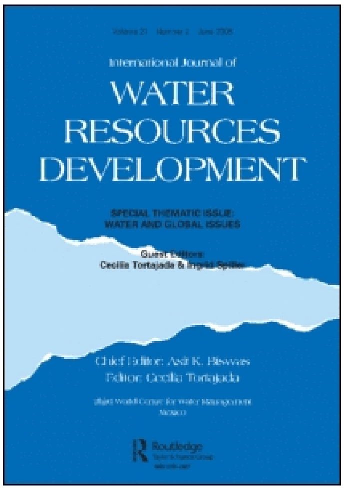

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There Is No Such Thing as an Average: How Farmers Manage Uncertainty Related to Climate and Other Factors

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There Is No Such Thing as an Average: How Farmers Manage Uncertainty Related to Climate and Other Factors

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ABSTRACT *Managing uncertainty related to climate variability has always been at the core of all agricultural activities. For farmers across the world, the concept of average rainfall is often less important than its dispersion and distribution during the cropping season. In most developing countries, farming practices are based on risk-mitigation strategies that do not allow for the development of highly productive agriculture, but mitigate the risks associated with the variability of climate and of other factors like markets or freshwater availability. The paper reviews the concept of average precipitation and discusses the stochastic nature of climate variables. It addresses the relationship between climate and crop production and related farmers' behaviour, and discusses the different tools and approaches that are available to anticipate, mitigate or compensate for the negative effects of climate variability in agricultural production.*

What Is an Average Precipitation?

Stochastic Nature of Climatic Variables

The stochastic nature of hydrological time-series has been recognized for centuries,[1] and hydrology was one of the first areas of science to use statistical concepts in an effort to analyse natural phenomena (Haan, 1994). The development of statistical tools was necessary to analyse and solve hydrological problems in support of decision-making. Statistical methods in hydrology are based on the assumption of stationarity of the stochastic processes, which makes it possible to describe them in terms of probability distribution functions of random variables like precipitation and runoff (World Meteorological Organization (WMO), 1984).

Statistical Distribution Functions of Rainfall, Measures of Mean and Dispersion

Figure 1 shows 100 years of monthly values of precipitation in Beira, Central Mozambique (Food & Agricultural Organization (FAO), 2009). Clearly, there are large variations from one year to another. There are also clear seasonal trends, with seasons with more or less rain. Clearly also there is not much that can be obtained from the analysis of such a graph.

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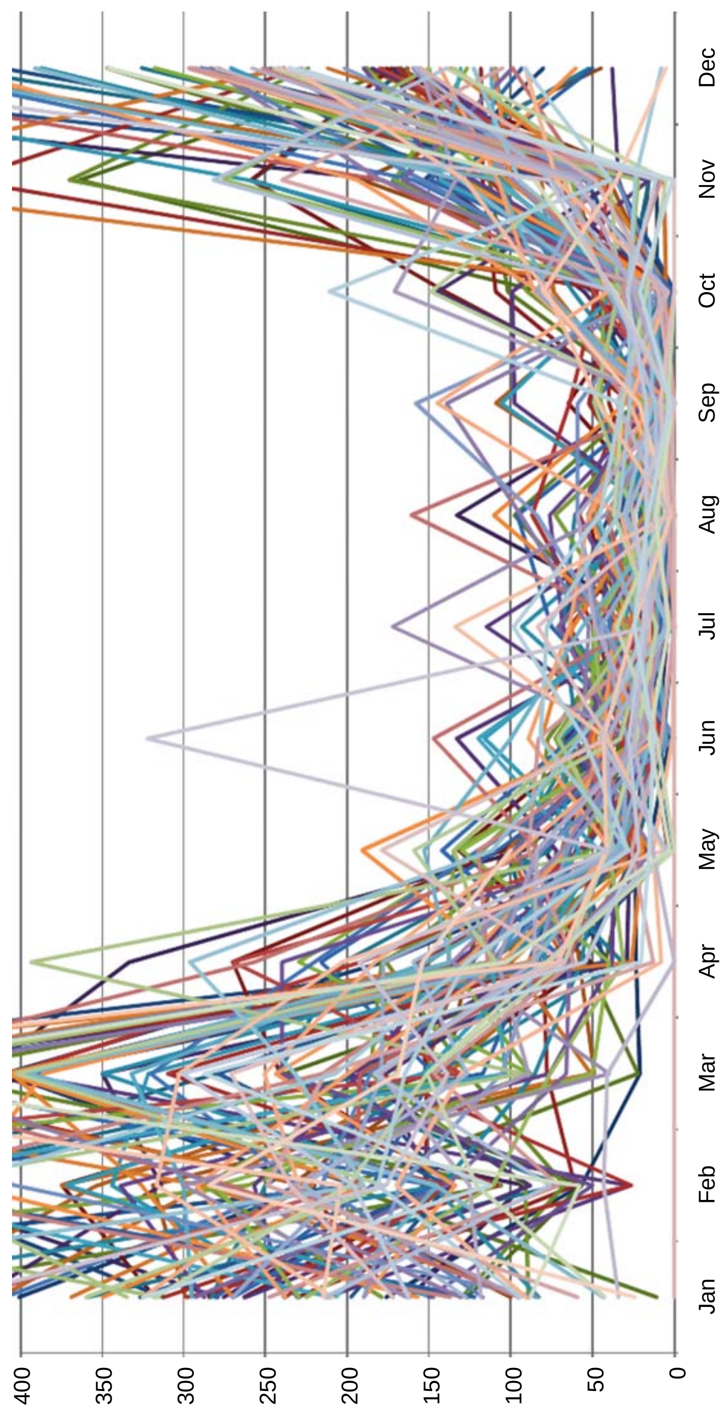

Figure 1. Beira, Mozambique: monthly rainfall distribution (in mm), 1908–2009 (each line represents a year).

Generally, the first property of a hydrological variable that is of interest is its mean, or average, directly followed by a measure of dispersion, the most common of which is variance. The use of averages is widespread in all aspects of life and professional activities. They provide the quickest and often most relevant way to assess a given variable, and therefore are a valuable support to decision-making in numerous situations. However, their use has too often excessively simplified the description of complex processes, and much less attention has often been given to their dispersion dimension.

Figure 2, which corresponds to the same rainfall station as shown in Figure 1, has much more interesting information than Figure 1. It presents both monthly averages and dispersion around these averages, and therefore helps to separate the deterministic part of the distribution from its stochastic part, i.e. the part that varies randomly. The analysis over different time periods shows, however, that such averages change with time.

