soil nitrogen availability, and a build up of root pathogens.

Although barley is a major source of livestock feed, farmers’ use various other sources of feed, depending on seasonal availability. General patterns of livestock feeding cycles are described later. Potential production in the barley/livestock systems is lower and more variable than in the wheat-based systems. Few national governments have developed policies that favor the introduction of improved technology into these drier areas; yet, urbanization and rising incomes throughout the region are leading to an increased demand for the livestock products they generate.

Because of the production risks inherent in the environment and the lack of available technology, few farmers are prepared to invest in costly inputs such as fertilizer. Faced with increased density of rural population and a national demand for more livestock products, farmers have responded by cultivating more and more marginal land for barley and overgrazing the natural pastures. Now, these factors severely threaten the natural resource base. Many farmers are forced to seek off-farm employment to supplement and secure their income.

Wheat-Based Systems

In the higher rainfall areas (between approximately 350 mm and 600 mm average seasonal rainfall), the main crop is wheat. Bread wheat predominates at the wetter end of this range, but durum wheat forms the basic staple at the drier end. A wheat/fallow rotation is
common, but in wetter areas and on good deep soils wheat is grown in rotation with food legumes and summer crops such as melon, maize, sesame, sunflower, and cotton. Among the legumes, chickpea predominates in wetter areas and lentil in drier ones.

Tree crops are often an important source of income. On smaller farms, many farmers own both sheep and dairy cattle; on such farms some barley is also grown, and both grain and straw are used as feed, together with other crop residues such as wheat stubble and lentil straw. Local native pastures on hilly terrain and weeds and volunteer cereals on fallow land are grazed as well. Where local water supplies exist (wells and seasonally filled dams or rivers), supplemental irrigation of both winter and summer crops is profitable and is becoming increasingly common.

Potential crop production is high in the wheat-based systems, and farmers are financially more secure. National Agricultural Research Systems (NARS) have allocated most of their research and development resources to these areas and have in many cases been successful in developing improved technologies, supported by policies that have encouraged rapid adoption by farmers.

Irrigated Farming Systems

In the driest regions, with annual rainfall below 150 mm, farming is possible only under irrigation using available surface water or groundwater. The main examples occur along the Nile River in northern Sudan and Egypt, along the Euphrates in Syria and Iraq, along the Jordan River, and in Saudi Arabia. Less common is cultivation based on water harvesting and wadi farming. Examples are found in the Yemen Arab Republic, northwest Egypt, and Baluchistan Province of Pakistan.

There is considerable interdependence between irrigated and rainfed farming systems. Crop residues and industrial crop by-products from irrigated systems are frequently used as supplemental feed for livestock from rainfed systems. Transfer of feedstuffs between the systems may be subsidized.

INTEGRATION OF LIVESTOCK INTO FARMING SYSTEMS

The Livestock Feeding Cycle

Livestock play a key role in the farming systems of the WANA region. Our attention is restricted to the role of small ruminants (sheep and goats) which predominate in the drier zones of the region; cattle tend to be confined to wetter areas and irrigated regions.

Feeding of livestock follows a yearly cycle (Figure 4). Following the onset of rains in October and November, fresh fodder becomes available in late winter or early spring and remains available until the beginning of summer. Weedy fallow lands and natural pasture are at their most productive during the spring months, when lambs are weaned and ewes produce most milk. Many flocks move from the barley belt to the steppe areas to graze during this period, but some flocks remain in the village provided there is sufficient natural grazing. Cereal crops may also be grazed during early growth, a practice which some farmers claim is beneficial to yield through improved tillering and reduced lodging. However, in the dry barley-producing zones of northern Syria, this practice has been shown to reduce yields considerably (ICARDA 1984, p. 48). During this period, income from stock sales and dairy produce is at a peak, sustaining many farmers until the crop harvest.

The cereal harvest starts in late May, and the flocks which moved to the steppe in spring return to the cropped areas. Crop stubbles and residues from wheat, barley, legumes, and summer
crops are used to feed the animals throughout the summer and early autumn months. In years of low productivity, standing crops of cereals - uneconomic to harvest - are also grazed. In general, all crop residues are used as animal feed and in many instances the value of the straw may equal or exceed the monetary value of the grain.

Livestock feeding is most difficult in late autumn and early winter. With the onset of the rains, early winter grazing may be good, but it is unreliable as it is dependent on both rainfall and temperature. In many areas supplementary feeding, largely of stored barley grain and straw, is required to sustain the flocks until the spring months when natural grazing is once again more assured. Other supplements used include wheat and lentil straw, cotton seed cake and hulls, cotton seeds, sugar-beet pulp, wheat bran, and often waste bread.

Studies in Syria revealed that one-third of the metabolizable energy from supplements fed in winter comes from barley grain, and another third from barley straw. These findings were used in estimating that the barley crop provides 53 percent, and natural pastures 27 percent, of the annual metabolizable energy needs of an Awassi ewe yielding 110 kg milk. Other supplementary feeds and crop residues provide the remaining 20 percent (Thomson 1987).

In drought years, the normal feeding cycle is severely disrupted as the feed supply from the communal grazing areas is drastically reduced and winter supplementary feeding is extended. Grazing areas cannot support the flocks, and farmers are forced to graze their barley during the early vegetative stage through to harvest. This practice greatly reduces the availability of storage feed for the next winter, but allows the farmers to fatten lambs for sale and reduce the number of ewes in their flocks. In such dry years, the feed supply in the villages is exhausted by June; the sheep then are moved to wetter areas where they are fed on rented wheat stubble and summer crop residues. In Syria during 1983-84, a drought period, an estimated three million sheep had to be slaughtered because of shortages in feed supply, illustrating the fragile nature of the barley/livestock farming systems (Cooper et al. 1987).

Because barley is the most important source of feed in the region, farmers attempt to sow a large enough area of barley to be self-sufficient. Where farms are large, or farmers own few sheep, barley may be grown as a cash crop with the stubble being rented for grazing by migrating flocks. As a multi-purpose crop which can be used for green- or mature-stage grazing, for harvesting as grain and straw, and for stubble grazing, barley is ideal for areas with a highly variable climate because farmers can make decisions on the use of the crop at various stages of growth.

The integration of barley and livestock management is crucial to the survival of many farmers, especially in dry areas. Few crop decisions are made without considering the feed requirements of livestock, and few livestock decisions are made without considering feed availability (Thomson, Bahhady and Nordblom 1982).

**Contribution of Livestock to the Farm Household**

On a national scale, livestock production is commonly viewed in terms of meat production for the urban consumer, and, as will be demonstrated, national flocks have expanded to meet the rising demand from a rapidly growing urban population. However, livestock play an equally important role in supporting the farm household, especially on smaller farms. They contribute a large proportion of farm income through the sale of lambs, cull animals, dairy products, and wool, and they provide a valuable dietary contribution to the household while serving as a buffer in years of low crop production.
Livestock are a relatively low-cost enterprise and in large part can be fed on by-products of food crop production and natural pasture (though supplemented by barley grain in the winter). Farmers with small holdings invest more in livestock, which may contribute up to half of their income, supplemented by off-farm employment (Cooper et al. 1987). In a survey of barley producers in Syria in 1981-82, it was found that in drier areas farm income comprised 64 percent to 74 percent of total family income, and barley and livestock were ranked as the most important activity (Somel and Mokbel 1986). Similarly, a survey of small- to medium-sized farms in an area of extensive cereal and livestock production in northwest Tunisia found that for 53 percent of farmers, livestock were the major source of income, while for 49 percent, off-farm activities were the major source, with "farming" playing a minor economic role due to the small size of holdings (Ben Achour 1988). A comparison of family income by production strategy from a random sample of farmers in Jordan reveals that farms with livestock not only obtain a greater part of their income from on-farm activities but also, on average, have significantly higher incomes than farmers involved only in cereal and olive production (Tutwiler et al. 1989).

Dairy products are a major source of high-quality protein for farm households. Milk is processed into yogurt, cheese, and ghee for sale as well as for home consumption. On-farm meat consumption, on the other hand, is limited (Somel and Mokbel 1986).

Finally, the ownership of livestock plays an important role in reducing the risk associated with climatic variability by acting as a buffer against uncertain crop yields. Unlike crop production, the raising of livestock requires a relatively low investment; they can also be sold immediately in times of need for cash. In drought years when crops are poor and harvesting would be uneconomic, farmers graze their crops and may also reduce their flock size through sales thereby generating income, which may be used for purchasing supplements for winter feeding. At the same time, flock reduction reduces feed requirements in the following winter when stored barley grain and straw will be in short supply due to the poor harvest. Thus, livestock add stability to a farmer’s income, liquidity to his cash flow, and provide flexibility in his management options (Nygaard and Amir 1988).

Regional Trends in Livestock Numbers and Sources of Feed

Forty years ago, the WANA region was a net exporter of food, but due to its rapidly expanding population it has become one of the largest food-importing regions of the developing world. Overall, WANA-region populations are growing at the rate of 2.6 percent annually, rising from 416 million in 1985 to an estimated 622 million by the year 2000. The region’s population is projected to stabilize at about 1.5 billion by the year 2030. Such population increases, coupled with rising standards of living and gradual urbanization, form the basis of predictions of major deficits in livestock feed (barley and maize) and livestock products by the year 2000, as well as other major food commodities (Table 1).

To meet such predicted deficits, increases in production would have to be sustained at over 5 percent annually, a rate that has never been attained in agricultural history. It is thus almost certain that food self-sufficiency, a policy objective in many countries, will be unattainable this century and probably well beyond. Increased self-reliance would appear a more reasonable goal.

In response to the increased demand for livestock products, the region has experienced a substantial increase in small ruminant (principally sheep) numbers in the last 25 years, which closely reflects the regional average population growth rate (Table 2).

Larger national flocks have created a derived demand for greater feed supply, and, as a result, regional barley production and importations have also shown parallel increases in most
countries (Table 3), while exports have declined. It should be pointed out that the national consumption figures in Table 3 reflect not only feed for livestock, but also to a lesser extent other uses such as seed requirements and human consumption.

Disaggregation of production data into area and yield (Table 4) shows that the area under barley production has expanded rapidly during the last 20 years. In most countries, yields also appear to have increased. But without a parallel examination of national climatic data, it is difficult to judge to what extent this is due to improved production technologies or to natural variability in seasonal rainfall. This is examined in more detail for Syria later in this paper.

SYRIA: A CASE STUDY

Recent Trends in Sheep Numbers and Barley Production

Reference to Tables 2, 3, and 4 indicates that of the selected countries, Syria demonstrates some of the most dramatic trends in livestock and livestock feed production. This is illustrated in more detail in Figure 5.

Since 1951, the national flock size has increased steadily from 3.1 million to its current level of 13.3 million in 1988, reflecting similar human population changes. Within this general upward trend, two periods of decline in numbers occurred, 1958 to 1961 and later from 1970 to 1973. These downward trends correspond to periods of successive drought years when national barley production levels were very low and other sources of feed must have been similarly affected. As indicated before, under such circumstances farmers are forced to sell a part of their flocks in order to raise capital to purchase feed to sustain the remainder.

The numbers of sheep slaughtered for consumption within Syria rose in proportion to population until 1982, but since then has levelled off suggesting that rising prices of meat may be reducing per capita consumption. Such a trend, if accurate, may well ameliorate some of the predicted demands for livestock products and result in larger than predicted demand for pulses as an alternative and cheaper source of high-quality protein (Oram and Belaid 1989). However, we must caution that the figures represent those animals registered in Syria’s official slaughterhouses, and do not include animals slaughtered privately (Bahhady 1989). The increasing difference in the national flock size and the number of sheep slaughtered probably reflects increased export of sheep to some of the Persian Gulf countries.

In contrast to the dramatic changes observed in livestock numbers, barley production has largely stagnated, with only a slow upward trend starting in the early 1970s. However, a more detailed examination (Figure 6) indicates that this increase in total production results entirely from an expanded area under production, rising from a relatively constant 750,000 ha between 1960 and 1970 to over 1.4 million ha from 1983 onwards. In the 1988-89 season, 2.9 million ha. of barley was planted in Syria, and government plans are for 2.5 million ha. in the 1989-90 season. A part of this area’s increase has occurred at the expense of wheat in the higher potential wheat-based systems, but the vast majority has been achieved through the expansion of barley cultivation into drier and more marginal environments and the gradual abandonment of fallow by farmers in traditional barley-growing areas.

National average yields of barley have, however, remained highly variable and show no upward trend over time. Such variability is typical within the region and is largely attributable to variations in seasonal rainfall. To illustrate this association, we took the seasonal rainfall totals from over 25 meteorological stations within the barley-growing areas of Syria, and from these
records we obtained a mean "national average" rainfall for each of the years from 1961 to 1986. These "national average" rainfall estimates were closely related to national average barley yields according to the equation:

\[ \text{Nat. Av. Yield} = -283 + 3.50 \times \text{Nat. Av. Rain} \quad (R^2 = 0.684) \quad \ldots \ldots \quad (1) \]

A great deal of research at ICARDA and elsewhere (see Cooper et al. 1987, 1989) has shown that improved crop and soil management offers considerable scope for greater crop water use efficiency and growth and yield of barley in these dryland areas. However, a simple comparison of "national water use efficiency" indicates no such improvement between the period 1960 to 1970 and 1975 to 1985 (Table 5). Our survey results and research trials would suggest that this apparent lack of change probably marks some improvement in production practices in the wetter areas, which are offset by the minimum-input practices followed by farmers as continuous barley becomes more widespread and production expands into more marginal and risky environments.

Barley's Potential to Meet the Energy Requirements of the Syrian National Flock

In the previous section we have shown that the national average barley yields show a natural variability, closely associated with seasonal rainfall, and that there are no apparent trends in yields or water-use efficiency. We do note however (and will discuss in more detail later) that the coefficient of variation (CV) of national average yields in the period 1975 to 1985 is considerably higher than that of 1960 to 1970, and yet the CV of national average rainfall was substantially lower (Table 5).

For the purpose of our analysis, however, we have utilized the entire 27-year database (1960 to 1986) to calculate the cumulative frequency distribution of national average yields, and we have assumed that this distribution was equally valid for the two five-year periods, 1960-65 and 1982-87. Based on this assumption, we have made a series of calculations which illustrate some dramatic changes in the ability of the barley crop (grain and straw) to meet the energy requirements of the national flock, and the extent to which additional sources of feed must be sought. Such sources include importation of barley grain, purchase of agro-industrial by-products, and the use of marginal grazing areas. These results are presented as cumulative frequency distributions in Table 6.

Section A of the table presents the cumulative frequency distribution of national average grain yields, and in section B, these are converted into cumulative frequency of grain production for the periods 1960-65 and 1982-87 using the average areas under production during those periods. A further transformation of the data into sheep feed equivalents is presented in section C, based on the energy content of barley, grain, and straw, an assumed harvest index, and the annual energy requirements of a breeding ewe. We should emphasize here that conversion into sheep feed equivalents can be done either on an energy basis or on a protein basis. Both are valid but give slightly different results (Jones 1989). One reason for choosing the basis of energy is that the protein content per kilo of barley grain and straw varies much more between seasons than the energy content, and therefore would introduce greater error through assuming a constant value across seasons.

Section D of Table 6 presents the cumulative frequency distribution of sheep feed equivalent deficits, based on the average national flock size in the two periods. These figures represent the additional feed required over and above that provided by barley and illustrate the dramatic changes which have occurred. Many observations are possible, but some of the most important ones are:
In the period 1960-65, the "sheep feed equivalent deficit" would only have been expected to exceed 3.2 million one year out of 10, whereas now it can be expected to exceed this figure by at least one million sheep feed equivalents nine years out of 10.

Traditionally, barley grain and straw were, on average, expected to meet about 60 percent of a sheep's energy requirements in Syria (Thomson 1987). Our calculations (section E) confirm that this would have indeed been achieved or exceeded in 50 percent of the years in the period 1960-65, but now it is only likely to be possible in the 20 percent most productive years.

Impact of Recent Trends on the Uncertainty of Barley Production

In order to meet the expanding feed requirements of its national flock, Syria has moved from being a frequent net exporter of barley to being a frequent net importer (Figure 7).

As illustrated in Figure 6, Syria has responded to this increasing dependence on barley imports by the abandonment of fallow and the expansion of barley cultivation into drier and more marginal areas. We believe that this trend has alarming implications for the future uncertainty of national barley production and for the conservation of the fragile resource base which is currently being exploited.

In 1975, Syria defined Agricultural Stability Zones based on expected seasonal rainfall and (to some extent) on the probability of receiving those amounts. The distribution and definition of those Zones are presented in Figure 8, together with the recommended cropping strategy for each Zone.

Clearly, more complex and detailed land suitability classifications, which take into account topographical features and contrasting soil conditions, are possible, but this classification was based on sound principles. Rainfall, the single most important factor determining crop performance, formed the basis of the zonation, and some account of its temporal variability was included. Recommendations of the agronomic suitability of crops and cropping sequences were based on years of previous experience, years when the absence of more recent pressures had allowed the development of farming systems well buffered against climatic uncertainty.

Barley was recommended to be grown in Zones 2, 3, and to some extent in Zone 4. In Zone 2 it was largely restricted to the shallow soils of low-water holding capacity -- such land usually being under a two-year barley/fallow rotation. In Zone 3, barley was identified as the principal crop, again largely being grown in a barley/fallow or barley/barley/fallow rotation but sometimes in rotation with lentils. In Zone 4, some barley was also recommended, but it was also recognized that much of Zone 4 was too dry for cultivation and should only be used as grazing land.

Zone 5 was clearly identified as an area unsuitable for the cultivation of rainfed crops, reserved only for the provision of winter grazing or for irrigated agriculture. Since the establishment of these zones in 1975, the area under barley cultivation has expanded from 1.01 million to 1.84 million ha. in 1988, and to 2.89 million ha. in 1989. For the 1989-90 season, 2.54 million ha. were planned. The details of this expansion in area for each Zone are given in Table 7 and the associated barley yields in Table 8. The percentage contribution of each zone to the national production is given in Table 9.

The area under barley has gradually expanded in all Zones except in Zone 1 (Table 7). In Zone 2, our survey results indicate that this is largely due to displacement of wheat by barley on
the better soils (Tully and Rassam 1985), but in Zones 3 and 4 the increased area largely results from the abandonment of fallow. In a national survey of 153 barley producers conducted in 1982, Somel et al. (1984) showed that many farmers were already growing continuous barley or were reducing the frequency of fallowing as shown below.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>B/F</th>
<th>B/B</th>
<th>B/B/F</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 2</td>
<td>53</td>
<td>20</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>Zone 3</td>
<td>33</td>
<td>36</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>Zone 4</td>
<td>25</td>
<td>65</td>
<td>10</td>
<td>0</td>
</tr>
</tbody>
</table>

The dramatic increase in area under barley in Zone 5 results from land traditionally reserved for grazing being put under the plow. Inevitably, it is the higher potential steppeland bordering on Zone 4 which is cultivated first. As can be seen in the area planned for the current season, this policy of plowing steppeland has received the official sanction of the government of Syria, together with the abandonment of fallow.

Average yields obtained in each zone are given in Table 8. As would be expected, yields decline steadily from Zone 1 to Zone 5, and the coefficient of variation rises dramatically. Accompanying this rise in the variability of yield is an increase in the frequency of occasions on which no grain would be harvested.

This does not, of course, constitute crop failure in the accepted sense, since both green grazing and the grazing of mature crops do provide valuable sources of feed. Such practices may make barley cultivation in Zone 5 economical for individual farmers, but we certainly question its wisdom at the national planning level. Not only are the severely threatened natural pastures of the steppeland, which are already overgrazed, being gradually destroyed through cultivation, but soil, wind, and water erosion in these areas has accelerated rapidly during recent years (Fryrear 1989). If we examine the percent contribution of each Zone to Syria’s national barley production (Table 9), this point is further reinforced. Even in extremely wet seasons, such as in 1988, the contribution of Zone 5 is marginal at 13 percent. Given that such seasons are only likely to occur once every 30 years, and the highly variable yields obtained (CV of 114 percent), we believe that cultivation of barley in Zone 5 is neither sustainable in economic terms, nor, and more importantly, in terms of the conservation of the natural resource base.

Furthermore, the trend toward barley monoculture, although attractive at first sight and now apparently officially recommended by government policy, is also unlikely to provide sustained increases in production. Long-term trials at ICARDA have demonstrated that yields decline unless fertilizer is applied regularly, and even when it is, the variability of yields over time remains greater than in the traditional barley/fallow rotation.

**Research on Improved Barley Production Systems in Syria**

In 1984 ICARDA and the Syrian Soils Directorate initiated a collaborative research project on fertilizer use on barley. The object of the project was to assess the biological and economic
effects of the use of nitrogen and phosphorus fertilizer on barley, through multiple-season, multiple-location trials on farmers’ fields in the agricultural stability Zones 2 and 3 of northern Syria.

The trials have been conducted over four years (1984/85-1987/88) on a total of 75 sites. The range of locations and seasons allows environmental variability to be taken into consideration. Sites were deliberately selected to represent a range of soil type and depth, rainfall and rotation, including land in both barley/barley (B/B) and barley/fallow (B/F) rotations. Although the trials were restricted to Zones 2 and 3, it should be noted that during the four years two extremely dry years occurred representing conditions normally prevailing in Zone 4.

The trials are described in detail elsewhere (SMAAR/ICARDA 1985 to 1988). Briefly, they consisted of replicated factorial trials with four levels of nitrogen fertilizer: 0, 20, 40, 60 kg N/ha, and four levels of phosphorus: 0, 30, 60, 90 kg P₂O₅/ha. Improved practices incorporated in all treatments included seed treatment with fungicide and precision drill planting. Chemical weed control was utilized only when necessary. At each site, soils were characterized and analyzed, and rainfall was measured weekly so that the critical parameters of available N and P and rainfall could be incorporated into the interpretation of the results.

Potential Barley Production from Improved Practices

Extensive economic analysis of results from the trials are reported elsewhere (Somel, 1989). In this paper, results from these on-farm trials (OFT) are used, in conjunction with data on national average rainfall and barley areas, to assess the potential of improved barley production to meet feed requirements.

To do this we have restricted our analysis to yield data from four treatments representing the two rotations without fertilizer (Bo/Bo and Bo/F) and with 20 kg N/ha. and 60 kg P₂O₅/ha. applied in the barley phase (Bnp/Bnp and Bnp/F). The treatments without fertilizer still represent improved practices of seed dressing and drill planting. The fertilizer treatment of 20 kg N/ha. and 60 kg P₂O₅/ha. was selected because it is close to the rate recommended from results from the trials and currently being demonstrated to farmers.

Yields (grain and straw) per hectare were converted to Sheep Feed Equivalents (SFE), as discussed earlier, and the relationships between SFE/ha and the rainfall recorded at each OFT site were estimated, with the following results:

- Bo/F: SFE/ha = -11.05 + 0.1008 Rain - 0.0001 Rain² (Adj R² = 0.552)
- Bnp/F: SFE/ha = -11.09 + 0.1136 Rain - 0.0001 Rain² (Adj R² = 0.632)
- Bo/Bo: SFE/ha = -7.68 + 0.0664 Rain - 0.0001 Rain² (Adj R² = 0.507)
- Bnp/Bnp: SFE/ha = -12.47 + 0.1073 Rain - 0.0001 Rain² (Adj R² = 0.649)

The estimated response relationships and our "national average" rainfall estimates were used to predict the potential "national average" SFE per hectare obtainable from each of the four selected treatments for the 27-year period.

To estimate the potential production from these treatments requires some assumptions to be made regarding the area planted to barley. The total arable area in agricultural stability Zones 2 to 5, and the Syrian government’s planned area for barley in 1989-90 are given in Table 7 and are reproduced as follows:
The planned barley area represents some two-thirds of the total arable area in Zones 2 to Zone 5. The planned area for Zone 4 implies that barley is to be grown in continuous rotation, reflecting a deliberate policy to abandon fallow rotations.

In estimating the production potential of the four selected treatments we hypothesized two scenarios. Scenario I retains the planned barley area for 1989-90, excluding that planned for Zone 5. Zone 5 is excluded because it was not included in the OFT and because the principal concern which prompted this research was to investigate means of reducing feed deficits while at the same time halting the expansion of cultivation into the fragile environments of the dry zones.

Scenario II reduces the barley area in the drier marginal zones even further. Here, we referred to the original definition of agricultural stability Zones (Figure 8). The planned area for Zone 2 was retained. The original description of Zone 3 states that barley is the principal crop, though some pulses can be grown. We therefore allocated 75 percent of the total arable area in Zone 3 to barley. This represents an increase of 65,000 ha. on the planned area in Zone 3 for 1989-90. Finally we allocated half the arable area of Zone 4 to barley, the remainder being conserved for natural grazing.

The two scenarios are summarized below:

<table>
<thead>
<tr>
<th>Million ha.</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total arable area</td>
<td>1.878</td>
<td>0.859</td>
<td>0.998</td>
<td>0.563</td>
<td>3.725</td>
</tr>
<tr>
<td>Planned barley area</td>
<td>0.646</td>
<td>0.580</td>
<td>0.867</td>
<td>0.400</td>
<td>2.493</td>
</tr>
<tr>
<td>% of arable area</td>
<td>34.4</td>
<td>67.5</td>
<td>86.9</td>
<td>71.0</td>
<td>66.9</td>
</tr>
</tbody>
</table>

Fallow is found to be valuable in maintaining output in only the very driest years, reflecting the soil moisture conserving advantage of a fallow rotation. In these driest years the B/F rotation would produce more than continuous barley despite the fact that only half the area is yielding a crop. However, as rainfall increases, the area advantage of continuous barley outweighs the moisture-conserving advantage of the barley/fallow rotation.

When fertilizer is applied to a barley/fallow rotation, production would exceed that from unfertilized continuous barley (from double the area) in all but the wettest 20 percent of years. However, continuous barley with added fertilizer clearly dominates Bnp/F in all but the driest years.
Production Potential and National Feed Requirements: Alternative Strategies

In selecting the OFT treatments and defining the two scenarios analyzed here, we were concerned with assessing to what extent improved production practices on a reduced area could fulfill national feed requirements compared with the current production strategy.

We will take as our reference point Scenario I (planned barley area excluding Zone 5) under continuous barley (Bo/Bo), reflecting current policy to abandon fallow. This represents a reduction in the cultivated area in only the very driest areas (steppe) and the minimum improvements in production practices (seed dressing, drill planting). This will be referred to as Strategy A.

Improved strategies are represented by Strategy B, which reintroduces fallow into the rotation, adds fertilizer to the barley phase (Bnp/F), and reduces the cultivated area in Zone 4 (Scenario II); and Strategy C, which adds fertilizer to continuous barley (Bnp/Bnp) on the same reduced area (Scenario II). The cumulative frequency distributions for these contrasting strategies are shown in Figure 9.

If barley were expected to provide the total annual feed requirements of the national flock then, based on the average national flock size in 1982 to 1987 (Table 6), Syria would have to produce 12 million SFE of barley annually. However, as noted earlier, barley grain and straw are, on average, expected to meet about 60 percent of sheeps' energy requirements in Syria. This was achieved or exceeded in 50 percent of years in the period 1960-65, but under current production strategies is only possible in 20 percent of years.

By adding the improved practices of seed dressing and drill planting to continuous barley production on the current planned area in Zones 2 to 4 (Strategy A), Syria would achieve or exceed 60 percent of its feed requirements (7.2 million SFE) in approximately 75 percent of years. However, the same result would be achieved by applying fertilizer in a barley/fallow rotation on a reduced area (Strategy B).

In Figure 9, the crossover point between the distributions from Strategies A and B occurs at approximately 6.5 million SFE. Below this crossover point, in drier years, potential production is higher under Strategy B. Strategy C, applying fertilizer to continuous barley on a reduced area, shifts the distribution to the right and potential production is higher in all but the very driest years. Sixty percent of national feed requirements would be achieved or exceeded in approximately 80 percent.

Any distinction made between the three strategies depends on the criteria used. If the objective is to maximize the probability of meeting national flock feed requirements, then Strategy C is preferred. If, on the other hand, the objective is to maximize the SFE obtained in the poorest of years, then Strategy B is preferred (but only marginally). Equating risk with variability, then Bnp/F (Strategy B) would be preferred (compare percentage CVs in Table 10).

In Strategy A, areas in Zone 5 were excluded. In a wet year, yields from the planned barley area in Zone 5 may indeed boost production above that shown in Figure 9. However, the negligible yields achieved in Zone 5 in dry years (see Table 8) would merely serve to increase the variability in production. Even in the infrequently occurring very wet seasons (e.g. 1987-88), the contribution of Zone 5 to Syria's total production is minimal (see Table 9).

In any event, the analysis demonstrates that there are alternatives to the current strategy of expanding cultivation into more and more marginal areas. Reducing the area under barley in the
marginal areas of Zones 4 and 5 and improving production practices on the remaining area (by encouraging fertilizer use and maintaining a barley/fallow rotation) would reduce the probability of drastically low production in dry years from land under continuous barley and increase the stability of production over time.

The Introduction of Forage Legumes into Barley Rotations

In assessing the potential contribution to the nation's sheep feed supply through the introduction of forage legumes in barley-based rotations, we have used a dataset from a single long-term rotation trial established in 1980-81 at Breda (long-term average rainfall 270 mm) in northern Syria. Unlike our analysis from the multi-season, multi-location on-farm trials, we recognize the dangers of extrapolating the results of this single-location trial across space and have not attempted to do so. Instead we have used long-term climatic data (1960 to 1987) for extrapolation over time only. Details of this trial have been reported elsewhere (Jones 1989).

Other studies at ICARDA have also examined the nitrogen, phosphorus, and water dynamics of this trial in some detail (Rached 1986; Keatinge et al. 1987; Harris 1988), but their important conclusions fall outside the scope of this paper.

We have selected the yield data from six treatments representing a combination of three rotations (barley/fallow, barley/barley, barley/vetch hay) and two fertilizer treatments (0, and 20 kg N, 60 kg P$_2$O$_5$/ha applied to the barley phase). The barley and vetch yield data were converted into sheep feed equivalents (Table 11), which follows, and the relationships between sheep feed equivalents/ha. and seasonal rainfall were established for each rotation/fertilizer combination.

Using the relationships in Table 12, and seasonal rainfall records from Breda village for the period 1960-1987, production in terms of sheep feed equivalents were predicted for the 27-year period. These are presented as cumulative frequency distributions in Table 13 and Figure 10.

The effects of rotation (barley/fallow v. barley/barley), and the implications of adding fertilizer are similar to those predicted from our on-farm trial results, and need not be further discussed. The introduction of vetch, either to replace fallow or continuous barley, appears to be beneficial. Compared with a barley/fallow rotation, a barley/vetch rotation is clearly superior in terms of sheep feed equivalents, except in the driest years (compare Bo/F v. Bo/Vo; Bnp/F v. Bnp/Vo at decile 0.1 in Table 13). In spite of twice the area being under production in the barley/vetch rotation, it has little or no advantage in such dry years. However, seasons with as little as 136 mm rainfall have not been experienced in the life of the trial, and hence we must view this conclusion with some caution.

Considering the situation of replacing continuous barley with a barley/vetch rotation, we again observe the benefit of including vetch except in the drier years (compare Bo/Bo v. Bo/Vo; Bnp/Bnp v. Bnp/Vo at decile 0.1 in Table 13).

Our analysis suggests that the introduction of vetch as a hay crop would produce more sheep feed equivalents in about 90 percent of the years compared with either a barley/fallow or barley/barley rotation both in the presence and absence of fertilizer. However, we must emphasize two important points:

- Concurrent on-farm surveys and trials in Syria, focusing on the introduction of forages, have clearly indicated that whereas farmers appear ready to accept this technology, they prefer to utilize the forage as a source of green grazing rather than a hay crop. This is associated with the cost of hand-harvesting (Tully 1984) and dry matter losses incurred...
during the hay-making process (Osman and Thomson 1985). More recent on-farm trials have shown that either green grazing or harvesting the forage as a mature crop are both economic and acceptable to the farmers (Thomson et al. 1989).

- Our analysis indicates that forages may be considered risky by some farmers due to their poor performance in the drier years. This assessment is based only on output data and does not consider the costs involved in the production of the various rotations. Thomson et al. (1989) have shown substantially increased production costs when replacing fallow with forages, and this would undoubtedly contribute further to some farmers reluctance to adopt this technology.

CONCLUSIONS

Syria’s rapidly increasing population and rising standard of living, accompanied by a gradual process of urbanization, has led to a dramatic increase in the demand for livestock products over the last 25 years in Syria. This has been reflected in a threefold increase in its national sheep flock and an equivalent increase in demand for livestock feed.

Resulting from this increased feed demand, several clear trends are evident:

- Syria has moved from being a frequent net exporter of barley to a frequent net importer.
- Due to greater livestock numbers and greater frequencies of feed shortages, the natural pastures are rapidly being destroyed through overgrazing.
- In order to increase its principal feed supply, Syria has officially sanctioned the cultivation of the steppeland and the abandonment of the traditional barley/fallow rotation and the adoption of barley monoculture.
- As a result of this policy, barley production is becoming more variable, but has only shown slight increases on a national basis in recent years.

We do not believe these marginal increases are sustainable, and already an accelerated degradation of the natural resource base is evident in the marginal environments where barley is being grown.

However, alternative strategies are possible. Reducing the area under barley in the marginal areas of Zones 4 and 5 and improving production on the remaining area through the introduction of simple improved practices, such as seed dressing, drill sowing, the use of nitrogen and phosphorus fertilizer, and the maintenance of the barley/fallow rotation has the potential to meet national flock feed requirements in 75 percent of years and, at the same time, will increase the stability of production over time. In addition, the introduction of forage legumes would further enhance the national feed supply in all but the driest years.

For such strategies to succeed, Syria would need to develop positive support policies which not only make the essential inputs available but also encourage an active demonstration of their effective use to farmers.
Table 1. Predicted food and feed deficits in the WANA region by the year 2000.