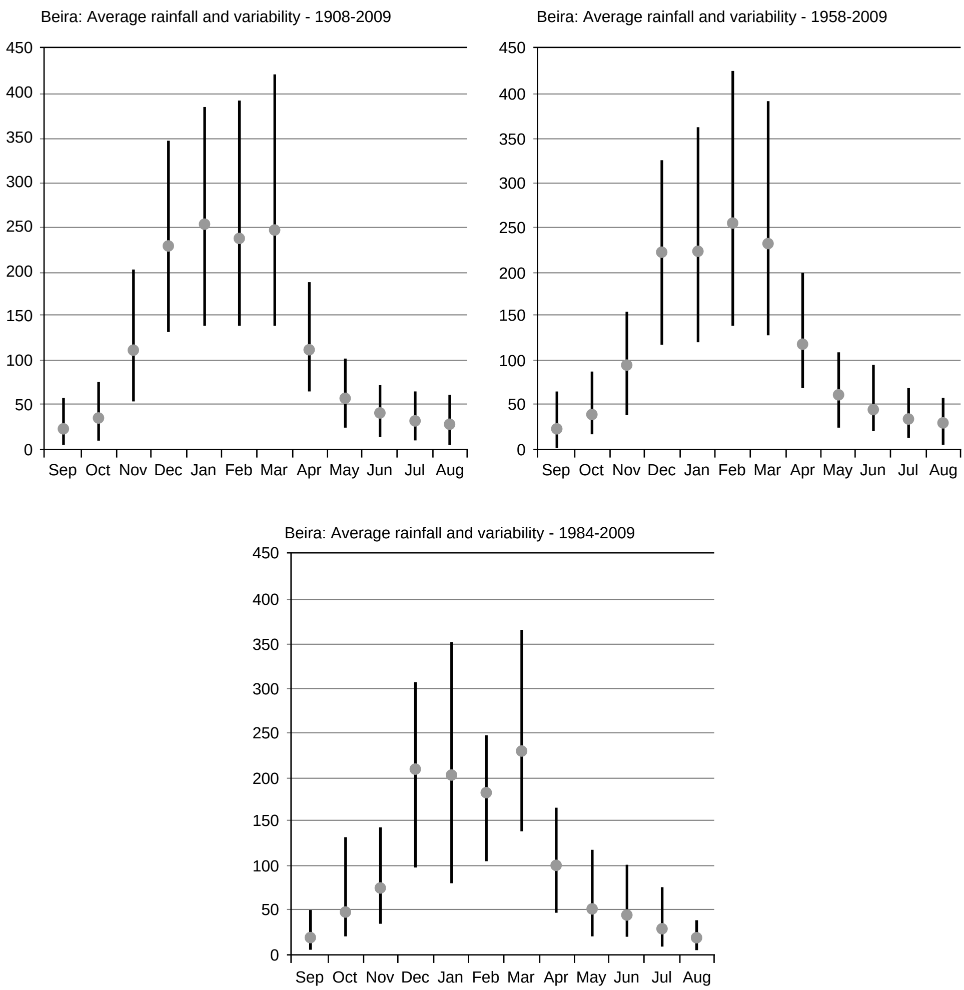

Figure 2. Beira, Mozambique: average rainfall and standard deviation for three different periods.

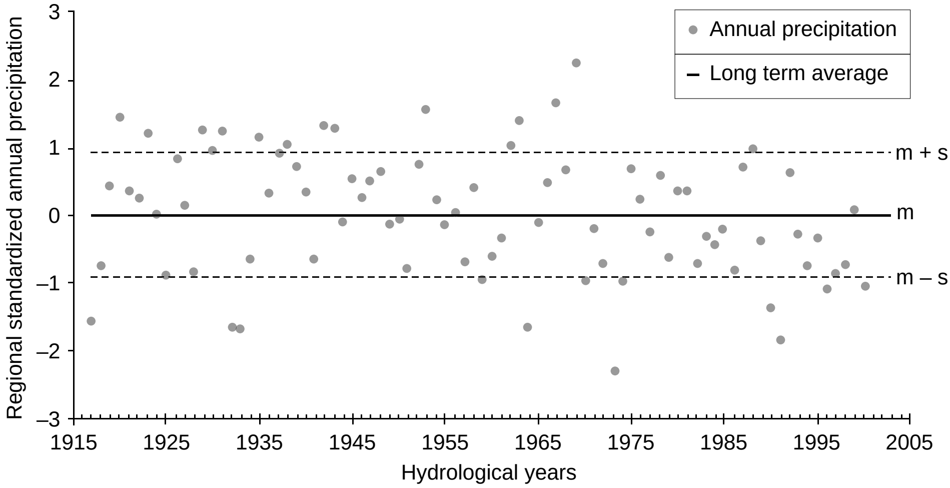

Figure 3. Annual rainfall, long-term average and standard deviation for a rainfall station in Cyprus.

Stationarity Assumption and Statistical Analysis

The assumption of stationarity is at the basis of statistical analysis of climatic time-series. Figure 3 shows the long-term average and standard deviation (SD) of annual precipitation for a region of Cyprus (Rossel, 2002a), based on assumption of stationarity. The concept of average in a hydrological time-series has been challenged in recent decades, in particular with growing evidence of changes in the climate regime, and statistical tools that relied on stationarity of hydrological processes were not fit for the analysis of possible changes. Tools like moving averages, with different time ranges, which were first used to describe climate cycles, are now used to analyse climate change-related tendencies. Statistical techniques have also been developed to look for step changes in hydrological regimes, but providing little plausible explanation for such variation. Again, such techniques tend to over-emphasize the importance of the average in statistical analysis.

Figure 4 is an attempt to identify a trend in the same time-series. In this specific case of Cyprus, such a trend has been analysed using the Mann–Kendall and Spearman tests and they were not found to be significant at the 5% level in most regions of the country. The study has further shown that not only is the linear trend not statistically significant at the 5% level in most regions of the island, but also that a single theoretical addition to the time-series (an above-average value of total annual precipitation in the year following the last measurement) affects the trend line considerably.

Is There Such a Thing as an Average ? Step Change in Mean Precipitation

Can an average vary with time? The analysis of time-series of climatic variables has been confronted with this problem for a long time, in particular in relation to the fact that observation series, their duration and period vary from one station to another (WMO, 1988, 2000). This has induced climatologists to establish arbitrary periods of 30 years

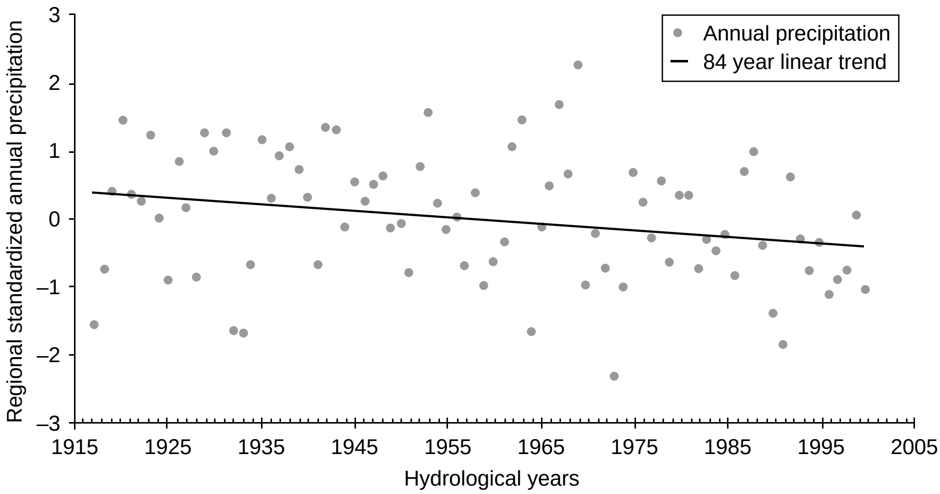

Figure 4. Analysing persistence and changes in statistical series: Cyprus.

corresponding to what is called WMO Standard Normals (WMO, 1984), and which are used to perform statistical analyses.