<table>
<thead>
<tr>
<th>Million Metric Tons</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>33.9</td>
</tr>
<tr>
<td>Rice</td>
<td>3.0</td>
</tr>
<tr>
<td>Maize</td>
<td>11.0</td>
</tr>
<tr>
<td>Barley</td>
<td>11.3</td>
</tr>
<tr>
<td>Meat</td>
<td>1.5</td>
</tr>
<tr>
<td>Milk</td>
<td>11.4</td>
</tr>
<tr>
<td>Vegetable oils</td>
<td>5.7</td>
</tr>
<tr>
<td>Sugar</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Source: FAO 1987

Table 2. National flock size in selected countries of the WANA region (millions).

<table>
<thead>
<tr>
<th>Average increase (percentage)</th>
<th>1961-1963</th>
<th>1986-1988</th>
<th>per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>4.6</td>
<td>14.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Morocco</td>
<td>10.9</td>
<td>14.8</td>
<td>1.4</td>
</tr>
<tr>
<td>Tunisia</td>
<td>3.1</td>
<td>5.8</td>
<td>3.5</td>
</tr>
<tr>
<td>Syria</td>
<td>4.0</td>
<td>12.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Turkey</td>
<td>32.8</td>
<td>40.4</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Weighted Average = 2.4 percent

Source: FAO Production Year Books
Table 3. Average barley production, imports and exports of selected countries in WANA for two periods (1000 metric tons).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>265</td>
<td>30</td>
</tr>
<tr>
<td>Morocco</td>
<td>954</td>
<td>10</td>
</tr>
<tr>
<td>Tunisia</td>
<td>181</td>
<td>23</td>
</tr>
<tr>
<td>Syria</td>
<td>510</td>
<td>3</td>
</tr>
<tr>
<td>Turkey</td>
<td>3433</td>
<td>4</td>
</tr>
</tbody>
</table>

Source: FAO Production and Trade Books

Table 4. Average barley yields (kg/ha) and areas planted (1000 ha) in selected countries of WANA for two periods.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>Area</td>
</tr>
<tr>
<td>Algeria</td>
<td>483</td>
<td>526</td>
</tr>
<tr>
<td>Morocco</td>
<td>560</td>
<td>1712</td>
</tr>
<tr>
<td>Tunisia</td>
<td>317</td>
<td>543</td>
</tr>
<tr>
<td>Syria</td>
<td>813</td>
<td>594</td>
</tr>
<tr>
<td>Turkey</td>
<td>1250</td>
<td>2743</td>
</tr>
</tbody>
</table>
Table 5. National average barley grain yields, rainfall, and water-use efficiency.

<table>
<thead>
<tr>
<th>Period</th>
<th>Nat. Av. Yield (kg/ha)</th>
<th>Nat. Av. Rain (mm)</th>
<th>Nat. Av. Water Use Efficiency (kg/ha/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960-1970</td>
<td>780 (37)</td>
<td>308 (29)</td>
<td></td>
</tr>
<tr>
<td>1975-1985</td>
<td>681 (50)</td>
<td>273 (18)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Figures in parentheses are CVs (%).
Table 6. Cumulative frequency distribution of national average barley grain yields, total grain production, sheep feed equivalents, and sheep feed equivalent deficits. Based on Syrian national statistics (1960-86).

<table>
<thead>
<tr>
<th>Decile</th>
<th>Grain Yield/kg/ha</th>
<th>Total Production (million tons)</th>
<th>Sheep Feed Equivalents (millions)</th>
<th>Sheep Feed Equivalent Deficit (millions)</th>
<th>Percent Energy Requirements of National Flock met by barley</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>230</td>
<td>0.172 0.345</td>
<td>0.81 1.61</td>
<td>3.19 10.39</td>
<td>20.3 13.4</td>
</tr>
<tr>
<td>0.2</td>
<td>318</td>
<td>0.238 0.477</td>
<td>1.12 2.23</td>
<td>2.88 9.77</td>
<td>28.0 18.6</td>
</tr>
<tr>
<td>0.3</td>
<td>424</td>
<td>0.318 0.636</td>
<td>1.49 2.98</td>
<td>2.51 9.02</td>
<td>37.2 24.8</td>
</tr>
<tr>
<td>0.4</td>
<td>609</td>
<td>0.457 0.914</td>
<td>2.14 4.29</td>
<td>1.86 7.71</td>
<td>53.5 35.8</td>
</tr>
<tr>
<td>0.5</td>
<td>723</td>
<td>0.542 1.084</td>
<td>2.54 5.08</td>
<td>1.46 6.92</td>
<td>63.5 42.3</td>
</tr>
<tr>
<td>0.6</td>
<td>826</td>
<td>0.619 1.239</td>
<td>2.90 5.81</td>
<td>1.10 6.19</td>
<td>72.5 48.4</td>
</tr>
<tr>
<td>0.7</td>
<td>929</td>
<td>0.697 1.394</td>
<td>3.27 6.53</td>
<td>0.73 5.47</td>
<td>81.8 54.4</td>
</tr>
<tr>
<td>0.8</td>
<td>1004</td>
<td>0.753 1.506</td>
<td>3.53 7.06</td>
<td>0.47 4.94</td>
<td>88.3 58.8</td>
</tr>
<tr>
<td>0.9</td>
<td>1119</td>
<td>0.839 1.678</td>
<td>3.93 7.87</td>
<td>0.07 4.13</td>
<td>98.3 65.6</td>
</tr>
</tbody>
</table>

Note 1/ Uses average area under production of 0.75 million ha in 1960-65 period, and 1.50 million ha in 1982-87 period.

Note 2/ Conversion of production to SFE assumes (1) Harvest Index of 0.40, (2) Barley Grain = 11.5 MJ/kg, (3) Barley Straw = 5.5 MJ/kg, (4) Annual Energy Requirement = 4200 MJ/ewe.

Note 3/ Uses average National Flock of 4.0 million in 1960-65 period and 12.0 million in 1982-87 period. Deficit figures represent additional feed required over and above that provided by barley.
Table 7. Total land area, arable area and area under barley production in the different Agricultural Stability Zones of Syria (1000 ha).

<table>
<thead>
<tr>
<th>Zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total land area</td>
<td>2710</td>
<td>2470</td>
<td>1300</td>
<td>1800</td>
<td>10200</td>
<td></td>
</tr>
<tr>
<td>Total arable land</td>
<td>1710</td>
<td>1878</td>
<td>859</td>
<td>998</td>
<td>563</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
<th>Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>110</td>
<td>270</td>
<td>285</td>
<td>323</td>
<td>100</td>
<td>1088</td>
</tr>
<tr>
<td>1980</td>
<td>101</td>
<td>308</td>
<td>280</td>
<td>328</td>
<td>177</td>
<td>1193</td>
</tr>
<tr>
<td>1981</td>
<td>130</td>
<td>335</td>
<td>279</td>
<td>414</td>
<td>170</td>
<td>1328</td>
</tr>
<tr>
<td>1982</td>
<td>118</td>
<td>331</td>
<td>303</td>
<td>505</td>
<td>317</td>
<td>1574</td>
</tr>
<tr>
<td>1983</td>
<td>106</td>
<td>357</td>
<td>341</td>
<td>519</td>
<td>181</td>
<td>1505</td>
</tr>
<tr>
<td>1984</td>
<td>69</td>
<td>361</td>
<td>291</td>
<td>363</td>
<td>189</td>
<td>1274</td>
</tr>
<tr>
<td>1985</td>
<td>58</td>
<td>358</td>
<td>299</td>
<td>435</td>
<td>217</td>
<td>1367</td>
</tr>
<tr>
<td>1986</td>
<td>79</td>
<td>463</td>
<td>302</td>
<td>464</td>
<td>221</td>
<td>1529</td>
</tr>
<tr>
<td>1987</td>
<td>71</td>
<td>486</td>
<td>330</td>
<td>455</td>
<td>221</td>
<td>1563</td>
</tr>
<tr>
<td>1988</td>
<td>88</td>
<td>562</td>
<td>402</td>
<td>463</td>
<td>308</td>
<td>1822</td>
</tr>
<tr>
<td>1989</td>
<td>87</td>
<td>807</td>
<td>634</td>
<td>806</td>
<td>541</td>
<td>2876</td>
</tr>
</tbody>
</table>

Table 8. Average yields of barley grain obtained in the different Agricultural Stability Zones of Syria (kg/ha).

<table>
<thead>
<tr>
<th>Year</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Zone 5</th>
<th>Mean</th>
<th>CV (%)</th>
<th>% Years no harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>840</td>
<td>620</td>
<td>300*</td>
<td>80*</td>
<td>20*</td>
<td>1367</td>
<td>885</td>
<td>9</td>
</tr>
<tr>
<td>1980</td>
<td>2360</td>
<td>1660</td>
<td>1220</td>
<td>970</td>
<td>780</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>1760</td>
<td>1080</td>
<td>920</td>
<td>910</td>
<td>810</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>1330</td>
<td>700</td>
<td>380</td>
<td>200*</td>
<td>10*</td>
<td>1512</td>
<td>103</td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>1340</td>
<td>860</td>
<td>680</td>
<td>490</td>
<td>440</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>1110</td>
<td>460</td>
<td>50*</td>
<td>10*</td>
<td>90*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td>1220</td>
<td>830</td>
<td>440</td>
<td>400</td>
<td>200*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>1470</td>
<td>980</td>
<td>610</td>
<td>510</td>
<td>360*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>1240</td>
<td>740</td>
<td>200*</td>
<td>80*</td>
<td>30*</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1988</td>
<td>1890</td>
<td>1644</td>
<td>1482</td>
<td>1577</td>
<td>1202</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>475</td>
<td>160*</td>
<td>55*</td>
<td>51*</td>
<td>12*</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Occasions on which the bulk of the crop would have either been grazed during the vegetative stage or as mature standing crop (Thomson et al., 1983).
Table 9. Percent contribution of different Agricultural Stability Zones to Syria's total barley production.

<table>
<thead>
<tr>
<th>Zone</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1979</td>
<td>24</td>
<td>45</td>
<td>23</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>1980</td>
<td>15</td>
<td>33</td>
<td>22</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>1981</td>
<td>17</td>
<td>27</td>
<td>19</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td>1982</td>
<td>25</td>
<td>40</td>
<td>18</td>
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<tr>
<td>1983</td>
<td>14</td>
<td>30</td>
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<td>25</td>
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<td>1984</td>
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<td>1985</td>
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</tr>
<tr>
<td>1986</td>
<td>11</td>
<td>42</td>
<td>17</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>1987</td>
<td>16</td>
<td>64</td>
<td>12</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>1988</td>
<td>6</td>
<td>33</td>
<td>21</td>
<td>26</td>
<td>13</td>
</tr>
<tr>
<td>1989</td>
<td>16</td>
<td>51</td>
<td>14</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td>Mean</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
Table 10. Cumulative frequency distribution of potential production (million SFE) from improved practices for two hypothetical scenarios.

<table>
<thead>
<tr>
<th>Deciles</th>
<th>Seasonal rain (mm)</th>
<th>Predicted SFE (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bo/F</td>
</tr>
<tr>
<td>Scenario I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>168</td>
<td>2.8</td>
</tr>
<tr>
<td>0.2</td>
<td>197</td>
<td>4.6</td>
</tr>
<tr>
<td>0.3</td>
<td>268</td>
<td>8.1</td>
</tr>
<tr>
<td>0.4</td>
<td>278</td>
<td>8.5</td>
</tr>
<tr>
<td>0.5</td>
<td>286</td>
<td>8.8</td>
</tr>
<tr>
<td>0.6</td>
<td>294</td>
<td>9.1</td>
</tr>
<tr>
<td>0.7</td>
<td>326</td>
<td>10.1</td>
</tr>
<tr>
<td>0.8</td>
<td>355</td>
<td>10.8</td>
</tr>
<tr>
<td>0.9</td>
<td>392</td>
<td>11.4</td>
</tr>
<tr>
<td>Mean</td>
<td>283</td>
<td>8.0</td>
</tr>
<tr>
<td>% CV</td>
<td>27.2</td>
<td>39.3</td>
</tr>
<tr>
<td>Scenario II</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>168</td>
<td>2.4</td>
</tr>
<tr>
<td>0.2</td>
<td>197</td>
<td>3.9</td>
</tr>
<tr>
<td>0.3</td>
<td>268</td>
<td>6.9</td>
</tr>
<tr>
<td>0.4</td>
<td>278</td>
<td>7.3</td>
</tr>
<tr>
<td>0.5</td>
<td>286</td>
<td>7.5</td>
</tr>
<tr>
<td>0.6</td>
<td>294</td>
<td>7.8</td>
</tr>
<tr>
<td>0.7</td>
<td>326</td>
<td>8.6</td>
</tr>
<tr>
<td>0.8</td>
<td>355</td>
<td>9.2</td>
</tr>
<tr>
<td>0.9</td>
<td>392</td>
<td>9.7</td>
</tr>
<tr>
<td>Mean</td>
<td>283</td>
<td>6.8</td>
</tr>
<tr>
<td>% CV</td>
<td>27.2</td>
<td>39.3</td>
</tr>
</tbody>
</table>

Notes:

a) Scenario I: Planned barley area (1989/90) excluding zone 5
Scenario II: Planned area in zone 2; 75% of arable area in zone 3; and 50% of arable area in zone 4.

b) Bo/F: Barley/fallow rotation, no fertilizer
    Bnp/F: Barley/fallow, 20 kg N/ha, 60 kg P2O5/ha
    Bo/Bo: Continuous barley, no fertilizer
    Bnp/Bnp: Continuous barley, 20 kg N/ha and 60 kg P2O5/ha

c) For Bo/F and Bnp/F areas were halved (only half the area utilized for barley in any given year).
Table 11. Basic dataset converted into sheep feed equivalents (SFE/ha).

<table>
<thead>
<tr>
<th>Season (mm)</th>
<th>Bo/F</th>
<th>Bnp/F</th>
<th>Bo/Bo</th>
<th>Bnp/Bo</th>
<th>Bo/Vo</th>
<th>Bnp/Vo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982/83</td>
<td>265</td>
<td>1.93</td>
<td>4.80</td>
<td>2.51</td>
<td>6.56</td>
<td>3.25</td>
</tr>
<tr>
<td>83/84</td>
<td>204</td>
<td>1.68</td>
<td>3.18</td>
<td>1.53</td>
<td>3.93</td>
<td>1.94</td>
</tr>
<tr>
<td>84/85</td>
<td>277</td>
<td>1.47</td>
<td>5.17</td>
<td>2.57</td>
<td>8.90</td>
<td>3.72</td>
</tr>
<tr>
<td>85/86</td>
<td>218</td>
<td>2.28</td>
<td>5.31</td>
<td>2.67</td>
<td>4.51</td>
<td>3.96</td>
</tr>
<tr>
<td>86/87</td>
<td>245</td>
<td>2.01</td>
<td>3.45</td>
<td>2.34</td>
<td>4.56</td>
<td>3.59</td>
</tr>
<tr>
<td>87/88</td>
<td>400</td>
<td>5.26</td>
<td>8.26</td>
<td>4.39</td>
<td>8.63</td>
<td>8.56</td>
</tr>
<tr>
<td>88/89</td>
<td>194</td>
<td>1.01</td>
<td>1.92</td>
<td>0.84</td>
<td>1.92</td>
<td>2.23</td>
</tr>
</tbody>
</table>

a) Conversions made assuming following metabolizable energy values:
Barley grain = 11.5 MJ/kg; Barley straw = 5.5 MJ/kg;
Vetch hay = 9.0 MJ/kg; and 1 sheep requires 4200 MJ metabolizable energy per year.

b) Values for Bo/F and Bnp/F were divided by 2 (only 1/2 ha utilized).

c) Values for Bo/Vo and Bnp/Vo assume 1/2 ha barley, 1/2 ha vetch.

Table 12. Relationships between SFE's of contrasting rotations and seasonal precipitation (P) at Breda.

<table>
<thead>
<tr>
<th>Rotation</th>
<th>Equation</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bo/F</td>
<td>SFE = -2.34 + 0.018 P</td>
<td>0.795</td>
</tr>
<tr>
<td>Bnp/F</td>
<td>SFE = -2.14 + 0.026 P</td>
<td>0.808</td>
</tr>
<tr>
<td>Bo/Bo</td>
<td>SFE = -1.31 + 0.014 P</td>
<td>0.840</td>
</tr>
<tr>
<td>Bnp/Bo</td>
<td>SFE = -2.17 + 0.030 P</td>
<td>0.670</td>
</tr>
<tr>
<td>Bo/Vo</td>
<td>SFE = -3.72 + 0.030 P</td>
<td>0.888</td>
</tr>
<tr>
<td>Bnp/Vo</td>
<td>SFE = -4.06 + 0.040 P</td>
<td>0.898</td>
</tr>
</tbody>
</table>

1/ B = Barley, F = Fallow, V = Vetch Hay
0 = no fertilizer, np = 20 kg N + 60 kg P₂O₅

Note: Using the relationships in Table 12, and seasonal rainfall records from Breda village for the period 1960-1987, production in terms of sheep feed equivalents were predicted for the 27 year period. These are presented as cumulative frequency distributions in Table 13 and Figure 10.
Table 13. Cumulative frequency distributions of sheep feed equivalents/ha from contrasting rotations at Breda, Syria.