Segmentation procedures have been developed that split time-series of precipitations in two periods and look for evidence of significant differences between the means. Studies for changes in mean annual precipitation have been realized in several parts of the world (Rossel, 2002a). Step changes in the precipitation in 1970 have been identified in part of Bulgaria and Romania (Carbonnel & Hubert, 1994). Several authors have analysed hydro-meteorological time-series in West Africa from Niger to Senegal (Carbonnel & Hubert, 1985; Snijders, 1986; Hubert & Carbonnel, 1987; Hubert *et al.*, 1989; Paturel *et al.*, 1997). They point out the non-stationarity of the series and suggest climatic jumps, the majority of which appeared between 1969 and 1970. Similar patterns have been observed in the Great Plains of the United States, with a shift in the late 1960s (Garbrecht & Rossel, 2000, 2002), and in the Amazon basin with a shift near 1975, downward in the northern area and upward in the southern part (Marengo, 1999). All these studies suggest the possibility of a change of climatic phase since the start of the 1970s, the origin of which may be found in a general perturbation of the atmospheric and oceanic circulation at a planetary scale, with different regional impacts (Rossel, 2002a), happening not in a progressive way but through threshold effects. Indeed, small variations in latitude of atmospheric systems such as jet-streams and low-pressure convergence zones can result in a relatively abrupt change in local mean precipitation.

The analysis of long-term patterns of precipitation in Cyprus through the Hubert segmentation procedure (Hubert, 2000) suggests a segmentation of the time-series between the hydrological years[2] 1968/69 and 1969/70 for most regions, and the analysis showed that in most regions of Cyprus a step change in rainfall average could be detected that was significant at the 5% level (Figure 5).

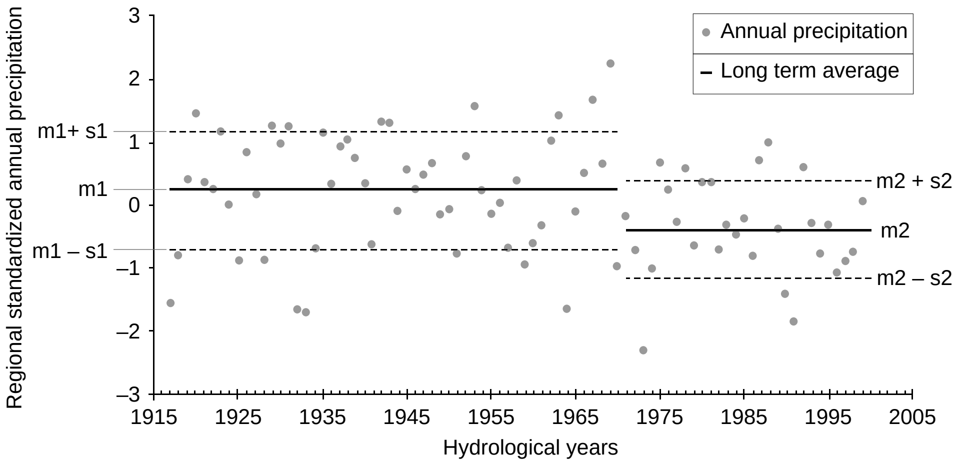

Figure 5. Looking for a change point in a rainfall time-series: Cyprus.

Multiplicator Effect of Rainfall Variation Over Runoff

The part of rainfall that does not return directly to the atmosphere through evaporation and plant transpiration flows into rivers or infiltrates into aquifers and is available for use by agriculture and other sectors. In relatively dry regions, runoff represents a small percentage of rainfall, the rest being returned to the atmosphere through evapotranspiration. Small variations of rainfall then usually translate into much larger variations in river runoff. In the study of Cyprus water resources, Rossel (2002b) showed that precipitation decreased by 10–20% between the period 1916/17–1969/70 and the period 1970/71–1999/2000. This reduction led to a much larger reduction in surface runoff. Indeed, when plotting the relation between the mean annual inflow to the Khouris dam and the mean annual rainfall through a simple regression (Figure 6), and comparing them for the average

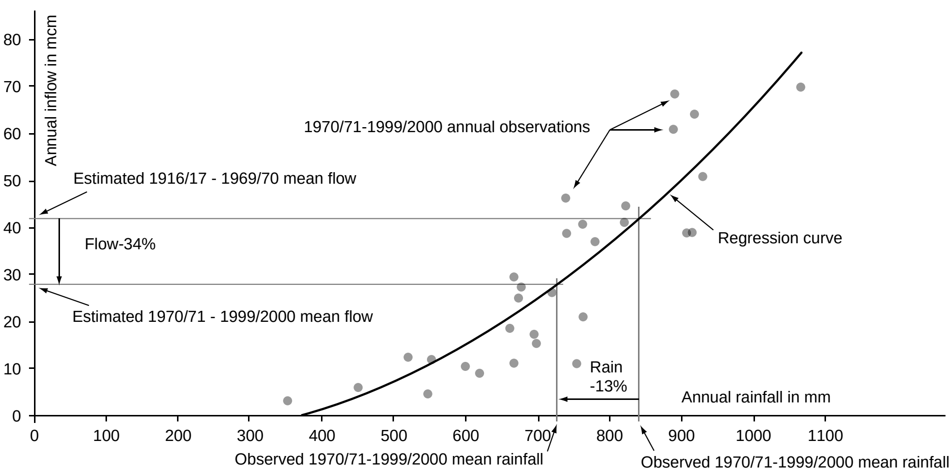

Figure 6. Relation between the decrease in annual rainfall and annual runoff: Kouris Dam, Cyprus.

rainfall of the two above periods, it can be seen that an average reduction of 13% of annual precipitation translates into a 34% reduction in runoff. This shows the extreme sensitivity of river runoff to changes in precipitation and the potentially devastating effect of rainfall reduction on water resources in arid and semi-arid areas.

Modelling Impact of Climate on Crop Production

Production refers to the total output of agricultural produce (grain, tubers, wood, meat, etc.) from a given area, usually a field, or a farm, a district or a whole country. It is the product of the number of producing units (plants, hectares, cows, etc.) and the intensity of production, usually referred to as yield. For each unit of production, there is a corresponding yield (grams of grain/plant, tonnes of potatoes per hectare, litres of milk per cow). Obviously, both production and yield also refer to a certain time span, usual a year, a marketing season, or a growing season).