<table>
<thead>
<tr>
<th>Bnp/F</th>
<th>Seasonal</th>
<th>Rotation</th>
<th>Decile</th>
<th>Rain (mm)</th>
<th>Bo/F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bo/Bo</td>
<td>Bnp/Bnp</td>
<td>Bo/V</td>
<td>Bnp/V</td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>136</td>
<td>0.11</td>
<td>1.49</td>
<td>0.59</td>
<td>1.91</td>
</tr>
<tr>
<td>0.2</td>
<td>203</td>
<td>1.31</td>
<td>3.14</td>
<td>1.53</td>
<td>3.92</td>
</tr>
<tr>
<td>0.3</td>
<td>238</td>
<td>1.94</td>
<td>4.05</td>
<td>2.02</td>
<td>4.97</td>
</tr>
<tr>
<td>0.4</td>
<td>260</td>
<td>2.34</td>
<td>4.62</td>
<td>2.33</td>
<td>5.63</td>
</tr>
<tr>
<td>0.5</td>
<td>269</td>
<td>2.50</td>
<td>4.85</td>
<td>2.46</td>
<td>5.90</td>
</tr>
<tr>
<td>0.6</td>
<td>284</td>
<td>2.77</td>
<td>5.24</td>
<td>2.67</td>
<td>6.35</td>
</tr>
<tr>
<td>0.7</td>
<td>298</td>
<td>3.02</td>
<td>5.61</td>
<td>2.86</td>
<td>6.77</td>
</tr>
<tr>
<td>0.8</td>
<td>333</td>
<td>3.65</td>
<td>6.52</td>
<td>3.35</td>
<td>7.82</td>
</tr>
<tr>
<td>0.9</td>
<td>419</td>
<td>5.20</td>
<td>8.75</td>
<td>4.56</td>
<td>10.40</td>
</tr>
</tbody>
</table>
Figure 1. Rainfall isohyet map of Syria.
Figure 2a. Inter- and intra-seasonal variability in rainfall. Seasonal totals at Jindiress and Breda, N.W. Syria.
Figure 2b. Inter- and intra-seasonal variability in rainfall. Weekly totals for eight seasons at Breda.
Figure 3. Cumulative frequency of frost days per season at contrasting locations in West Asia and North Africa.
Figure 4. Schematic presentation of the metabolizable energy requirements of sheep and the contribution of different feedstuffs during traditional feeding cycles.

(1) Concs-feed grains (including forage legume grains) and industrial by-products (brans and oil-cakes);
(2) ICR-irrigated crop residues.
Figure 5. National trends in sheep number, human population and barley grain production: Syria 1951-88.
Figure 6. Barley grain production in Syria, 1951-87.
Figure 7. Net trade in barley in Syria.

Thousand Tonnes

Export

Import

1960 1970 1980
Figure 8. Agricultural stability zones in Syria.

Zone 1a Average rainfall over 600 mm. A wide range of crops may be grown here. Fallowing is not necessary.

Zone 1b Average rainfall between 350 and 600 mm and not less than 300 mm in two thirds of the years surveyed. At least two crops can be grown every three years. The main crops are wheat, pulses and summer crops.

Zone 2 Average rainfall between 250 and 350 mm and not less than 250 mm in two thirds of the years surveyed. Two crops are normally planted every three years. Barley, wheat, pulses and summer crops are grown.

Zone 3 Average rainfall over 250 mm and not less than this in half the years surveyed. One or two crops will yield in every three years. Barley is the principal crop but some pulses can be grown.

Zone 4 Average rainfall between 200 and 250 mm and not less than 200 mm during half the years surveyed. Barley is grown. The area is also used as grazing land.

Zone 5 Covers the rest of the country. This desert and steppe land is not suitable for unirrigated agriculture but parts of it offer some winter pasturage.
Figure 9. Comparison of production strategies.
(Cumulative Frequency Distributions.)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[A]</td>
<td>National Planned Area (1990) excluding zone 5 under Bo/Bo</td>
</tr>
<tr>
<td>[B]</td>
<td>Reduced area under Bnp/F</td>
</tr>
<tr>
<td>[C]</td>
<td>Reduced area under Bnp/BnP</td>
</tr>
</tbody>
</table>

Sheep Feed Equivalents (Millions)

Cumulative Frequency

SHEEP FEED EQUIVALENTS (MILLIONS)

0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1

7.2 M S.F.E.
Figure 10. Comparison of fertilizer addition on production (SFE/ha) of three rotations at Breda, N. Syria. (Cumulative Frequency Distribution.)

Rotation

- Barley/Fallow
- Barley/Barley
- Barley/Vetch Hay

Fertilizer Addition

20 kg N and 60 kg P2O5 added to the barley phase
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Tully, D. 1984. Land use and farmer strategies in Al Bab: The feasibility of forage legumes in place of fallow. ICARDA.


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INTRODUCTION

International interdependence offers the opportunity for enhancing growth of all countries by means of exchange of goods and services, capital flows, and transfer of technology. But international interdependence also presents difficulties, especially those arising from the fluctuations in world markets. Developing countries with a heavy dependence on primary commodity trade are susceptible to the variability of foreign demand for their exports (involving fluctuations in both export volumes and export prices), to the variability of exchange rates of trading partners or competitors, and to the variability in import prices of important inputs, such as crude oil.

The variability of primary commodity exports and prices creates a difficult management environment for developing countries at all levels, from producers and consumers to central governments. Sharp declines in export revenues create problems, for example, in importing needed inputs or in servicing external debt. On the other hand, sharp increases in export revenues have led to sharp increases in inflation or to other economic waste in the form of, among other things, uneconomic projects. These difficulties have spurred many national and international attempts to find ways to dampen the variability in export revenues of developing countries or to develop mechanisms to cope with such instability.

This paper discusses the various price stabilization measures and introduces the role of the financial markets in hedging some of the price risk. The paper illustrates the importance of this problem for the developing countries, discusses some of the limitations of price stabilization schemes, and shows how some new financial innovations can be used by developing countries to manage their commodity price risk more effectively.

Commodity Price, Interest Rate, and Exchange Rate Exposure

The exposure of developing countries to these risks and their limited ability to deal with them effectively has been made obvious during the 1980s. In the decade of the 1980s, sustained declines in commodity prices and sharp increases in interest rates and in the exchange value of the U.S. dollar were followed by increases in indebtedness and debt-servicing difficulties among developing countries.

The exposure of developing countries to instability in commodity prices requires little emphasis to this audience and can be quickly illustrated in Table 1 by showing their...
dependence on commodity exports. This dependence is highest in Africa, Oceania, and America while less so in Asia and Southern Europe. For purposes of comparison, the share of primary commodity exports accounts for 42 percent of developing country exports but only 25 percent of industrial country exports. The exchange rate and interest rate exposure of developing countries is illustrated in Figure 1 with information on their debt composition. Most public and publicly guaranteed debt is denominated in U.S. dollars, though increasingly less so since 1982. However, the shares of British pound sterling, the Japanese yen, and the German deutsche mark in public and publicly guaranteed debt are increasing. These three currencies and the dollar account for almost all borrowings by developing countries.

Commodity Price Impact on World Bank Projects

What may not be so widely appreciated is the impact of substantial changes in commodity prices on the outcome of International Monetary Fund (IMF) and World Bank programs and projects. A recent review of experiences with unforeseen external developments in 125 IMF standby and extended arrangements that were approved in the 1982-87 period showed that the average adverse deviation was 3 percent of gross domestic product and was primarily due to weaker-than-expected export prices and volumes. The IMF review noted that net shortfalls in the external account were at times translated through price and output effects into a significant deterioration in the fiscal position. Since the scope for quick and full offsetting measures was often limited, it proved difficult to achieve the original program objectives or to comply with the performance criteria established under the IMF arrangements. As a result, a large number of program interruptions were typically dealt with through understandings reached via the waiver or modification process.

Organization of Economic Cooperation and Development (OECD) reports frequently point out the role which unfulfilled commodity price expectations play in the persistent gap between the estimated and the actual rates of return for World Bank projects. However, the adverse effects of commodity price variability do not seem to be reflected adequately in the way in which the Bank and the developing countries approach the evaluation and design of projects and programs. For example, the limited awareness of the adverse impact of commodity price fluctuations, as reflected in macroeconomic analysis and project evaluation in the World Bank, was recently noted following a review of 36 Country Economic Memoranda (CEMs) produced in fiscal year 1986 and of 74 Structural Adjustment Reports (SARs) issued in fiscal year 1986 for the agriculture, industry, power, and energy sectors. Of the 36 CEMs, only two explored the sensitivity to commodity price fluctuations. Of the 74 SARs, only about 10 percent considered the impact of fluctuations in agricultural, power, and energy prices. These findings resulted in an Operational Policy Note that recommended that "sensitivity analysis is essential both in project evaluation and macroeconomic projections when commodity prices play an important role."

The limited attention given in project appraisal to the assessment and management of risk is also verified by a recent International Finance Corporation (IFC) report of a review of the reasons for the poor performance of IFC agricultural lending (though probably not so much different from the World Bank's), which noted that the IFC greatly underestimated the degree of variability associated with agricultural projects.

Forecasting Is Not a Substitute for Hedging

On the issue of commodity price forecasting, a matter of close interest to me, I want to make the point very strongly that price forecasting is not a substitute for hedging. Price forecasts come in for much criticism when the performance of projects and programs are evaluated. But this hindsight response misses the important point: Forecasts are necessary in all
forms of planning, and we should do the best we can. In retrospect, with better information, better resources, and better luck, World Bank forecasts may well have been more accurate -- but here, perhaps better luck would be the most important ingredient. However, economic variables largely behave as random variables, i.e., by definition, they are not forecastable (although, over the longer term, there is a degree of systematic behavior in primary commodity prices). Hence, after making a commodity price forecast, it has to be recognized that there is a large risk of it being wrong, and it pays in most cases to hedge against this risk. Which is one reason why my Division has been working in the commodity risk management area for the past three years.

A full appraisal of the various sources of risk for projects or for sector and country adjustment programs -- and the development of financial and other management strategies to hedge these risks -- requires a level of familiarity, knowledge, and skills which most Bank staff do not possess. Thus, I believe the Bank needs to push hard in three areas:

- To develop -- in both Bank staff and developing-country policy makers -- a much higher awareness of the various risks which developing countries face (This may sound trite, but when a central bank president of an export-commodity dependent country or the management of a large export crop marketing board are unaware that they face substantial commodity price and exchange rate risk, respectively, it is cause for concern.);

- To train Bank staff in risk management techniques so that all aspects of risk involved in a Bank-financed project or structural adjustment program will be identified and assessed (i.e., that the consequences of the various likely events are thoroughly assessed), and the appropriate risk management strategies are implemented; and

- To help build appropriate institutions in developing countries for managing risk and to assist in training personnel from developing countries in this area of expertise.

The Bank staff training and the training for developing country personnel would not only help them recognize and appreciate the problems related to the risks emanating from projects or programs but would also help them to identify their risk profiles, measure their risk exposure in relation to the project's or program's performance, analyze the costs and benefits of alternative risk management instruments, and devise or engineer innovative solutions to risk situations. Or, at the very least, such training should provide information on where to go for assistance carrying out these tasks.

**Hedging Commodity Price Risk**

There are, in fact, many commodity risk management instruments available to developing countries. They can be categorized into three groups: self-insurance instruments, third-party insurance instruments, and other instruments.

The first group includes instruments such as reserve management schemes, domestic price stabilization schemes, macroeconomic policies, infrastructure programs such as irrigation schemes, and activity diversification programs. The second group encompasses financial market instruments, such as futures, forwards, options, swaps, and long-term contracts. The third group takes in all other instruments, including international commodity agreements and compensatory financing schemes such as the STABEX/SYSMIN schemes of the European Community.

I want to concentrate on management of commodity price risk and, in this area, mainly focus on the most commonly used instruments and discuss the role which a new financial
concept -- commodity-linked financing -- can play in managing commodity price risk in developing
countries. Other forms of hedging against commodity price and production risks, such as activity
diversification or modifying the environment to cope with weather fluctuations, will be discussed in
other papers at this symposium.

INTERNATIONAL COMMODITY AGREEMENTS

At this stage, I wish to make some points about the most commonly discussed
forms of commodity price stabilization. However, these are not the kind of points that you will
usually hear. International commodity agreements have been strongly supported for a long time as
a means of stabilizing world commodity prices. But, leaving aside the some of the usual arguments
against them (e.g., they favor the inefficient over the efficient), the stark reality is that these
agreements cannot be relied upon to stay on the books. The recent collapse of the International
Coffee Agreement is the latest example. In other words, it is unwise for developing countries to
look to international commodity agreements as effective price and risk management tools.

Domestic price stabilization schemes have been and remain a popular form of
commodity price risk management. These are normally buffer fund schemes under which a fund is
accumulated when prices are high and then released when prices decline. Reserves management
(whether at the country or corporate level) can be classified as a buffer fund scheme; whereas
buffer stock schemes are usually not in practice at the country level because stockholdings by
single countries are usually too small to affect world prices. The Australian wool price stabilization
scheme is an exception only because Australia is such a large producer.

Again, I do not want to dwell on the normal criticisms of domestic commodity price
stabilization schemes, e.g., they insulate producers from changes in the direction of world prices
which gives the advantage in response to those who are not "protected." (This criticism even
applies to moving-average schemes, which are currently popular in the Bank.)

Other criticisms are that most savings and investment by smallholders occur in
periods of high prices (and therefore stabilizing prices to producers will reduce investment), and
governments have had difficulty in resisting the temptation to use the appropriated funds held in
reserve for other uses, with the result that the funds are not available when prices do fall.

I want to focus on another issue, however, which is domestic price stabilization
schemes in developing countries -- whether run by the government or by the producers themselves
and which transfer the price risk to a body which is even less able to bear it than the producers
themselves. Primary producers, including those in developing countries, use many ways to hedge
price and production variability and thereby smooth their income/consumption stream over time.
These include, for instance, activity diversification, spatial diversification, and intra-family loans.
By comparison, governments, which rely heavily on the tax revenues from an export commodity or
a marketing board (whether public or cooperative) handling a single product, have a very large
commodity price and exchange rate exposure in that particular commodity.

So we have seen in recent years examples of schemes, such as the Papua New
Guinea coffee and cocoa stabilization schemes, designed by economists and run with integrity but
gradually going bankrupt because of the more than 60 percent decline in the world prices seen in
these commodities. The highly regarded Caisse de Stabilisation et de Soutien des Prix des Products
Agricoles in Cote d'Ivoire has been similarly affected.

Which brings me to the role which commodity-linked financing can play in hedging
commodity price (and exchange rate and interest rate) risks, whether these risks are faced by
governments, central banks, marketing boards, cooperatives, or entities such as oil companies or utilities. I do not intend to provide a full description of these instruments, which have proliferated in the late 1980s, but only to convey a flavor of their characteristics.

Commodity-Linked Financing and Commodity Bonds

Commodity-linked financing is a hybrid instrument. It is a risk management as well as a financing instrument. As commodity-linked financings can extend well beyond a one-year timeframe, their risk management properties become of strategic importance to the commodity price exposure of organizations. They are therefore complementary to the use of futures or options in the physical commodity, which are useful hedging instruments over short periods of time. Stabilization of commodity prices -- and therefore of incomes and expenditures over periods of years -- can now through such financing be realized.

Utilizing commodity bonds, investors have sought to link their investment to real assets. A conventional bond makes semi-annual coupon payments determined by a coupon rate and pays out the principal amount at maturity. The nominal return to the investor is known, but with the inflation rate being uncertain over time the real rate of return is uncertain. Commodity bonds, on the other hand, exist in two forms: those of a forward type, often called convertible or indexed bonds, and those of the option or warrant type.

In commodity bonds of the forward type, the coupon and/or principal payments are linked to a stated quantity of a commodity. A commodity bond of the option type makes normal coupon payments (just as conventional bonds do), but upon maturity the holder of these bonds has, in addition to the principal, the option to buy or sell a predetermined quantity of the commodity at a predetermined price. Because of the inherent value of such an option, the coupon payments of this bond are lower than they would be in a conventional bond.

For example, a conventional US$1,000, 10 percent coupon bond would make annual payments of US$100, while a similar oil bond of a forward type would make coupon payments equal to the current monetary value of five barrels of Brent oil, for example. The payoffs to these bonds reveal them to be similar to a conventional bond and a set of forward contracts. Each coupon payment is analogous to a forward contract; however, there is one major difference. In a forward contract the agreement is that the monetary settlement will take place at maturity; in a commodity bond, the investor who holds the "long" side has already fulfilled his obligation by buying the bond. Forward contracts are negotiated between two parties and are not easily traded. Commodity bonds can be publicly issued and traded freely.

In a commodity bond of the option type, one or several call or put options may be attached to the coupon or principal payments. In this case, the investor receives the US$1,000 face value and has, in addition, the option of buying or selling a predetermined quantity of a commodity at a predetermined price. Since these bonds include an option feature that has a market value, the coupon rate is generally lower than it would have been for a conventional bond. The advantage to the issuer is thus the fact of making lower interest payments, with the trade-off being an undertaking to share the benefits of any appreciation in the price of the commodity by writing a call option on the commodity.