The impact of climate on production must thus consider the impact of climate on the number of producing units, the yield per unit and, to be meaningful, it should only consider the life cycle of the plant or animal. To simplify, this discussion will be limited to a specific crop (maize) grown in southern Africa, where the growing season typically starts in October–November and harvest takes place from March. In this case, it is not meaningful to consider weather variables from January to December. August to July would be more meaningful, among others because weather displays persistence, which entails that there is some unity/coherence in the way weather variables behave over the agricultural season. For products that take more than one year to develop, such as most palm products (palm oil, copra), which take about 3 years to develop from flower initiation to harvestable produce, the whole period must be taken into account.

Returning to area and yield, they both somehow depend on weather, although yield much more so than area. Cultivated areas tends to depend mainly on socio-economic factors, such as land and labour availability, crop prices and others which farmers will more or less consciously build into their strategy or maximizing income from cash and food crops and stabilizing production for food security reasons. Harvested area may, however, depend on weather, as in the case when drought wipes out the crops from a farm, resulting in the harvested area being much smaller than the planted area.

Yield, on the other hand, is very much the result of the overall health of the plants, which is affected in more or less subtle and direct ways by weather, starting with sunshine, the driver of photosynthesis, and water availability from rainfall and irrigation, which defines to which extent plants can actually make use of available solar energy. As was recognized in the 1950s by de Wit, the relation between water consumption and crop yield is a very direct and amazingly linear one that hold across scales, from plant to field to province, provided no very severe water stresses occur (De Wit *et al.*, 1978). In most places, water availability is the factor that most directly conditions crop yields, and in the areas where water is plenty, the main limiting factors usually becomes sunshine.

So far, only direct weather factors have been mentioned, but there are many indirect ways too in which agricultural production depends on weather. For wind-pollinated crops, for instance, wind will affect the rate of pollination; rainfall distribution will play a part in fertilizer loss to ground water and high temperatures are known to affect male fertility in rice. There are many such examples that can account for a non-linear (threshold-based) response of yield and production to weather factors. The role of weather in the development of pests, diseases and weeds should also be mentioned. Many pathogens (such as the Phytophtora fungus that causes potato blight) respond to a combination of moisture/rain and temperature, so that one occurrence of favourable conditions can lead to the loss of a crop (refer to the 1845 Irish potato famine for a good example; Ó Gráda, 1999). This list can be expanded almost *ad libitum*. Wind direction, for instance, can play a role when it conveys atmospheric pollutants (e.g. ozone, acid rain) towards sensitive crops such as onions, tobacco or forests.

Figure 7 illustrates that the verification of the quality of yield simulations is not so obvious, even where there is an overwhelming limiting factor, such as water. After a yield model was calibrated against actual yields, it is easy to use a stochastic weather generator (itself calibrated against 28 years of observations) and to generate runs of rainfall and then to compute the resulting yields. Not surprisingly, bimodality and skew are carried over to the yield series. But do they exist in actual agricultural statistics? The 1979–2006

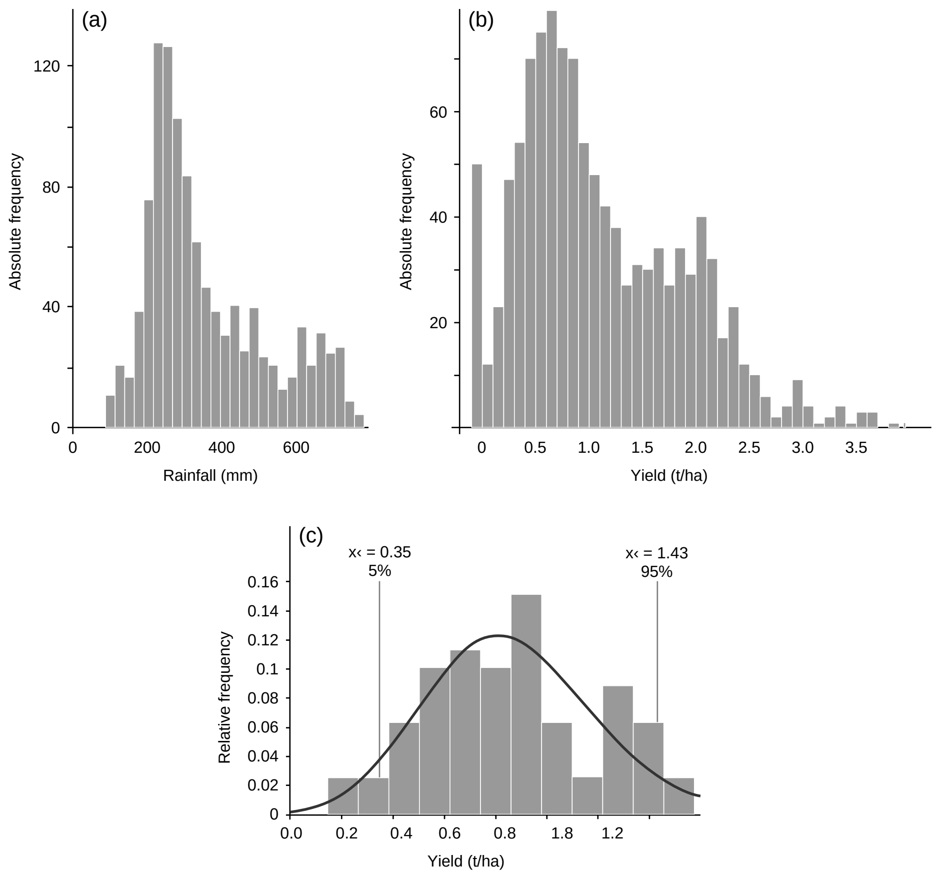

Figure 7. Statistical distribution of barley yields in the 'Intermédiaire' agroecological zone of Morocco: (a) rainfall distribution (absolute frequency, calibrated against the 28 years from 1979–2006; 600 runs) (mm); (b) simulated barley absolute yield distribution (1979–2006; 600 runs) (tons/ha); and (c) de-trended observed relative barley yield distribution (1940–2006, 67 observations) (tons/ha). Source: Gommes *et al.* (2009).

training period is too short meaningfully to infer any characteristics of the statistical distribution of actual yields. This is why the authors of Figure 8 resorted to using a longer time-series that seems to confirm the skew and the bimodality, albeit not very convincingly.

Many, if not all, of the steps that lead from agricultural production to their consumption (including transport and storage of inputs and produce) are directly or indirectly dependent on weather. Although this cannot be proven easily in quantitative terms, the global losses associated with inconspicuous deficiencies in weather or unusual combinations of weather factors induce many more losses to agricultural production than the more spectacular impacts (hurricanes, hail, floods, even desert locust outbreaks) which tend to have very severe but local impacts that often do not even show in agricultural statistics.

At the very local scale, the impacts of weather on agricultural production are particularly obvious. At the regional scale, some averaging takes place, so that the effects must be

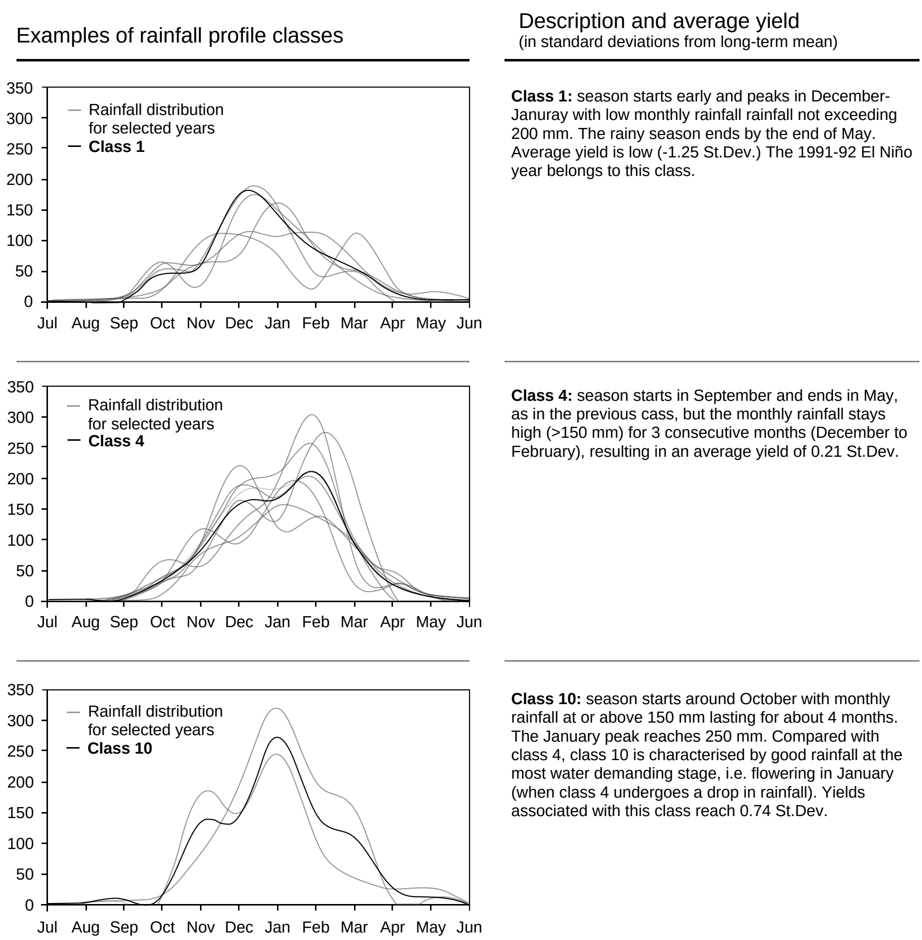

Figure 8. Selected rainfall profiles in Zimbabwe with their associated yields (based on data used in Gommes, 2007). Twelve classes are required to describe rainfall profiles in the country meaningfully; only three are illustrated here.

looked at differently, by noting, for instance, that statistical patterns that are visible in, say, rainfall are also present in agricultural production.

The same is also apparent in the identification of typical weather patterns that induce typical responses (Figure 8). Of course, a weather pattern is a complex description of the development of a cropping season. Even if the pattern is described, as in Figure 8, based on rainfall data, the coherence of climate systems ensures that several other important variables are also, at least indirectly, taken into account, including cloudiness and sunshine.

The above has illustrated that the quantitative effects of weather on agricultural production, especially rainfall, are not so straightforward as can be anticipated. To start with, spatial scale plays an important role: the more local the scale, the easier the identification of factors that are effective and the easier their modelling through process-oriented and statistical methods. At a regional scale, other variables may become significant (such as technology trends, or the cost of inputs such as fertilizer). The scales are linked, but up- and downscaling of impacts remains a difficult issue.

In some very specific conditions, however, the importance of water as the main factor affecting production can be made more evident. In semi-arid countries of Sub-Saharan Africa, in particular, the amount and distribution of rainfall over the cropping season affects yields and production considerably. Figure 9 compares annual cereal production in Burkina Faso with the national rainfall index, a measure of rainfall over the country that has been designed to reflect better the overall conditions in the country's major

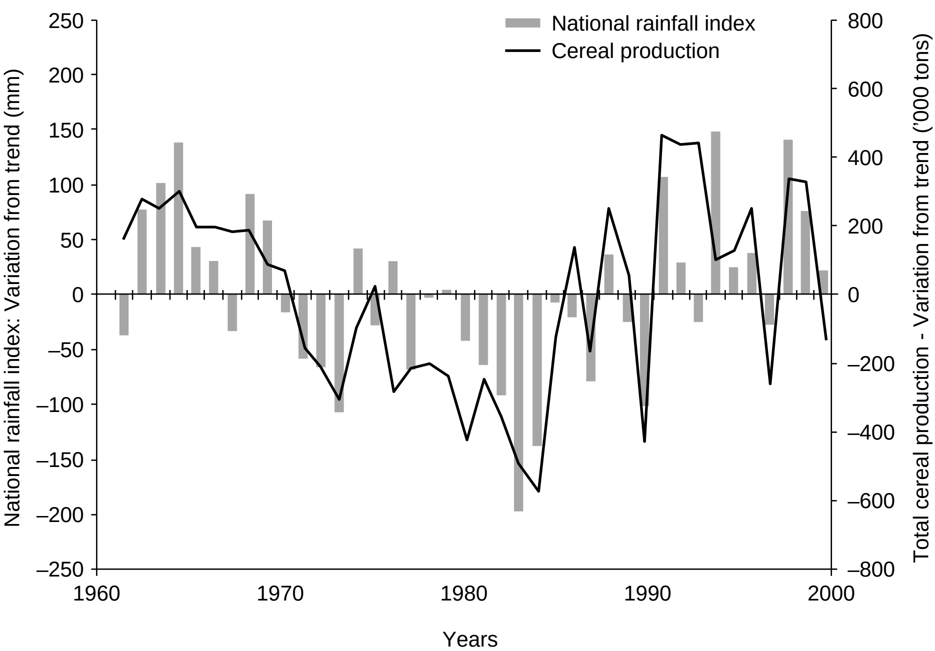

Figure 9. Burkina Faso: comparing the national rainfall index with cereal production, 1961–2001. Source: Faurès *et al.* (2007).

agricultural areas (Gommes, 1993; Molden, 2007). It shows clearly the impact of rainfall on production in a situation where other factors play a relatively minor role.

Agriculture: 'The Art of Managing Uncertainty'

Agriculture is certainly one of the human activities most directly affected by climate variability, in particular precipitation and temperatures, but also to a certain extent river runoff and groundwater recharge. From the beginning of agriculture, farmers have had to adapt to the vagaries of climate, developing highly sophisticated risk-mitigation strategies that help them cope with local-level climate variability, based on long-term experience transmitted across generations.

Over time, farmers have learnt how to accommodate routine risk through the use of traditional risk-mitigation strategies and a cautionary approach. This is particularly so for resource-poor subsistence and semi-subsistence farmers whose planning and management is generally characterized as prudent, circumspect and cautious (Dixon *et al.*, 2001). Being resource poor and directly dependent on their own production of food staples, these farmers and their families are at risk of malnutrition and starvation if they fail to meet the risks they face from nature (FAO, 1997). Caution comes naturally when one's life or family are at stake, and the farming systems observed around the world today are all the result of such experience accumulated over years.