Commodity-linked financing has taken other forms than those of the forward- or option-type bonds. Some of these forms include commodity-indexed certificates of deposit, commodity variable rate loans, gold repos, bullion loans, commodity swaps, and caps, floors, and collars.
The Challenge to Developing Countries

Most of the commodity-linked issues have been made in terms of oil, gold and silver, and (a few) for copper and other primary commodities. These are large, liquid markets dealing in homogeneous products. For these reasons it has been easy to develop these markets in relation to hydrocarbons and metals. To date there have been few applications to agricultural products. Almost all issues have been made by corporations and governments in the developed countries. The challenge is to assist the developing countries to enter this market more easily and to expand the range of commodities in which such securities can be issued.

This is a challenge which my Division has recently taken up by forming a Commodity Risk Management and Finance Unit which will provide technical assistance to developing countries in the use of financial markets for commodity risk management. It will help them identify units of the government and entities within the country which face commodity price risks, assist them in developing an institutional capacity to manage these risks, and assist them in developing hedging strategies, including advising them on the best instruments for their purposes. At the same time, we have a research program under way to investigate, inter alia, risk hedging strategies to be adopted in using the various financial instruments, including futures and options, new forms of commodity-linked financial instruments, and ways to combine other risk management activities, such as product diversification, with financial hedging. At the same time we hope to see interest develop in the use of such instruments to hedge commodity risks in World Bank-financed activities.
### Table 1

Share of exports of 33 primary commodities from developing countries by region, 1982-84. Average (number of countries).

<table>
<thead>
<tr>
<th>Region/Share</th>
<th>0-25</th>
<th>25-30</th>
<th>50-75</th>
<th>75-100</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>America</td>
<td>3</td>
<td>10</td>
<td>11</td>
<td>3</td>
<td>27</td>
</tr>
<tr>
<td>Africa</td>
<td>6</td>
<td>13</td>
<td>10</td>
<td>14</td>
<td>43</td>
</tr>
<tr>
<td>Asia</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Oceania</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>South Europe</td>
<td>5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>22</td>
<td>29</td>
<td>26</td>
<td>21</td>
<td>98</td>
</tr>
</tbody>
</table>


### Figure 1

Currency composition of public and publicly guaranteed developing country debt.

(percent) (amounts in US$ billions)

- **Figure 1:** The World Bank, December 1988, *Financial Flows to Developing Countries*, Washington, D.C.
INTRODUCTION

The arid and semi-arid environments characteristic of African pastoralism cover more than one billion hectares, with roughly 120 million rural inhabitants and perhaps a quarter of a billion cattle. Many of these cattle are managed by specialized pastoralists, whose importance to the population is small. The importance of the pastoralist animal population is great, however, in terms of livestock production and potential trade. While sedentarization of pastoral peoples has obscured the differences between them and crop farmers, they remain a distinct, if smaller, target of development efforts.

Pastoral systems have received major investments in pastures, water, and markets in the last 20 years. Yet, the population remains poor, as technology has changed little over the past 50 years and stocking rates, offtake, yields per animal, and producers' incomes have all remained low. The inherently unproductive environment has made it hard for most development efforts to succeed, and the principal exogenous change is still the historical development of veterinary services, which enabled an increase in animal numbers. The main endogenous one is gradual sedentarization, associated with the uptake of cropping.

High variability is associated with low productivity. The basic determinant of productivity -- rainfall -- changes greatly over space and time in this environment, and this variation induces corresponding changes in pastures and in animal output. This environment thus confronts the dual handicaps of weak productivity and high risks.¹

Among the policy issues in pastoral systems is the impact of variability on the growth of producers' incomes. Observers accept that risk is detrimental to productivity, but they view it with a somewhat contradictory viewpoint. The general view is that variability harms incentives to invest, and reducing risks in livestock production would then boost output via increased investment and in herd numbers.

The other viewpoint is more specific in pastoral societies because it argues that risk inflates incentives to invest and since animals are the only asset, herders hold more than the profit-maximizing number in order to insure that they will remain viable after some disaster. (This is not the same argument which contends that producers hold stock for motives of prestige and wealth [Doran et al. 1979].) Risk aversion, therefore, encourages overstocking and eventually destroys the resource base. Reducing risk would, in this light, decrease animal numbers.

Given the variability of this environment, it might be that reducing pastoral risks can promote growth. Various improvements have been proposed, including offtake rules, tax policies,

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¹ John McIntire is an Economist in the World Bank's Agriculture Operations Division of the Latin America and Caribbean Country Department II.
and credit and price policies to improve herders' investment capacity. Such policies may be all the more important given the widespread failures of technical interventions (World Bank 1985).

This paper provides a stylized overview of the pastoral environment and describes risks and responses to such risks. It describes risks and responses to them and presents results of some simulations of various risk management policies. The paper takes an overly pessimistic view related to the prospects for rapid technical change in African pastoral systems and about prospects for external forms of risk management, such as price stabilization policies. Some internal types of risk management, notably herd offtake policies, are modeled under various conditions of credit availability and price regime.

PRODUCTION SYSTEMS AND SOURCES OF RISK

Pastoral environments are those in which animal production, sometimes associated with crops, is the major economic activity and the principal form of wealth. Most references to "pastoral systems" or to "pastoralism" will be to those receiving at least 50 percent of total income from animal production, but other systems will be mentioned.

The pastoral areas are the Sahel-Savannah zone of West Africa, Sudan, northern Cameroon, and sections of lowland east and southern Africa. They are arid with low population density, comparatively little animal disease, and sparse vegetation. Rainfall is scant with high relative variability in amount, timing, and location. Transport costs are high, trade is expensive, cash inputs are few, and modern technology is absent, except for veterinary drugs.

Pastoralists face common risks (Table 1) in all systems. The principal risk is rainfall failure. Rainfall failure stunts pastures, desiccates water points, and kills stock. Because pastoralism is inherent to arid areas, it is riskier than crop production in the more humid areas. Analyses of West African rainfall (Cocheme and Franquin 1967) show that the mean and absolute variation are significantly negatively related. There is some indication (McIntire 1981) that arid areas have more non-normal rainfall distributions. Precipitation is often positively skewed; in such conditions, part of the advantages of good years is wasted in surface runoff.

Price ranges are secondary to quantity risks. An analysis of the Burt-Finley type (Valdes and Konandreas 1981) would show that nearly all variation in producers' revenues is due to quantity, not to price. This is confirmed indirectly by analysis of food import bills in the Sahel (McIntire 1981) showing that from 56 percent to 90 percent of their variance was due to fluctuations in import quantities.

Pastoral risk is higher than cropping risk, not only because arid environments are naturally more variable than humid ones, but in isolated areas some forms of risk reduction, such as trade and storage, are inviable. Arduous transport makes importing feed too costly, while moving animals to water areas increases their death rate. Pasture yields are so bad that gains in good years are small. Yield gains cannot be kept as pasture improvements or as fodder but must be reinvested, as it were, in animal weight gains so that the portfolio stays undiversified (Binswanger and McIntire 1987, and Monod 1975).

Animal capital has risks unlike those in cropping. Fluctuations in income cause capital gains and losses because they affect the stock of animal capital. If herders withhold breeding or growing stock from the market because of short-term price gains, they increase their future output. If farmers withhold grain stores, there is no effect on future output. And, if herders sell in response to short-term declines, they lose breeding stock and, thus, part of their future income.
Animal markets operate differently from those for agricultural goods. In essence, the storage cost of animals is much greater than for crops. If crop prices are too low, farmers can withhold until prices rise because storage losses and costs are not too high. However, if livestock prices are low, animals must be sold as the owner cannot maintain them. In such a market, prices fall even more, and animals die and the capital stock is destroyed when transport costs prevent all distress sales in extreme situations.

Disease risks were historically important but have been reduced by modern veterinary interventions. Such interventions have typically been the most successfully introduced livestock techniques (Schafer 1988, World Bank 1985). This is not to say that such risks are now trivial, but only to point out that they have to be managed differently. Indigenous remedies are of little use and producers must depend on modern institutions, and when institutions fail, they are powerless to do much about it.

RESPONSES TO RISK

There are no studies of pastoralists’ risk attitudes. Many observers presume that pastoralists are risk-averse, sometimes even more so than farmers, but there is really no evidence to support this view. Rather, we must presume that risk attitudes among primarily stock-raising people are similar to those among crop-raising farmers.

Diversification is the general endogenous response in all systems. Herders own various species, graze widespread pastures, and split animals among discrete herds; they diversify by working as wage laborers, trading commodities, and growing crops. Because there are no insurance markets, it is impossible to insure stock against general or specific perils, and the absence of insurance markets is endogenous. There is no insurance available because of high correlations among pastoral risks and the costs of eliminating moral hazard. Therefore, insurance is not available as a policy alternative to risk.

In the least diversified pastoral systems, mobility is the principal response. Herders exploit expected seasonal variations in pasture as a matter of course, and they react quickly to unexpected annual variations in water and pasture availability by longer and novel migrations. They appear to have reacted to secular declines in Sahelian pastures by moving more permanently to the sub-humid zones (von Kaufmann and Blench 1989). At the same time, herders have developed complicated systems of stock sharing to complement their mobility. Mobility, on the other hand, increases supervision costs, thus stock owners must establish contracts to monitor the condition of their animals and to encourage managers to provide proper care. Such contracts are most cheaply arranged among members of extended families and involve intricate networks of animal ownership and responsibility and which provide appropriate incentives for stock management in widely dispersed production areas.

Investment response to risk is limited in pastoral areas. External investments -- in water points, fencing, institutions, and input supplies -- have generally given low rates of return, partly because they were carried out by inefficient public agencies (World Bank 1985). It is not possible to say what their effect has been on variability. Endogenous investments consist of water supplies and of the extension of cultivation into what were once exclusively pastoral zones.²

The principal innovation in the transitional, partly settled system is that mixed farmers have a different asset base. Transitional herder farmers (Toulmin 1983) show characteristics of both extremes of production patterns. By growing crops, producers can accumulate food stores to insure against consumption losses when they lose their animals.
The crop production benefits from sedentarization, which reduces mobility. The main compromise between the two systems is seasonal herd splitting among different family sub-units, each having responsibility for discrete activities. This division of labor between crops and animals is efficient in reducing risks but largely prevents adoption of intensive production techniques because there is no labor to manage them.

True mixed farmers are immobile; they can only gain the diversity benefits of mobility by entrusting their animals to herders via a type of labor market, while continuing to grow crops. Delgado (1979) showed that such a specialized division of labor can produce higher income than mixed farming in a single production unit. While Delgado did not discuss the effects of specialization on the overall labor to adapt to risk, the continuing evolution of production systems toward the type he studied suggests that the benefits in productivity and in consumption insurance outweigh the costs of lost mobility.

Animal traction in mixed farming presents a new risk – that of losing the animals and hence a principal input into crop production. Farmers devise rental and exchange contracts to bar the risk of losing them, but such contracts are unnecessary in the pure pastoral systems.

MODELING RISK

Unexploited opportunities for raising incomes and reducing risks are few in the pastoral environment. Efforts to build institutions in research, extension, input supply, and producers' organizations have been underway for some time, but these efforts have not been greatly successful, except for the noted exception of veterinary work. While it is wrong to be completely pessimistic about prospects for technical change in the most extensive systems, the primary possibilities have been studied without a great deal of success. The focus in what follows is on evaluating the possibilities for changes in herd management and their interactions with credit and price policies as ways of reducing income variability and, perhaps, of raising its average.

A quasi-deterministic economic simulation model (von Kaufmann et al. 1990) is used to study herd management alternatives. Pasture productivity is a random variable with a skewed distribution. Its mean is estimated using the Hiernaux' method (Wilson, Hiernaux, and McIntire 1990) under which a random number generator simulates pasture productivity and herd mortalities. Other variables are deterministic functions of the stochastic ones, herd demography, and decision-making rules about purchases and sales of stock.

In the model of an arid environment with low population (Table 2), there is minimal conflict between crop and livestock production for land. The herd structure is like that found in studies of Sahelian pastoralists: about half are females, a quarter are young stock, and the rest are males. Animal weights and milk production are low, as the only feed sources are the open range, crop residues, and browse.

In all livestock production, there is a conflict between present and future sales affecting the supply response to price. The econometric literature about short-term response is ambiguous, as some studies show negative responses, and others show positive ones. Nothing is said about long-term response because it is consistent with supply theory (i.e., it is always positive). Table 3 distinguishes short-term movements by class of stock and expectations about price movements. If producers believe price changes are permanent, then the expected sales value rises at all times, and it rises more in the future because output can be adjusted to produce more at the higher prices. This requires sacrificing some sales to produce the short-run negative supply response.
This negative short-run effect with respect to permanent price changes differs by class of stock. As females are inputs into cattle production, positive price changes have a negative effect on sales of mature females and heifers because their future value — and that of their offspring — has increased. This effect is small as female offtake rates are low anyway and cannot fall much more.

The value of maturing males increases more than that of already mature males, so that the short-term negative effect on their sale is greater. The effect is small, again because offtake of maturing males is small to begin with. The effect on offtake of mature males is slightly positive, and since withholding other classes of stock causes competition for feed, the more mature males must be sold to provide feed for those other classes.

Overall, the effect of temporary price changes is zero or positive. For example, it is roughly zero for females and growing males since producers think price changes are temporary and are unwilling to sacrifice future gains in offspring and weight for short-term profit. For mature males, the short-run response is positive, because producers believe the price gain will be short-lived and because the value of the animal is not growing except from price changes; producers, thus, are eager to sell. The short-run response for young males is less positive because selling now causes losses in the future, which is not the case with older males.

In the present model, sale ages for breeding females and males are set at the profit-maximizing levels. Young stock are not sold. Because we have no real information about producers’ risk attitudes, we cannot use a mean-variance approach to analyzing risk. Alternatives are to use a safety-first rule, or stochastic dominance (Anderson et al. 1977). A variant of the safety-first rule is that producers seek to exclude the risk of falling below a minimum herd size (Dahl and Hjort 1976).

Pastoralists have little profitable scope to sow forages, raise new breeds, or purchase feed. Their principal option is offtake policy — or the entire decision-making process affecting buying or selling stock. Examples are changing herd size and/or herd composition according to various rules.

This leads to two questions: What are the effects of such rules on the mean and variability of income? And, does larger base herd size reduce the variability of income? Incomes were simulated over 10-year periods, and sample sizes of 50 sequences (i.e., 500 sample years) for herds of 20 and 100 head are illustrated in Figure 1, with target and fixed policies. The coefficients of variation of income do not vary much between herd sizes, and, while larger original herd sizes obviously produce greater incomes, relative variability is not smaller. Expanding herd size, if it is not accompanied by diversification of pasture sources, has a small effect on income relative to variation with the target offtake rule but has a substantial one with the fixed rule.

### Effects of Herd Size

<table>
<thead>
<tr>
<th></th>
<th>20 Head</th>
<th>100 Head</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income (millions CFAF)</td>
<td>-0.19</td>
<td>-0.45</td>
</tr>
<tr>
<td>%&lt; = 0</td>
<td>48 %</td>
<td>40 %</td>
</tr>
<tr>
<td><strong>Fixed 90 84</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income (millions CFAF)</td>
<td>+0.14</td>
<td>+1.50</td>
</tr>
<tr>
<td>%&lt; = 0</td>
<td>28 %</td>
<td>8 %</td>
</tr>
</tbody>
</table>
Do larger herds reduce the probability of disastrously low incomes? The answer is yes, but the costs of such insurance depend on economies of scale in herding. If income per person is proportional across herd sizes (i.e., if there are no economies of scale) then the insurance of holding more animals derives only from cooperative arrangements among owners, since income per animal does not change with herd size. Extended families, typical of pastoral societies, can be viewed as ways of reducing transaction costs associated with this type of insurance.

If income per animal increases with herd size (i.e., if there are economies of scale) then the insurance of holding more animals derives from greater wealth per owner. It is then possible with such economies of scale to avoid cooperative arrangements to a limited extent. However, herd size has only a small effect on risk, unless it is associated with other forms of diversification such as grazing different pastures, watering at fresh points, or market access.

Would different offtake policies affect variability? Offtake policies (see Table 4), include target breeding herds, constant offtake rates, and a skewed offtake response to pasture supply. With the target policy, the owner strives to maintain some minimum number of breeding females. This is a formulation of the Dahl-Hjort argument. With the constant policy, the owner takes off constant shares of breeding females and adult males annually at the optimal expected sale age. With the "skewed" policy, the owner sells no animals at all when pasture production is above average, and the owner uses the constant policy when pasture production is below average.

Maintaining a target breeding herd by buying and selling animals around the target is inefficient. Setting fixed offtake rates is the least variable strategy, but it has a slightly lower mean than the skewed pasture response. Because pastoral systems are often physically and economically isolated from markets, changes in offtake affect prices significantly. Therefore, modeling herders' offtake decisions has to take into effect changes in prices as functions of sale. This is done by incorporating a skewed demand curve into the analysis. If pasture production is above average, offtake is zero and prices do not change; if pasture production is below average, then offtake increases linearly and prices fall correspondingly. In Table 4, this is the skewed response with price variation, which has a somewhat lower mean than the fixed offtake model and similar relative variation.

CREDIT

Credit is recommended to allow herders to repurchase stock after drought or other disasters (Sutter 1983 for Senegal; White 1984 for Niger). It is held that stocking rates can be restored more rapidly to previous levels if credit finances animal investments or if credit finances consumption and thereby reduces distress sales.