More than climate variability, it is its randomness and unpredictability that most affect farmers and limit their capacity to invest in their crops. As discussed above, climate is not the only factor that impacts agriculture. Farmers continuously have to take difficult investment decisions about all aspects of farming amid large uncertainties, including volatility of market prices for their produce, prices of fertilizers, labour, land and other farm inputs, irrigation water availability, interest rates, and other factors affecting their business.

For all farmers around the world, the key term is 'predictability', and climate and markets are certainly the two most important variables that affect their choices. Figure 10 shows minimum and maximum farm gate price for major products in irrigated systems in Mozambique (FAO, 2009). The variation in price over a season typically ranges between 100% and 400%, and this case is emblematic of most horticultural production systems. Too often farmers bear the full risk of fluctuating market prices. The examples are numerous of places where the successful introduction of new crops has turned into a financial nightmare for farmers when, a few seasons after their introduction, prices have dropped under the effect of a rapid increase in offers against stable demand. Recent studies on the rapid development of supermarkets associated with global urbanization and the model of contract farming show that in most cases farmers are requested to bear the entire burden associated with uncertainty related to their production.

Predictability is also seen as the most important factor determining farmers' behaviour in irrigated agriculture. Here, again, the average amount of water available during a season is only part of the equation, and without information on the timing, volume and rate of water supply, or without sufficient guarantees about the reliability of water delivery, farmers are forced to take a conservative attitude that usually translates into the selection of low-value but more resistant crops that can sustain relatively long periods without water supply. As discussed below, farmers typically do all they can to store irrigation water, in

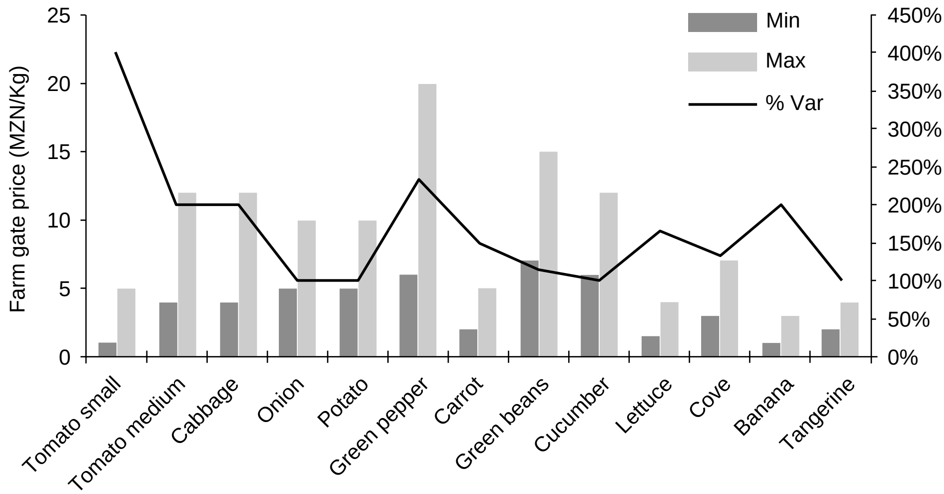

Figure 10. Variations in the farm gate price for selected products in Mozambique. Source: Food & Agricultural Organization (FAO) (2009).

either ponds or underground, through excessive irrigation, in order to compensate for unreliable water supply.

Such behaviour has often been the source of incomprehension between farmers and water managers in irrigation schemes. Technicians claim that farmers over-irrigate their field, thus disrupting water distribution, affecting downstream users and reducing the capacity of the irrigation schemes to operate as per their design. They usually blame this on their lack of knowledge about crop water requirements, and considerable efforts are often made to help farmers better assess irrigation needs through the use of climate-based models. Farmers, on the other hand, claim that such behaviour is dictated primarily by the lack of a reliable water supply and the need to protect their crops against potential defaults in water distribution. Such debate is at the heart of the discussion about irrigation service modernization (Shah, 2009), together with the capacity of managers to raise irrigation water service reliability to a level that induces farmers to modify their behaviours.

In conclusion, climate, market prices, access to water and a series of other factors affect the capacity of farmers to invest in their crops and climb the productivity ladder. A high risk associated with a high level of uncertainty in all these factors leads to conservative decisions that often favour the choice for low-value staple crops. Much can be done, in particular in developing countries, to mitigate the above risks and progressively allow farmers to invest in more rewarding crops. These options are discussed in the next section.

Options to Reduce Uncertainty in Agriculture

Options to reduce uncertainty in agriculture can work either on reducing the causes of uncertainty or on mitigating their consequences. There is room, for instance, for improved use of climate statistics the better to adapt farming practices to climatic conditions. Better control and use of water (through storage, irrigation and better varieties) has long been practised in response to the vagaries of climate. Predictability can also be enhanced through the use of seasonal forecasts, which are becoming increasingly more accurate. Finally, managing risk can be done through the use of crop insurances. These four approaches are discussed below.

Fitting Agriculture Practice to Prevailing Climate Statistics

The terminology of fitting practice to climate may give the impression that there is one optimal way of running a farm that will make the best use of available climate resources. This is not the case because farmers define for themselves a strategy that determines farming practices. A strategy may be to achieve the largest possible average income, or to produce a low but less variable income, or maybe to obtain a regular food supply. Additional variables include labour availability, the level of technology (including irrigation), the cost of inputs and the prospective yields.

In developed countries, it has been the practice of farmers to protect their farms as much as possible from weather variability. For instance, by preventively applying large amounts of inputs whenever possible (fertilizer and, particularly, pesticides), farmers avoid depending on the accurate monitoring of environmental conditions, for instance conditions that would be favourable for the development of potato blight. The approach is more expensive and certainly less environmentally friendly than the relatively error-prone (and thus more risky) approach of modelling pests and diseases and combating them only when necessary.

There is a large potential in farm-level monitoring and warning systems if farmers adopt, by choice or by necessity, strategies that reduce production costs and more environmentally friendly approaches.

The most fundamental rule to adopt is to know local climate conditions and to fine-tune practices accordingly. As illustrated in Figure 9, climate does not vary randomly; there is coherence in the way seasons develop, in terms of both persistence (correlation between months of the same season) and correlation between weather variables. Although this will sound tautological, seasons with low rainfall are also those with abundant sunshine, and those with high moisture will be characterized by low daily thermal amplitudes. The result is that ‘average yields’ are even less obvious than ‘average weather’. A year with low rainfall will be characterized by more sunshine and high temperatures, meaning also high evapotranspiration rates, which is to say that water demand is relatively higher in drought years than in average years, thereby making the shortage of water even worse. Similarly, a year with high moisture will be exposed to much higher risk from pests and diseases, which, again, introduces a relatively larger risk of crop loss than in average years. Things behave, somehow, as if departure from average conditions introduced a risk factor that is proportionally larger than the departure itself. This is reminiscent of a point made above, i.e. the variability of run-off is larger than the variability of rainfall.

Farmers are well aware of the risks, and they have developed time-tested empirical rules that allow them to reduce risk. One of them is *wait for the first good rain*, and *plant early if you can*. By doing so, crops germinate under good conditions by using stored soil moisture; they benefit from (soil) nutrients supply before they are leached out by more rainfall, and, should rainfall cease (false start of the season), there will hopefully be a possibility to replant. Strategies may be more complex, for instance, where seasons are markedly bimodal. The best option may be, in that case, to plant at the end of the first season, just before the dry spell that separates the first season from the second, and to adjust the crop/variety to the amount of stored soil moisture and the conjectured duration of the dry spell.

In many cases, particularly where long rainy seasons prevail, there is a risk that crops will be exposed to excessive amounts of water during the maturation phase. To avoid that, farmers often plant at a date that ensures that grain filling coincides with the decreasing part of the rainfall cycle. However, it may not be the best strategy to plant at the optimum planting date, because there is always a risk that the season will end early. This illustrates that maximizing yield and optimizing food security (i.e. a lower but guaranteed yield) may be contradictory options.

Controlling Water

Irrigation, the provision of water to plants to supplement rainfall, has for a long time been the favoured solution to allow farmers to compensate for the erratic supply of water from rain. The second half of last century saw rapid development of water-storage capacities in an attempt to control water supply and boost agricultural productivity (Molden, 2007). Mastering water in agriculture not only prevents crop failure, but also allows farmers to invest in other inputs (fertilizers, labour, pest control) as uncertainty about water supply vanishes, thus increasing yields much beyond what would be the single effect of water. Studies show how agricultural economies are affected by climate variability, and suggest that economic development is heavily correlated with the level of the country's water control. However, there are limits to such a practice, and as water resources become scarce, competition between uses increases, leading, in the absence of adequate institutions and laws, to a new level of unpredictability related to the supply of irrigation water.

For centuries, the model of irrigation has been the storage of water behind dams and its distribution to fields through canals. This model of surface irrigation, combined with improved technology, was used in the second half of the 20th century, where, in response to demand for food from a growing population, it led to a rapid expansion of irrigated agriculture (Faurès *et al.*, 2007). At the turn of the century, however, the model started showing its limits in terms of financial, managerial and environmental sustainability (Burke, 2000; Faurès *et al.*, 2007). At the same time, the World Commission on Dams (WCD) (2000) showed that dams constructed for irrigation and other purposes needed to be designed with much more careful attention given to the above considerations.

Other ways to control water supply are available, but still today they do not receive the same level of attention as dams. Groundwater storage is the most obvious alternative to surface water storage and offers substantial advantages. It is much less environmentally and socially destructive than reservoirs, and much less subject to evaporation losses in arid areas. The advent of cheap drilling and pumping technologies starting in the 1980s has boosted the use of groundwater in agriculture wherever aquifer conditions are favourable (Molden, 2007).

The drilling, often anarchic, and rapid expansion of wells inside surface irrigation schemes, in particular in South Asia, clearly showed that groundwater was farmers' preferred irrigation option (Shah, 2009). In theory, groundwater is more expensive than canal water: in most cases farmers bear the full cost of drilling and of pumping, which is usually higher than the cost of canal water. However, again, the choice is related to the reliability of water supply: with full control of their water sources, farmers can invest in high-value crops that require safe and reliable access to irrigation water. Groundwater, where available, is often the farmers' preferred option as it provides more reliable access to water than most surface irrigation schemes.

Developing and Using Seasonal Forecasts

Predictability of the outcome of farming activities is directly related to forecasts. Meteorological forecasts are essentially of three types: (1) weather forecasts (forecasting the next few days), (2) seasonal climate forecasts (forecasting the next few months) and (3) decadal climate forecasts (projecting the climate in the years to come). In all three situations, the basic requirements for making valuable predictions are good observations as an input to a model to be run on fast computers. Concerning the first requirement, ground-observing networks have unfortunately declined, particularly in developing countries and, in the recent years, limited progress has been made in filling gaps (Bernardi, 2008). Efforts in reducing gaps in the ground-observing network's coverage includes the need to rescue and digitize historical climate data records currently on paper as such data are critical for improving climate prediction models.

Important efforts have been done in the recent past to improve climate forecasting. While substantial progress has been made for short-term forecasting, a lot remains to be done in terms of seasonal forecast of temperature and precipitation, in particular at local scales. Yet, linking local climate with regional and/or global phenomena has shown encouraging results: one good example of models that simulate the interactions of the world's weather systems, and their likely future behaviour up to 6 months in advance, is the measurement of sea-surface temperature (SST) in the Pacific, which allows one to simulate the likely evolution of the El Niño Southern Oscillation (ENSO), leading to seasonal forecasts in Eastern and Southern Africa, for example. Seasonal forecasts have being initiated by the Regional Outlook Fora (ROFs) in 1996 for the Southern African region (National Oceanic & Atmospheric Administration (NOAA)/US Department of Commerce (USDC), 1999). They are now extended to tropical America, the Caribbean, South and South East Asia, and West Africa. Other models use different signals such as those from the North Atlantic Oscillation (NAO), which has the strongest correlation over West Africa. Seasonal forecast is now used in the Sahel and in Eastern and Southern Africa and in Australia to support agricultural decisions (McIntosh *et al.*, 2007; Stone & Meinke, 2005). In many regions, the degree of reliability and the spatial resolution are still too low to adapt the analysis at the farming level (Vogell & O'Brien, 2006). In addition, it is important to mention that those seasonal forecasts cannot predict extreme seasonal events such as the heat wave that hit Central and Southern Europe during the summer 2003 (Stott *et al.*, 2004). Outputs provided by ROFs are plotted on national or regional maps and then disseminated to national weather services providing probabilistic predictions about the aggregate rainfall,[3] but they do not provide information about its variation in time and space.

Seasonal forecasts have a great potential to improve food security of farming communities by improving the timing and reliability of forecasts. Equal emphasis should be given to improving the accuracy of forecasts as to increasing the capacity of farmers to make better use of climate information and to respond quickly to climate variability. Today, the greatest challenge to expanding the use of seasonal climate forecasts lies in improving the capacity of small-scale farmers to take advantage of climate forecasts and their flexibility to adapt to climate variability and change (Gommes *et al.*, 2010).

Six main constraints to a more systematic use of seasonal forecasts have been identified by Jones *et al.* (2000): credibility, legitimacy, scale, cognitive capacity, procedural and institutional barriers; and last but not least, the availability of choice. There is still a clear institutional gap between producers and end-users of climate information, particularly at the local level where seasonal climate forecasts must be translated into appropriate terms and strategies for given regions to support adaptation practices (Ziervogel & Calder, 2003). In many cases, national institutions focus on emergency measures instead of implementing preparedness measures. Strategies that enable complex probabilistic information to be communicated more effectively to end-users have been tested and described by Power *et al.* (2007). An amazing implication of improved seasonal forecast is the difference in the capacity between large and small farmers to take advantage of such information, leading in extreme cases to increased production, a reduction in grain price, and further negative impacts on smallholders who cannot benefit from such information as much as commercial farmers.