There are two arguments against credit for that purpose. One is that the supply of breeding stock is very inelastic (i.e., the barrier to herd reconstitution is not cash but availability of breeding stock to buy with the cash). The second argument is that there are moral hazard problems associated with credit for animal purchases where the use of credit can't be monitored cheaply.

The principal constraint to the stocking rate is not further capacity to finance investments, rather it is breeding stock, pasture production and animal health. Therefore, unless credit relieves these constraints, it can have little or no effect on the distribution of herds or on the speed with which herds recover from droughts. As the supply of breeding stock is highly inelastic, credit for animal investments drives up the price of breeding stock, thus lowering the return to the credit extended and encouraging stock consumption. Moreover, there are adverse selection problems in buying breeding stock.
What are the probabilities that credit can be repaid under different offtake rules? This question can be answered by modeling the cash flow from the herd, as shown in Figure 2. Using the credit terms given in Table 2 and the offtake rules modeled above, the repayment probabilities are estimated as follows:

<table>
<thead>
<tr>
<th></th>
<th>3-Year Credit</th>
<th>10-Year Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>68%</td>
<td>90%</td>
</tr>
<tr>
<td>Fixed</td>
<td>90%</td>
<td>84%</td>
</tr>
<tr>
<td>Skew</td>
<td>98%</td>
<td>98%</td>
</tr>
<tr>
<td>Skew with Price Response</td>
<td>80%</td>
<td>72%</td>
</tr>
</tbody>
</table>

Long-term credit is nearly always riskier. Repayment probabilities depend less on credit term than on the offtake rule followed.

CONCLUSIONS

In summary, pastoral production systems face risks of exceptionally high magnitude, and with the nature of the pastoral environment, producers have few alternatives to reduce those risks. Some of the externally proposed interventions to reduce risks are implementing technical changes and changing herd management, credit, and price policies.

But looking at the record of such policies, development interventions -- that is, changes in techniques, institutions, and prices -- have often produced negative average returns. The literature on this within the World Bank and elsewhere is very convincing on this point. While there is little empirical evidence on the impact of such interventions on variability, they have surely been too small to make up for the low or negative returns. The outstanding exception to this generalization is veterinary care.

Herd management is a kind of indigenous risk policy. Simulations of a West African-type pastoral system showed that the best policy is to skew sales, withhold stock in the good years, and sell off stock in bad years. Even when this policy is complicated by price collapses brought about by higher sales levels, it is still superior to maintaining a target herd and is competitive with a fixed offtake rule. Herd size in and of itself provides some benefits in lowered risk, which are related to the decision rule chosen.

This skewed sales policy has been criticized as being irrational, in that it leads to overgrazing by holding a larger herd than would otherwise be optimal. However, the only estimates (Jarvis 1985) we have of the costs of overgrazing are small and are admittedly overestimates. More to the point, the social costs of overgrazing appear to be less than the private benefits of maintaining larger herds. In that case, it would be possible to tax excess herds without eliminating all their private benefits.
External credit to allow herders to re-stock is limited by the same factors which hamper endogenous credit supply -- notably moral hazard and the costs of monitoring its use. Even if external credit could overcome those problems, the ability of pastoralists to repay substantial amounts of credit is restricted by the low inherent productivity of the system. Simulations show that if credit has to be given that short-term credit is less risky.

FOOTNOTES

1/ Comparisons of Botswana pastoralists to ranchers and of Ethiopian pastoralists to Australian ranchers have sometimes concluded that pastoralists are more productive. Such comparisons are based only on offtake per hectare, not on efficiency in the use of all resources. More complete studies would show that pastoralists are indeed less efficient.

2/ Rapid growth in private wells has been found in Niger (Niger 1982). The same study shows a fair amount of cultivation in the very arid mid-north of that country.

3/ Important work remains to be done in improving the efficiency of delivering veterinary services by privatizing them, but this is another issue (de Haan and Nissen 1985).

4/ The rise at one time need not portend any further rise; it is only necessary that producers believe the change to be permanent. If producers expect a rise in price at time "1" to portend a further rise at time "2", then they withhold animals, and the short-run response is even more negative. Expectations are unnecessary to produce a short-term negative effect.

5/ This is a cumulative effect which would be hard to detect without a complicated estimation on age-specific stock classes.

6/ Ariz-Nino and Shapiro (1984) have shown that sale age of adults in Sahelian conditions is insensitive to price because feed costs are so low. This conclusion is discussed at length in Jarvis (1985).

7/ I understand that the subsistence constraint is defined over the family life cycle. In the model formulated here, the constraint is held to be exceeded if the herd falls below the minimum in any model period.

8/ White's (1984) paper recognizes these constraints.
### Table 1. Risks in pastoral systems.

<table>
<thead>
<tr>
<th>System</th>
<th>Pure Pastoral</th>
<th>Transitional</th>
<th>Mixed Farming</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Response to</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climatic risk</td>
<td>Herd mobility, unit diversification</td>
<td>Herd mobility, unit diversification</td>
<td>Grain reserves, crops, livestock</td>
</tr>
<tr>
<td>Animal disease</td>
<td>Herd mobility, vet services</td>
<td>Herd mobility, vet services</td>
<td>Vet services</td>
</tr>
<tr>
<td>Price risk</td>
<td>sell &gt; buy long-term</td>
<td>sell &gt; buy long-term</td>
<td>buy-sell seasonal transactions</td>
</tr>
<tr>
<td>Risk of losing draft animals</td>
<td>none</td>
<td>none</td>
<td>contracts, rental markets</td>
</tr>
</tbody>
</table>

### Table 2. Model structure.

**Animal production**

| Herd size | 50 |
| Number of females | 20 |
| LW of 1 cow, kg | 250 |

**Pasture production**

| Mean yield/ha, kg of DDM | 1.500 |
| CV, % | 30.0% |
| Opportunity cost of 1 hectare of land, $ | 16.0 |

**Prices, $**

| 1 kg of liveweight | 1.2 |
| 1 liter of milk | 1.0 |

**Credit terms**

| Principal, $ | 750 | 1,500 |
| Interest rate, %/year | 10.0% | 2.0% |
| Herd fraction to finance | 25.0% | 50.0% |
| Term in years | 3 | 10 |
| Annual payments, in scaled values | 302 | 167 |
| Total loan payments, $ | 905 | 1,670 |
| Price reduction caused by drought | 50.0% | 50.0% |
Table 3. Supply in response in pastoral systems.

**Short-term response to price change**

<table>
<thead>
<tr>
<th>Price change</th>
<th>Adults</th>
<th>Young</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>temporary</td>
<td>++</td>
<td>--</td>
</tr>
<tr>
<td>permanent</td>
<td>+</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 4. Pastoral simulation results.

<table>
<thead>
<tr>
<th>Target breeding herd size</th>
<th>Fixed offtake rates</th>
<th>Skewed pasture response</th>
<th>Skewed pasture response with price variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>.33</td>
<td>.83</td>
<td>1.75</td>
</tr>
<tr>
<td>CV, %</td>
<td>330.6%</td>
<td>60.9%</td>
<td>40.8%</td>
</tr>
<tr>
<td>n&lt;=0</td>
<td>11</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Minimum</td>
<td>(3.26)</td>
<td>(1.25)</td>
<td>.97</td>
</tr>
<tr>
<td>Maximum</td>
<td>1.70</td>
<td>1.66</td>
<td>5.45</td>
</tr>
</tbody>
</table>

Herd size is 50 head
Figure 1. Offtake rules and herd size.
Figure 2. Offtake rules and credit.
REFERENCES


INTRODUCTION

In recent years, crop insurance in one form or another has been the subject of considerable interest in the development community. Both economists and policy makers have increasingly advocated some form of crop insurance as the means of confronting yield variability and its consequent impact upon producers, lenders, and particularly on the small-farm sector.

It is ironic that the increasing level of advocacy and a sharp increase in the number of programs around the world has occurred at a time when empirical evidence is pointing to these public sector, all-risk schemes as a costly failure. Not only are the current schemes in operation a financial disaster, but there is increasing evidence that their damage is not limited to consuming valuable development resources but may actually worsen the financial situation of rural sector institutions, particularly agricultural lending banks.

Characteristics of Current Systems

Before beginning to understand why this is so, first I would like to clarify a few terms that are used interchangeably, but which really are quite distinct in practice. Secondly, I would like to summarize as succinctly as possible the basic characteristics of the distinct types of systems that are in operation today.

Crop insurance is a generic term for the insurance of almost any agricultural activity without reference to the content of the insurance. Crop insurance is understood to be a financial transaction that transfers risk to a third party via the payment of a premium, as opposed to an entitlement or a disaster relief scheme.

All-risk or multi-peril insurance is a form of insurance that covers either all the supposed production risks in agriculture or a very broad spectrum of those risks. It usually, but not necessarily, covers losses from causes that cannot be demonstrated to have affected the crop. These perils, such as too much moisture, excessive heat, or excessive cold, implicitly cover a multitude of problems, including management problems or the inviability of the enterprise. As a general rule, pests and diseases are also included.

Yield guarantee insurance provides the grower with an insurance product that will compensate him for any shortfall when his yield declines below the level set in the policy. As a...
general rule, all-risk insurance is coupled with a yield guarantee type of policy. This type of policy is written exclusively by government or quasi-government organizations that enjoy a substantial administrative and premium subsidy, as well as an assumption by the public sector of massive insurance losses. Premiums, underwriting, loss-adjustment rules and yield guarantees are generally set in coordination with ministries of agriculture and state lending banks, so that the insurance covers the credit extended by the bank and the yield expected by the ministry of agriculture (but not necessarily related to the actual yields) and is affordable to the producers. The clients tend to be the smaller and more marginal farmers who rely upon public sector lending institutions providing loans at below the market rate.

The financial results are uniformly bad and, in most cases, disastrous. The product is so distasteful to farmers that (not withstanding the heavy subsidy) almost all of the schemes are obligatory or are tied to obtaining government credit. Almost none can successfully market a product that farm operators will voluntarily buy.

These government-run schemes are at best a costly and inefficient welfare delivery system characterized by massive bureaucracies that introduce significant price distortions and sustain inviable farming enterprises through resource transfers at very high transaction costs. Their true premium rates, if charged to farmers, would virtually ensure that few, if any farmers, would buy the cover.

Specific risk or named peril coverages are quite different both in their scope and in their system of underwriting and loss adjustment. As the name implies, these coverages list the perils that are to be insured. The underwriting process is on a for-profit basis and generally screens out operators who are so exposed as to make loss probable, as well as those producers whose operations are so marginal that a reasonable return on investment is unlikely. The premiums are set so as to cover the cost of operation, loss adjustment costs, and usually a contribution to a catastrophic loss reserve. The loss adjustment generally is not based upon a guaranteed yield to the producer but instead upon physical evidence that one of the insured perils has occurred and has produced a quantitative (and rarely, a qualitative) loss to the crop.

In their most traditional dimensions, crop, fire, and hail risks have been covered for almost two centuries. In recent years, broader perils have been written to include most of the major climatological risks in agriculture, including frost, flood, hurricane, and drought. The clients tend to be larger farmers who have better control of technology and whose on-farm management practices can successfully manage most risks except such major climatological and meteorological phenomena.

This cover seldom includes phenomena not subject to quantification, such as excess humidity, heat, or cold. It almost always specifically excludes pests, and disease as, with few exceptions, these are management problems. Almost without exception, it includes a deductible or coinsurance to encourage the insured to keep his losses down.

This type of cover is written almost exclusively by the private sector and is reinsured in international reinsurance markets, particularly London and Europe. Almost all of this cover is sold on a voluntary basis to producers, although some may be compelled to buy the cover as a condition of obtaining credit. The risks insured, the premium charged, and the method of loss adjusting are set and readjusted by market mechanisms. Operators can, and frequently do, refuse to purchase insurance if they find that the cost of the product is not closely related to the risks that they want to transfer to the insurer. Likewise, insurers who do not know the riskiness of agriculture as well as the operators they insure generally do not last very long.
The financial results of this class of business is rather hard to determine, as commercial secrecy and competitive pressures do not permit most companies to reveal their results. One may assume that given the rapid expansion of the number of companies doing this class of business around the world and the increasing premium volumes that it is not their eleemosynary instincts that lead them to do this business.

**Government Sponsored All-Risk Crop Insurance in Developed Countries**

**The United States**

In the United States, the crop insurance program began in its present form in 1948. It is an all-risk, yield guarantee which gives the farmer a guarantee that he will harvest either 50 percent, 65 percent, or 75 percent of the historic yield of his county. The premium is heavily subsidized with the government absorbing about 30 percent of the premium cost and paying 100 percent of losses in excess of premium income. In addition, the entire administrative cost (currently set at 34 percent) of the program is borne by the U.S. government. At present, the program insures 50 different crops in almost 2,000 counties across the country.

Between 1980 and 1989, the U.S. government has incurred costs of about $4.3 billion to sustain this program, of which $1.8 billion has been incurred since 1986. Between 1980 and 1986 the total cost of the program was about $4.3 billion, of which the government provided about $2.5 billion while farmers paid only $1.8 billion in premiums. The government paid in premium subsidies and administrative costs about 58 percent of the total costs. This figure does not include losses in excess of premiums. Viewed in another way, the U.S. government provided $1.40 in subsidies for each dollar of premium paid by farmers.

The unsubsidized premium required to make the system self-financing is somewhat difficult to determine due to the way in which the Federal Crop Insurance Corporation (FCIC) presents its data. If we look at 1987, a typical year in terms of the experience of the scheme over the past 20 years, we see that the total sum insured was about $8.4 billion, and total losses were about $730 million. Thus, to pay these losses, a premium of 8.7 percent is required. In the same year, farmers paid premiums of $371 million, or a rate of 4.4 percent. The government’s premium subsidy was about $129 million for a total premium of $500 million. Losses were about $730 million, implying that the government picked up the remaining $230 million not covered by farmer premiums and that in addition to the premium subsidies, the subsidies to cover losses were about 50 percent of the total premium.

Administrative costs are even more difficult to break out due to incorporation of loss adjustment costs into indemnity figures, but, as an estimate, the system cost about $190 million per year. Of this amount, about $75 million was absorbed by FCIC itself. Administration costs are therefore about 38 percent of the premium collected.

When the administrative costs are added to total indemnities, the cost of the system is about $920 million per year, of which the government paid all but $371 million. About 58.6 million acres were insured at a total cost to government of $549 million. The government subsidy was therefore about $9.30 an acre ($22.30 per hectare). To sustain the system without a subsidy, a premium rate of about 11 percent would be required.

Despite this substantial subsidy transfer, a majority of farmers still do not like or use the program. The number of acres participating in the program was only about 24.5 million out of a total of about 133 million acres cropped in the United States in 1986 (18.4 percent). More telling still of the general unpopularity of the program is the percentage of eligible acres
participating in the program. In 1980, eligible acre participation were only 9.6 percent. By 1988, the additional subsidies had attracted only 24.5 percent of the eligible acres. This experience seems to modify the Gardner and Kramer conclusion that the subsidy would have to exceed 50 percent of the premiums charged to get a majority of U.S. farmers enrolled. Given that the government picks up the losses, the subsidy may well exceed 50 percent already without attracting even one-quarter of the eligible farmers.

To the extent that past experience can be projected into the future, the cost of enrolling 50 percent of the eligible U.S. farmers would imply that the annual cost of the program to the government would increase from some $400 million to $500 million per year to about $800 million to $1 billion per year.

Are U.S. farmers economically irrational not to participate in a heavily subsidized program that has over time provided them with a substantial cash infusion? More important, what can we learn from a program that has been operating for over 40 years with a heavy subsidy and still cannot attract over 25 percent of the eligible farmers?

First, U.S. farmers are probably no more economically rational or irrational than are farmers anywhere else in the world. They are, however, more politically enfranchised than are most. Secondly, U.S. farmers are no more homogeneous than farmers elsewhere.

There is general agreement that the majority of farmers have not participated in the insurance program because they have historically been very successful in pressuring the government to grant disaster relief. During the 1980-89 period, when crop insurance cost the government about $4.3 billion, the U.S. government made disaster loans of $6.4 billion and provided $6.9 billion in direct cash payments. Why buy what can be had for the cost of political organizing? Despite various pronouncements that the disaster relief program would not be continued, farmers have preferred to believe that they can organize after a disaster to press successfully for relief.

Second, there is almost universal agreement that the worst farmers have selected themselves out for participation in the program. This anti-selection is apparent at two levels: Within a given program, farmers who have lower yields tend to buy a crop insurance program whose guarantee is closest to their actual expected yield; the better farmers, however, do not find even a 75 percent yield guarantee attractive because the guarantee is based on county, not individual, yields. To give an example of this anti-selection process, let us take a hypothetical case. Suppose that the county average for corn (maize) production is 100 Bu/Acre. Producer A consistently produces 125 Bu/Acre while Producer B averages 80 Bu/Acre. Producer B would opt for the 75 percent yield guarantee insurance as he would only need suffer a loss more than 5 Bu. (7.5 percent) to qualify for an indemnity. Producer A in contrast would need to lose half of his production to qualify for an indemnity. Both farmers are charged the same premium as premiums are made on a county basis.