The term 'perfect knowledge of daily weather' has been used to simulate farm gain in conditions of zero uncertainty. While this situation is still a long way off, it is observed that substantial gain can be obtained in gross margin for farmers when in such conditions (Hansen *et al.*, 2009). Again, this study indicates that it is not only the availability of information that matters, but also the end-user's capacity to act upon it.

Reduced uncertainty about climate change would be of critical importance for longer-term investment decisions in agriculture. While climate change brings a new dimension to uncertainty, it is somewhat 'hidden' by the much larger short-term variability of climate, and therefore hard for farmers to internalize. Yet, reduced uncertainty about climate change would be of critical importance for medium-term investment decisions in agriculture.

Using Crop Insurances

Insurance represents an interesting solution that could be considered as an alternative to water storage in some semi-arid countries. In developed countries, when agriculture has limited weight in the economy, various schemes are available to farmers to compensate for excessive losses in the case of a natural disaster. There has been renewed interest recently in various types of crop insurance, especially in developing countries. National-level crop insurance schemes have also been tested in some developing countries like Ethiopia, but they still face substantial challenges in terms of costs (including transaction costs) and institutional settings, and few commercial insurance companies find it an attractive business so far.

There are different types of crop insurance, all with advantages and disadvantages for both insurer and the insured, according to the type of farming, the prevailing climate and overall market conditions. An insurance is a commercial product that must be economically sustainable, and while climatic risk is an inherent component, it is certainly not the only one (Roberts, 2005; Barrett *et al.*, 2007; Gommes & Grieser, 2010; Patt *et al.*, 2010).

In the traditional crop insurance scheme that is often practised in developed countries, a farmer agrees with an insurer that compensation will be paid if yield (damage-based products, multi-peril crop insurance) or income drops below an agreed level. If this happens, the insurer must verify that the farmer's claim is justified, a process which is very

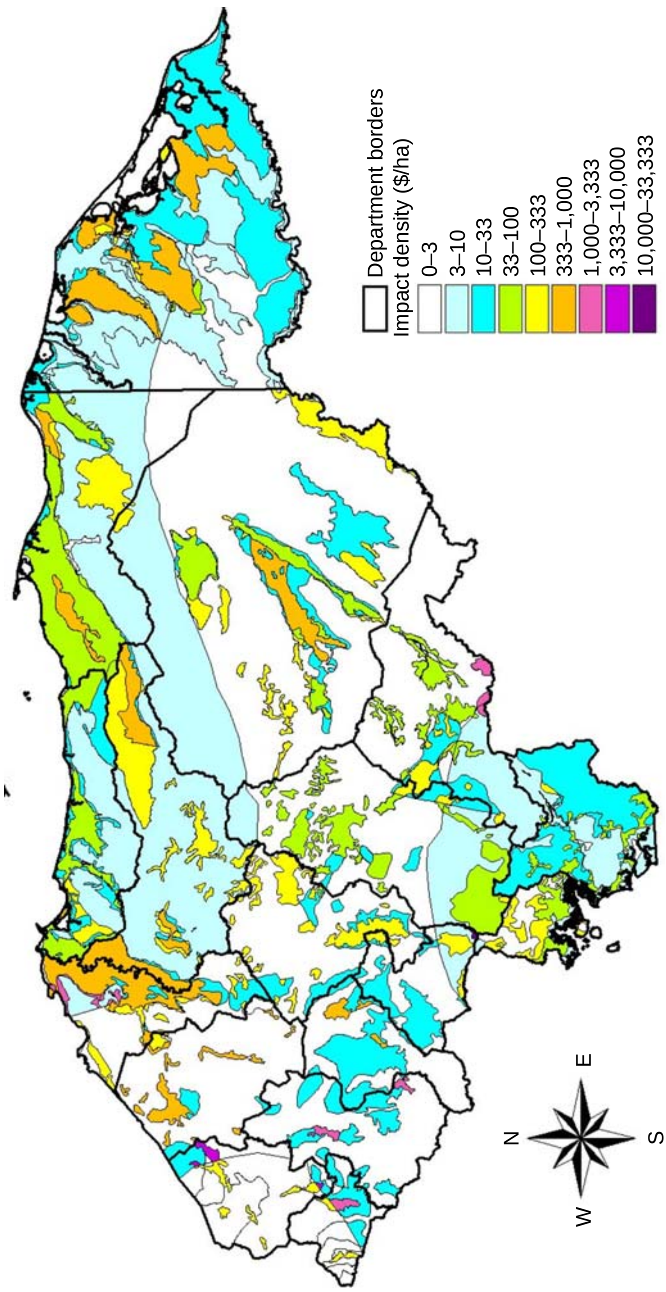

Figure 11. Density of losses to the agricultural sector due to Hurricane Mitch (October–November 1998) in Honduras. Source: Borgia *et al.* (2008).

labour intensive and therefore expensive. As mentioned above, this is one reason why crop insurance is more commonly practised for high-value crops, such as orchard crops or grapes than for field crops. Named peril policies, which are designed to cover gaps in other coverage (e.g. the cost of replanting after the failure of a first planting), also belong to this category.

A type of insurance that has recently been applied in developing countries is known as index-based insurance. In index-based products, compensation is paid to the insured if the agreed threshold of an index is exceeded. The indices must be defined in such a way that they bear a direct relationship to the performance of the product insured. For instance, a maize yield index can be based on weather conditions, but it must be directly related to yields. As an example, Figure 11 shows the estimated agricultural loss density of Hurricane Mitch (1998) for Honduras based on a locally applied crop-yield model for major agricultural production zones. Index-based insurance is difficult to apply to small-scale perils (e.g. hail), but seems to have good potential for hazards with regional impacts.

Conclusions

In conclusion, variability of weather has always been and is probably still one of the most significant constraints to farming, in particular in semi-arid and sub-humid regions, and a substantial restriction to increased crop productivity. A range of 'hard' and 'soft' options exist to compensate for the negative effects of rainfall variability in agriculture, but many developing countries do not have the necessary infrastructure and institutional environment necessary to manage such risk. For millions of farmers in developing countries, there is no such thing as average rainfall or stable market prices, and the burden on their livelihood is often excessive. Probably the most effective agricultural policies are those that help manage the risk of crop failure and maintain predictable price levels. By increasing uncertainty, climate change will only add a new dimension to a very old challenge.

Notes

1. A stochastic process is one whose behaviour is not fully deterministic in that a system's subsequent state is determined by both the process's predictable actions and an element of randomness.
2. The hydrological year is defined as any 12-month period, usually selected to begin and end during a relatively dry season, and used as a basis for processing stream flow and other hydrologic data.
3. A standard format has evolved to present the likelihood of precipitation classes over a given region. Percentage probabilities are assigned to terciles and are typically shown as follows: above normal, 50; near normal, 30; and below normal, 20. This indicates that the chance of rainfall being above normal is 50%, of being average is 30%, and below normal is 20%, respectively. For an example of the Seasonal Forecast Precipitation Bulletin for West Africa, see http://www.acmad.ne/en/actualite/ACMAD_Bulletin_Final_PRESAO13_29_mai2010.pdf/.

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