The same holds true on a regional level. Participation is not evenly spread across the United States. Instead, the most risky farmers tend to select themselves out for participation in the program. For example, in the high, dry plains region, where agriculture is far more exposed to risk than in the lower rainfed areas, participation is much higher. In fact, one frequently hears from the farmers that if it were not for crop insurance, they would not be farming. Viewed purely as an economic decision, there is an argument that they should, in fact, not be farming, and the land should be put to other uses.
While much of this situation may be particular to the United States, there are some valuable lessons about how state-sponsored yield guarantee crop insurance interacts with the political system and how some parts of the farming industry can use that system to protect and enhance "their" program.

First, it is clear that the U.S. system can not make rates -- in part due to political pressure and in part due to bureaucratic indifference to financial outcomes -- that reflect the true cost of the risk transferred. The U.S. government for political reasons has been unable or unwilling to adopt rules that would charge farmers in the same area differential premium rates or to issue realistic yield guarantees that would prevent anti-selection.

Second, the U.S. cannot set yield guarantees that will attract the better farmers with higher yields. Finally, the loss adjustments do not truly reflect the losses caused by nature as distinct from those arising from unsuitability of the land for farming or even losses caused by the lack of knowledge or management skills.

The U.S. government is under constant pressure from the participating farmers to raise the guarantee level and to lower the premiums charged, as well as to soften the loss adjusting rules. These pressures are particularly effective in the U.S. Congress and in the FCIC bureaucracy. Crop insurance has become a "locked in" subsidy for some of the more marginal and less efficient operators. And, like all subsidies, once granted it is difficult to take it away.

If instead of incurring the cost of administration and premium subsidies, the government were to offer a fertilizer subsidy or other input vouchers for the $20 to $25 per hectare ($9.30 per acre) that the program costs, it is likely that participation would be nearly universal. When farmers do not participate in a subsidy program, clearly that program is flawed. In this case, the majority of U.S. farmers are unconvinced that crop insurance is useful to them in managing their risks, even with these subsidies. But a minority of more marginal farmers use the crop insurance program to keep them producing in areas where without the subsidy their operations would be inviable.

Japan

The Japanese crop insurance scheme began in 1947. It is organized on the basis of agricultural mutual relief societies that operate a fund to pay losses. The fund, in turn, is backed by the national treasury, which pays between 50 percent and 79 percent of the total premiums. The scheme is compulsory for rice farmers. At the time the program was established, Japan was suffering post-war food shortages and had begun to utilize all available policy instruments to promote the production of food, including all-risk crop insurance.

The original scheme offered a village-level yield guarantee, but like in the United States, the Japanese found that the better farmers were provided with inadequate protection. In 1957 the system was changed to an individual yield scheme.

The results of the scheme have been quite mixed. The existence of the insurance has encouraged the expansion of farming to more marginal areas characterized by high risk of disastrous losses. Overall, the program has transferred resources to the small farm sector, although at present average farm household incomes are higher than those of suburban families. The program probably did help promote the production of rice; however, today that objective and the costs implicit in the program are irrelevant. Japan produces rice at many times the world market price and has a costly domestic surplus. Yet, the insurance program continues to transfer resources to producers who, in many cases, are weekend farmers. Such farmers produce a crop
surplus that costs the government substantial resources over and above that of the production subsidies.

Unfortunately, complete data for Japan has not been collected. However, by way of illustration, if we take the estimated total government subsidies for 1979 of almost 160 billion yen (down from 213 billion yen in 1976) for the insurance program and compare it to the additional yield produced by the subsidy of about 71,000 tons, it appears that it costs over two million yen (at the 1980 rate) of subsidy to produce a ton of rice, a product that is a surplus commodity.

In 1980, approximately 210,000 hectares of rice (and to a lesser extent, barley, and wheat) were farmed by some 409,000 farmers who were insured. This implies a subsidy of about 800,000 yen per hectare and some 391,000 yen of subsidy per farmer. Even at an exchange rate of 200 yen to the U.S. dollar, this implies that the Japanese program supplies subsidies of about $4,000 per hectare -- or an average transfer of almost $2,000 per farmer.

The unsubsidized premium required to pay the losses on the principal crop of paddy rice, according to data available for paddy rice in selected years between 1947 and 1980, would need to be increased by 50 percent if the subsidy were removed. This additional premium does not include the administrative costs. The average national premium for rice of about 6 percent would need to rise to about 9 percent of the sum insured to meet loss costs, exclusive of administration. The least risky district, Niigata Prefecture, would see its premium rise from 2.4 percent to 3.6 percent. In Hokkaido where the standard premium is 15 percent, this would imply a premium of slightly over 22.5 percent.

In recent years, administrative subsidies in Japan have averaged about 100 percent of farmers' premiums. Thus, a self-financing premium that covered losses and administrative costs would be about 18 percent nationwide, 45 percent in the most loss-prone area, and 7.2 percent in the least loss-prone area.

While these Japanese transfers appear to be massive -- and economically nonproductive -- they are probably not too far removed from the U.S. transfers per insured farmer. If we remember that subsidies in the United States are about $22.30 per hectare ($9.30 per acre), the average insured farmer in the United States would need only farm about 90 hectares (215 acres) to receive a subsidy similar to that of Japan. Given that corn (maize), wheat, and soybeans constituted 210,000 or 61 percent of the 342,000 insured U.S. acres in 1986, and that most of these grains are grown on quite extensive operations in America's midwest region, this assumption is likely to be borne out.

While the Japanese clearly provide substantially larger subsidies on a per acre or hectare basis, it appears that on the basis of the farm unit, Japan and the United States probably transfer about the same amount of resources. In terms of a self-financing scheme, it would appear that Japan and the United States would need a premium of about 9 percent to cover their losses. Japan would have to charge close to 18 percent to meet losses and administrative costs. The United States in a typical year would need about 11 percent to meet both losses and administrative costs.

**Government Sponsored Multi-Peril Crop Insurance in Developing Countries**

It may well be argued that expensive programs like those of Japan and the United States characterize the developed countries. For these countries these expenses are not a large part of the total outlay and resource constraints are not as tight as in the developing countries. Programs that cost $600 million to $1 billion are not overly expensive for the developed countries.
Unfortunately, when we look at the multi-peril, state-sponsored programs in the developing world, we find an even bleaker picture. In some cases, the overall costs of the scheme rival that of the United States, while in other cases the amount of the administrative subsidy actually exceeds that of Japan.

Asia

Taking a look at three of the programs that have published their results at international meetings may be illustrative. In Bangladesh, the loss ratio is about 300 percent; in the Philippines it is 123 percent (excluding administrative costs and 185 percent including administrative expenses); and Thailand’s small program reports a loss ratio of over 320 percent. The premiums have been set artificially low, and thus the loss ratios appear quite high. However, the absolute levels of premiums would have to rise significantly to meet these costs. In Bangladesh, for example, premiums would need to be between 9 percent and 16 percent to pay losses. In the Philippines, premiums need to rise from about 8 percent to nearly 15 percent to meet the loss costs, and Thailand would require a premium of 16 percent. The cost of administering the programs would have to be added to these premium rates.

The Philippines

A recent annual report from the Philippine Crop Insurance Corporation (PCIC) sheds further light on the underlying problems of these state run, small farmer schemes. The 1989 agricultural year in the Philippines was surely one of the worst in the history of country. It was hit by five major typhoons, all of which crossed directly over the islands between January and November. Under these circumstances, heavy losses are to be expected. Interestingly, the typhoons caused only 21 percent of the damage suffered by PCIC’s insured farmers. The major cause of loss was drought (46 percent), with pests and diseases contributing 16 percent and 12 percent, respectively. Thus, the typhoons notwithstanding, almost one-half of the losses were attributed to too little rain, not floods associated with typhoons.

In 1988, the PCIC issued 1.1 million policies covering about 174,000 farmers growing 289,000 hectares of rice and corn. It collected premiums of 91.4 million Philippine pesos. Its losses totaled almost 204 million Philippine pesos, paid to about 86,000 claimants farming 152,000 hectares. In other words, the PCIC indemnified about 50 percent of the insured farmers and about 53 percent of the insured hectares. A premium of almost 45 percent would be required to pay losses of this magnitude. In the absence of historical data, it is difficult to generalize about the level of premium that would be required, however.

The administrative cost of delivering a net subsidy (indemnities minus premiums) of about 112.6 million Philippine pesos was set at almost 145 million Philippine pesos. In other words, the transaction costs exceeded the indemnities. In the Philippines, it costs 1.3 pesos to deliver one peso of indemnity to farmers. The administrative costs of the Philippine scheme are thus not too far removed from those of Japan, where a large number of quite small farm units are insured.

The cost to the government of the Philippines however is considerably greater than the administrative costs of the system. The total premium for the crop insurance is set at 11 percent for rice and 13 percent for corn. The farmer pays only 2 percent for rice insurance and 2.5 percent for corn insurance. Thus, the subsidy component of the premium averages 9 percent to 11 percent. Of the average premium of 12 percent, the government contribution is about 80 percent of the total premium. As total premium income was about 91.4 million pesos, this implies that about 73 million pesos was contributed by the government.
Thus, premium subsidies of 73 million pesos plus the administrative costs of 112.6 million pesos implies that the program's cost to the government was about 185.6 million pesos, or about 642 pesos/hectare or about US$29/hectare at current exchange rates.

**Latin America**

Several Latin American countries have state-run, all-risk crop insurance programs. To date the experiences in terms of the premium levels and administrative costs of these programs has been quite similar to those that we have reviewed above.

**Costa Rica**

The Costa Rican program has historically been very restricted in geographical scope and quite expensive. Traditionally only dry-land rice farms in Guanacaste Province have been insured. The farms have consistently reported drought and have claimed substantial indemnities.

In the decade of the 1970s, the state insurance institute (INS) collected about 65.5 million Costa Rican colones of premium. In the period it paid out about 270 million colones of claims, producing a pure-loss ratio in excess of 400 percent. The administrative cost of delivering this indemnity was placed at about 40 million colones, or about 61 percent of the farmers' premium. As about 387,000 hectares were insured during the decade and the deficit of the system [(premium) - (claims + expenses)] totaled about 241 million colones, the implied subsidy was about 623 colones (or US$73 at the exchange rate that prevailed during most of the decade). This would appear modest indeed, except that during the decade only a total of 10,997 policies were issued. Thus, the subsidy was almost 22,000 colones (or about US$2,600) per policy issued.

As the total sum insured during the decade of the 1970s was 1,278.8 million colones and the losses were almost 270 million colones, an unsubsidized premium would have been around 21 percent of the sum insured, roughly five times the 5 percent rate charged farmers. Expenses for the decade were put at almost 37 million colones, or about 56 percent of the premiums. Thus, to pay both losses and administrative costs the Costa Rican system would have needed a premium of 26 percent of the sum insured.

The pattern of losses accelerated in the early years of this decade. In the 1981-82 crop year, indemnities rose to about US$5,000 per policy. By the middle of the decade, the portfolio had been somewhat diversified. Rice however still contributed about 75 percent of total premiums. The experience of the 1980s remained similar to the decade of the 1970s. In 1987, about 5,500 hectares were insured. Premiums were 10.9 million colones while losses reached 75.4 million colones and expenses added an additional 42.8 million colones to the cost of the crop insurance program. Stated in another way, expenses were nearly four times the premium income, while the loss ratio was almost 700 percent. The subsidy per hectare was about 19,500 colones (or roughly US$300).

In 1988, the most recent year with data available, 26 million colones of the total premium of almost 35 million colones was derived from rice. Losses for 1988 totaled 47.5 million colones while the administrative costs reached 23.4 million colones. The administrative costs were 67 percent of premiums, slightly above the average for the decade of the 1970s. The subsidy per hectare declined to 3,000 colones -- or about US$46.
ANAGSA, the Mexican agricultural insurer, is the oldest and largest in Latin America. It began in the 1940s and has grown to insure about seven million hectares per year in all parts of the country. It insures principally the clients of BANRURAL, the state-owned lending bank, which in turn lends predominately to the Ejidos. Over 90 percent of ANAGSA's operations are with BANRURAL, which then recovers over 30 percent of its loans via ANAGSA indemnities.

During the 1980-88 period, in 1988 U.S. dollars, the government provided premium subsidies of $3,231 million and paid expenses of $602.8 million. In addition, the government assumed losses of an additional $61 million. Total government outlays were therefore $3,894.8 million. Total farmers' premiums were about $1,268.9 million.

The amount of the annual indemnities rose steadily from about $240 million (1988 dollars) in 1980 to about $654 million (1988 dollars) last year. The annual premium subsidy was therefore about $433 million per year.

Using seven million hectares as the average number of insured hectares per year, the premium subsidy per hectare was about $62. Administrative costs are put at about $63 million per year. This adds about $9 per hectare to the government subsidy, making the average subsidy cost about $71 per hectare for the 1980-88 period.

Last year, however, farmers' premiums aggregated $197 million, while the government premium subsidy was $283 million -- plus administrative costs of about $61 million and the assumption of losses in excess of both the farmers' and the government's premium of $219 million. After these calculations, the cost to the government was about $563 million. The total number of hectares insured was 6.6 million (of which 5.2 million, 79 percent, were indemnified). Therefore, the subsidy per hectare rose by about $85 per hectare.

The total agricultural coverage issued by ANAGSA between 1980 and 1988 was $13,944.6 million. Losses over the decade reached a level of about $4,227.4 million. Thus, the premium required to pay the 1980-88 losses would be about 30 percent of the sum insured. To cover the expenses of ANAGSA, the farmers' premium would need to be doubled, and the total premium would have to be increased from 30 percent to almost 35 percent of the sum insured.

It is clear that either ANAGSA has lost underwriting and loss-adjustment control capability or that it is an explicit subsidy channel to make the results of BANRURAL, the lending institution, appear substantially better than they, in fact, are. In the Mexican system, the insured is not paid directly, rather his loan at the bank is canceled via the indemnity payment. If it is the case that ANAGSA is used to help BANRURAL channel subsidized credit to farmers, principally on Ejidos, and to forgive loans that are not or can not be paid off, then it is a costly system indeed. The government pays $61 million of administrative charges to acquire a paper transfer of $197 million from the farmers. In fact, few farmers pay premiums; instead, BANRURAL adds it to their loan amount and finances the total amount. The farmer neither pays the premium nor sees the indemnity. He is essentially incidental to the system under which a government insurer pays a government bank. The costs of such a system are substantially higher than they may appear. It is generally recognized that there is a fair amount of what we might call "slippage" in the system under which the insured are sometimes required to make payments in return for having their losses recognized by the field agents.

Exactly what is gained by having a government insurer pay off a government bank is mostly appearance. The bank's books look somewhat better, and it appears that the losses were
due to risks beyond the borrowers' control. The bank can make loans that the creditworthiness of
the borrower otherwise would not permit. It can also relax its field supervision when it knows that
a substantial part of many loans are used not for production but instead to provide poor, marginal
farmers with relief payments.

In looking at this system, one realizes that what is lost under the system is
considerable indeed. The credit discipline breaks down completely, and, in addition to subsidized
lending losses, the system further vitiates the credit system by running a hidden transfer
mechanism.

While there is certainly a very strong argument for supporting many of the clients of
BANRURAL and ANAGSA through transfer payments, this system of trying to make it appear that
they have suffered crop losses and can not pay their loans is costly indeed. It would be both
cheaper and far more effective to separate the credit system from the transfer payment mechanism
and to make transfers without the involvement of a large bureaucracy, which comprises about
7,000 individuals and the inevitable "slippage" that this entails. Until such a reorganization is
undertaken, the agricultural credit system in Mexico can not be put on a self-sustaining basis.

PREMIUMS AND SUBSIDY LEVELS

The multi-risk, state-run crop insurance programs reviewed here are all characterized
by very high costs, both to pay losses and to cover the administrative charges. Both in the United
States and Japan, premiums of about 9 percent of the sum insured would be required if the
government were to withdraw the subsidy. In the United States, the premium would rise to around
11 percent if the administrative subsidies were withdrawn. Japan, characterized by small-farm
units, incurs administrative costs of 80 percent to 100 percent of paid premiums. The Japanese
system would have to charge about 18 percent to run the scheme without any subsidy.

The cost of operating all-risk crop insurance in the developing world is substantially
higher than that of the United States and Japan when the true premium rate required to operate
without subsidy is used as the yardstick of measurement. In Mexico, which has operated its
scheme for 40 years, the risk premium required to pay losses is almost 30 percent. In order to
meet all of the costs of the scheme, a premium of about 35 percent would be required. Costa Rica
would have to charge its farmers in excess of 20 percent of the sum insured to pay the losses of
its scheme. The total charge to farmers for an unsubsidized scheme would be around 26 percent.

Subsidy levels on a per-hectare basis are quite high. In the United States, it is in the
range of $22.30 per hectare. In Mexico, it is considerably higher -- $71 per hectare. Costa Rica
is an intermediate case, as per-hectare subsidies for the scheme during the 1970s were quite small.
However, very few policies were issued during the decade, and the subsidy per policy issued was
about $2,600.

Participation and Adverse Selection

These subsidies do not seem attractive to the majority of the farmers where the
schemes are not compulsory. In the United States, only about 25 percent of the acreage eligible
for participation actually is covered by FCIC. In Mexico, with very few exceptions, only those
farmers borrowing from the state bank (BANRURAL) are insured. In Costa Rica, it is only a very
few rice growers who are principally located in the Pacific coast province of Puntaarenas who
voluntarily purchase insurance. The Philippines case appears to be similar. Almost all of the
insureds borrow from state banks and are compelled to purchase insurance. Other farmers do not
seem interested, notwithstanding that the premiums charged are only 2 percent to 2.5 percent.
It is a notable feature of farmer participation in Mexico, Costa Rica, and the United States that the most exposed farmers have selected themselves out for insurance. This process of adverse selection inevitably drives the cost of the scheme up and makes it increasingly costly. Likewise, we have found in the schemes reviewed that the states have not yet acted to introduce financial discipline and to price the premiums in line with the true cost of providing the service.

Table 1. Summary results of all-risk public sector crop insurance programs.

<table>
<thead>
<tr>
<th>Year</th>
<th>Country</th>
<th>Premium to Pay Losses</th>
<th>Costs % of Premium</th>
<th>Unsubsidized Premium</th>
<th>Subsidy/ Ha ($)</th>
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</thead>
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<tr>
<td>1980-89</td>
<td>USA</td>
<td>8.7</td>
<td>26</td>
<td>11</td>
<td>22.30</td>
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<tr>
<td>1947-80</td>
<td>Japan</td>
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<td>100</td>
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<td>1989</td>
<td>Philippines</td>
<td>45</td>
<td>130</td>
<td>90</td>
<td>32.00 *</td>
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<tr>
<td>1970-79</td>
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<td>56</td>
<td>26</td>
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</tr>
<tr>
<td>1980-89</td>
<td>Mexico</td>
<td>30</td>
<td>5</td>
<td>35</td>
<td>85.00</td>
</tr>
</tbody>
</table>

* This is an atypical year in the Philippines in terms of losses. Losses are over 160 percent higher than the previous year. In terms of administration costs, the results are average, being only about 17 percent higher than in the previous year.

In the United States, the struggle between farmers and the government over the premiums and the implicit subsidy has been in the open. Farmers have successfully used the political system to keep rates down and to raise guarantee levels to a point where those who do participate have a very good chance of realizing an indemnity. Less exposed and more productive farmers have decided not to insure, given that the guarantee levels are still quite far below their expected yields.

In Mexico a different process has led to essentially an identical end result. As many of the farmers who borrow from BANRURAL cannot expect even in normal years to be able to repay their loans, ANAGSA's insurance makes the recoveries seem considerably higher than they are. In fact, over 30 percent of total BANRURAL recoveries come from ANAGSA payments. This shuffling of subsidies between institutions has gone unnoticed by international lenders until
recently, when the World Bank began to view ANAGSA and BANRURAL as a single entity engaged in extending and recovering agricultural credit. Many other farmers who normally can repay their loans, but do not do so because the bank holds no realizable collateral, are forced to use the ANAGSA insurance as a condition for receiving credit. The better farmers are not attracted to the system because the yield guarantees are set so low that they would have to lose a very substantial portion of their crops before they received any indemnity.

**An Alternative Risk Management Strategy: Private Sector, Specific-Risk Insurance**

Clearly the agricultural industries in the developed as well as the developing world are exposed to climatological risks beyond their control. If these state-sponsored systems have proved costly both for the public sector and unattractive to growers on a voluntary basis, is there a mechanism that can offer a voluntary cover that some producers would purchase on a voluntary basis and would utilize to transfer some of these unmanageable risks to a third party?

There is evidence that the private sector is capable of and, in fact, is engaged in offering limited- or named-peril insurance for a broad range of crops around the world. Much of this development has gone unnoticed because of commercial secrecy and the need to keep a low profile to avoid conflicts with state-run schemes.

As one involved in this area, I can perhaps outline these developments and suggest the criteria that the private sector uses to develop these programs and to make them a commercially viable proposition. Unfortunately, I am somewhat restricted by the need not to reveal trade and financial information that could be utilized by an increasingly competitive market. However, I am able to provide in broad terms an overview of the development of one of today's newest, largest, and most exciting insurance and reinsurance markets.

In general, the development of the multi-peril private sector market on an international scale began about a decade ago as several of those working in the field began to realize that the government-run schemes could never be fine-tuned sufficiently to produce viable and sustainable results. We began to turn increasingly to the private market to underwrite some risks. In general, the response of the national insurance industries was that they had no interest in or knowledge of agriculture and did not want to enter the market. Furthermore, they had no infrastructure in rural areas. Insurance in the developing countries tends to be an urban phenomena and seldom extends beyond the suburbs. Therefore, those of us working in the field were in a quandary. We were working with agricultural industries that needed a mechanism to transfer some commercial risks to a third party but confronted an insurance market in the countries that had no interest in working with agriculture.

We began to approach reinsurance markets, first in the United States, thinking that if we could find reinsurance capacity for the local insurers, they would do the business. The U.S. reinsurance market had no interest. However, we discovered that the market in London and the continental European market, especially the professional reinsurers, would provide reinsurance to local companies under certain stringent conditions. Based upon this willingness to venture some capital in agriculture, we were able to develop an increasingly broad market under fairly strict guidelines as to how the business must be structured and administered.

I would like to outline for you the three basic principles that guide the private sector initiative in the field of agricultural insurance:

**Principle one:** Offer agricultural and livestock producers a risk-transfer mechanism to "lay off" on an insurer those specific meteorological risks beyond their control through farming
practices and offer on-farm risk management at a premium that reflects the true long-term cost to the insurer of assuming those risks.

The structure of the private sector policies offered and sold to the agricultural industries around the world are remarkably similar. They are all specific-risk or named-peril policies that enumerate the insured risks. These risks are carefully defined and tend to be those that are truly beyond the control of the grower. Risks such as hurricane, flood, frost, fire, and sometimes drought are the most common insured perils.

Management-related risks are almost always specifically excluded. These risks include pest, disease, and usually rodents. Also excluded are risks that can not be clearly defined and quantified or that can not be separated from natural yield variation. These risks, generally included in state-supported schemes, such as "too much" humidity or "excessive heat," are excluded by private sector insurers because in most cases the physiological impact can not be seen or measured. There are numerous difficult cases where the market determines whether the cover is written, such as frost on cereal grains at the "boot" or flowering stage. As a general rule, the insured peril has to cause a clear and visible damage that is directly related to a loss of yield.

The private sector, with few exceptions, has been unwilling to issue yield guarantees. The loss adjustment is always based on the quantity (and rarely quality) of the insured product lost. Yield guarantees are not given for several reasons. First, it is almost always too costly for the farmers to purchase a yield guarantee unless the premium is heavily subsidized. Second, it is very difficult to determine an appropriate yield guarantee, given the high normal variability of yields among the farming community in a given area.

The premium rate charged by the private sector is unsubsidized and therefore has to be adequate to pay all of the loss costs, plus the administration. Setting this premium could be defined as part "an art" and part "a science." In general, the premium has to reflect the "incidence" and "severity" of the risks assumed by the insurers.

Generally, the insurance, and in particular the reinsurance, industry is prepared to take a relatively long-term view of the business. They are quite prepared to take the massive losses associated with a major disaster if there is a reasonable expectation that in future years they will recover their losses. In a sense, reinsurance works very much like banking: by spreading risks around the world, bankers attempt to create a reserve adequate to sustain a major loss in one part of the world and offset it with premium income from other parts of the world. Over the long term, they expect to recover the losses in a given country.

Profits for insurers and reinsurers come from two sources. The first is a "technical" or "underwriting" profit. This is the difference between the premium collected and the losses paid. The second is the investment income on the reserves held against disasters. Agricultural premiums have to be set to provide the insurer and reinsurer both. Agriculture can be a catastrophic business activity, and, much like earthquakes, when a major loss occurs everyone loses at once.

As a result, the premiums tend to be relatively high. In very general terms, the premiums range from about 5 percent to about 75 percent depending upon the severity of the risks assumed. It should be pointed out, however, that the market plays a significant role in determining the premium level. When there competition is minimal, there is considerably more liberty in setting premiums. However, as competition develops, premiums are driven down, frequently to a point where companies are knowingly writing the business on a loss basis in hopes of acquiring immediate premiums on which they can make a short-term investment profit sufficient to offset the expected losses. Thus, the agricultural insurance market exhibits the characteristics of other
capital markets, including quite a few casualties among participants who do not understand risk in agriculture.

**Principle two:** There is no government subsidy to cushion a loss. The insurer and reinsurer must absorb the full consequences of their rate setting and management abilities to provide adequate field services.

The fact that the insurers and reinsurers are not protected either from the financial results of ignorance or careless underwriting and risk management. And, this fact brings us to the next guiding principle of private sector agricultural insurance -- that is that insurers are keenly aware that a farmer through his management practices can have a major influence on yield. If it is more profitable to collect an indemnity, in many cases he can produce a loss and do so. This in turn leads to an underwriting program that provides coverage to growers that have sufficient knowledge, resources, and experience to produce a profitable crop which provides a reasonable return to the grower. Thus, the capital structure, the technology, and the skills of the insureds take on added importance to the insurer. As a result, the commercial insurance of agriculture has been concentrated in the commercial and agribusiness sectors of the agricultural industries. There is little room for the inclusion of small or marginal farmers who are not commercially viable. If a business is not commercially viable, insurance seldom can make it so.

Neither can the private sector allow itself be guided by goals other than a reasonable return on a very risky investment. While the industry can and frequently does work closely with governments and others to help sustain existing industries or establish new industries, it must do so on a commercial basis and leave to others the role of providing subsidies. Thus, it can be assumed that insurers and reinsurers are prepared to extend coverage only when they can be reasonably certain that adequate infrastructure is available to protect their investment. These processes must be objective and uninfluenced by external factors, such as socioeconomic status. These field services must be factored into the premium. As a general guideline, we calculate that about 25 percent of premium income is required to operate a moderate-sized program.

The fact that field costs must be included implies that many small-farm operations can not be included as they would not generate sufficient premium at a rate acceptable to growers to induce the farmers to purchase the coverage. This does not imply that smaller operations are excluded. Frequently, we are able to design a product for an organized group of farmers who collectively generate sufficient premium to pay the field services costs of their insurer.

Agricultural insurance is a bruising and frequently brutal business. If an insurers' knowledge of the risks confronted by his insureds is limited or if his management practices in the field are poor, he will suffer the financial consequences. The market as it has developed to date is a free market, but it could not be termed a fair one in terms of keeping all the players in the game. Those who do not understand risk in agriculture are fairly quickly parted from their capital.

**Principle three:** Private sector named-peril agricultural insurance is a completely voluntary program. The industry must design products that meet the needs of their clients, otherwise farmers will not purchase them. This in turn implies a very detailed understanding of the particular ecological niche that their clients occupy and a minute understanding of the business of their clients. It is seldom, if ever, possible to design a general product that will be attractive to a wide range of producers. Each group of producers must be considered separately, and a product must be "tailor-made" for that group.

For example, the risks for winter wheat and summer wheat are quite different, as are the risk profiles of a grower on the high plains and one in an coastal irrigation district. One may
be affected by frost and drought, while the other is concerned about hurricanes and floods. Each set of risks has to be considered separately, and a product sufficiently attractive to the grower has to be designed. Likewise if the same two growers are using different technologies, the insurance product must reflect the differences. In addition, should the irrigated grower be producing soft wheat primarily for feed, while the high plains grower is growing seed wheat, the insurance program has to reflect the very different values of these crops. The sum insured per hectare will be very different, as will the premium rate. The industry can seldom dictate the terms of the policy. Rather it takes what is essentially a joint effort between the insurers and farmers to find a compromise acceptable to both.

The fact that the private industry has to develop a broad range of attractive products that growers will voluntarily purchase necessarily implies establishing and maintaining a bargaining relationship. Insurers have to work with growers to design the product, but they also have to negotiate a fair price. Usually there is little room for monopolistic pricing. Farmers can, and frequently do, walk away from a product that they view as not reasonably priced. In many cases, they walk no further than over to the competition. Growers around the world -- where market mechanisms are allowed to operate -- are quite adept at bargaining with several insurance companies for the lowest premium rates and best terms. In fact, they are quite clever and successful at securing favorable loss-adjustment conditions. If growers' losses are low, they also are generally successful in demanding a premium reduction.

The Magnitude of the Private Sector Market

The size of the agricultural multi-peril insurance industry is difficult to determine with any degree of precision. The reasons for this difficulty are primarily the higher level of commercial secrecy and increasingly tough competition. In some cases, the industry is allowed to operate on the margin of what is permitted under the law, while, in other cases, in countries that have state-run insurance monopolies, selling private insurance would be illegal, unless the transaction took place abroad.

To date, I have identified about 60 crops around the world ideally suited for private sector insurance coverage. These include cereals, pulses, horticultural products, forage crops, fruits, aquaculture, tropical beverages, flowers, forest products, tree crops, and vegetables as well as some highly specialized agricultural activities such as planting or raising mushrooms, snails, and crocodiles, and cheese aging. The insured perils range from floods, freezes, fires, hurricanes, and drought to the more exotic risks, such as foraging elephants, snakes, parrots and kangaroos -- not to mention maritime algae blooms and wildlife stampedes caused by passing aircraft.

The following list by country and crops covered will provide you with a flavor for the variety of countries developing private multi-peril agricultural insurance programs:

- **United States** -- From 40 to 50 crops, mostly specialty crops not covered by the government-run FCIC. These include tree crops, such as pine timber nuts and Christmas trees; horticultural crops such as raisins, raspberries, cranberries, and specialty citrus; and aquacultural crops, including shrimp and catfish.

- **Western Europe** -- Some extensive agriculture, but primarily high-value crops such as wine grapes, flowers, olives, citrus, and specialty horticultural crops.

- **Australia and New Zealand** -- Extensive areas used for livestock production are insured in both of these countries. In Australia, insured crops include grains, cotton, and fruits and
vegetables. In New Zealand, substantial volumes of aquaculture and livestock raising are insured. Coverage is growing very rapidly in both countries.

- **Latin America** -- Extensive private sector programs operate in Mexico, Venezuela, Chile, Jamaica, the Dominican Republic, Barbados, the Windward Islands, and to a lesser extent in Brazil, Argentina, Guatemala, Ecuador, and Costa Rica. In some countries extensive areas of cereals, pulses, and tubers are insured. Other crops include a large part of the export winter vegetable crop; tropical plantation crops such as coffee, cocoa, tea, bananas, coconuts, oil palm, and rubber; flowers and ornamental plants; and poultry, swine, and cattle as well as the rapidly growing aquacultural industries.

- **Asia** -- Programs have been initiated in Turkey covering grains and vegetables. In India, table grapes and some export fruits are insured. Pakistan has an extensive livestock program. Malaysia has a long-standing program on rubber and increasingly on aquacultural risks, such as shrimp farms. Thailand has coverage on several crops including rice, tree crops, and some livestock.

- **Africa** -- In most of Africa, private sector insurance would be technically illegal, given the state monopoly of insurance and usually reinsurance. Notwithstanding, some exceptions can be noted in various countries. Kenya has private sector insurance of tea, export flowers, tree crops, and vegetables. Zambia has a maize insurance program, which, while technically within the state-owned company, operates as a private company. South Africa has a long-standing cooperative insurer that covers about 30 crops. The Mauritius sugar scheme is a model program in Africa and for all developing countries. Sudanese and Egyptian cotton has been insured for a number of years. Recently, Moroccan and Tunisian produce has been insured as has extensive areas of bananas, cocoa, and some coffee in tropical African states where insurance is a state monopoly.

- **Middle East** -- Cyprus and Israel both have state-owned companies which have operated more like private sector insurers. More recently Jordan has insured its vegetable crop, and Saudi Arabia has developed programs for its nascent dairy and wheat industries.

The amount of premium generated by these programs around the world is very difficult indeed to estimate. A reasonable guess would be about $1 billion per year, and the volume appears to be growing very rapidly indeed. On average, about a dozen new programs per year are launched; perhaps six to eight of these survive their first five years.

**CONCLUSION**

In conclusion, I would argue that public sector all-risk insurance has proven to be an expensive failure. Governments around the world have been unable to set adequate premiums and have as a consequence had to supply these programs with a substantial subsidy. Furthermore, the administration of such government-run schemes has been very costly indeed. Despite the heavy subsidy component, farmers have generally refused to voluntarily participate due to the unattractiveness of the products offered by the state companies. In some cases, such as Mexico, these programs have constituted a major transfer of public resources on the order of approximately $500 million dollars per year. Notwithstanding those resource transfers, farmers still prefer to absorb their own risks.

In contrast, there is a small but rapidly growing private sector insurance industry that is providing a specific-risk alternative to the all-risk, state-run schemes. Each year larger
numbers of farmers voluntarily transfer some of the risks that they can not manage to these private sector schemes. The products are characterized by a responsiveness to the risk management needs of the farmers and a pricing structure that farmers find competitive and reasonable.

These commercial schemes require no public resources and are generally quite efficiently managed. Yet, the growth of the industry has been impeded by the fact that agriculture is a catastrophic business and the consequences of wrong decisions on the part of insurers is very similar in consequences to a major mistake or miscalculation on the part of producers. Furthermore, in many countries their activities are either on the margin of the law or strictly prohibited.

Notwithstanding these difficulties, an increasingly competitive market is developing to offer producers risk management products that concentrate in the capital-intensive, export-oriented industries. As the agricultural insurance industry gains experience and develops an infrastructure in the rural areas, the industry will be able to expand its service network to reach an increasingly large agricultural market.

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