CLIMATE-RELATED RISK IN AGRICULTURE

A note prepared for the IPCC Expert Meeting on Risk Management Methods

Toronto, AES, Environment Canada

29 April-1 May 1998

By René Gommes[1]

This note is subdivided into three sections.

The first, a rather basic discussion of climate risk and vulnerability applied to agricultural production, was written essentially because the literature does not show any consensus about even the most basic concepts. Risk, for instance, indifferently stands for the probability of an extreme factor, the loss associated with it, and the factor itself.

The next section attempts to quantify, at a national and global scale, the losses actually suffered by agriculture due to climate variability. This is not so obvious a task as might appear. It certainly stresses the difficulty of making reliable predictions about future losses!

The third section, finally and more specifically deals with risk management, after spending some lines on some fundamental differences - as far as risk is concerned - between developing and developed countries.

1. Risk and vulnerability

1.1 Definitions

There is little coherence in the literature about the quantitative assessment of risk, including climatic risk, in agriculture. According to White (1994), agronomists and engineers (for instance Nash and Nash, 1995) tend to define risk as a loss, while economists tend to use the word as a synonym of "probability of occurrence of a damaging event".

---

[1] FAO, Environment and Sustainable Development Service.

This notes adopts the first definition, which, it is suggested, provides a convenient and consistent way of defining *vulnerability* and several related concepts, which are often dealt with in a very "impressionistic" fashion.

We start with the simple definition below. For a given factor (or ***stress***), we have

Average loss / annum = Average number of events / annum * Average loss / Event

which we can rewrite as

Risk = Frequency * Vulnerability

where the loss can be expressed using different units (for instance loss of agricultural production in metric tons, loss of human life, loss of income, etc.). If losses can be due to several different factors, the unit acts as a common denominator, which is a convenient way of expressing a combined loss.

Most geophysical factors can be expressed on a scale of intensities, in which case the definition above applies for each intensity (discrete case) and becomes

$$\textbf{\textit{Total risk}}_{\text{(loss/annum)}} = \Sigma_{\mathbf{i}} \, (\textbf{\textit{Frequency}}_{\mathbf{i}} * \textbf{\textit{Vulnerability}}_{\mathbf{i}})$$

According to the definitions adopted here, total risk and impact are roughly synonymous.

Figure 1 below illustrates a hypothetical case where the frequency displays an asymmetrical distribution as a function of intensity. This is very often the case with climatic variables, where J-shaped distributions are typical of rainfall in semi-arid areas; U-shaped curves apply to cloud cover, S-shapes to relative moisture... Positively skewed bell-shapes apply to vapour pressure, wind speed, rainfall in the more humid climates, etc. Of course, the shape of the distribution also depends on the time interval considered (see, for instance, Arléry et al, 1962, or any text of statistical climatology).

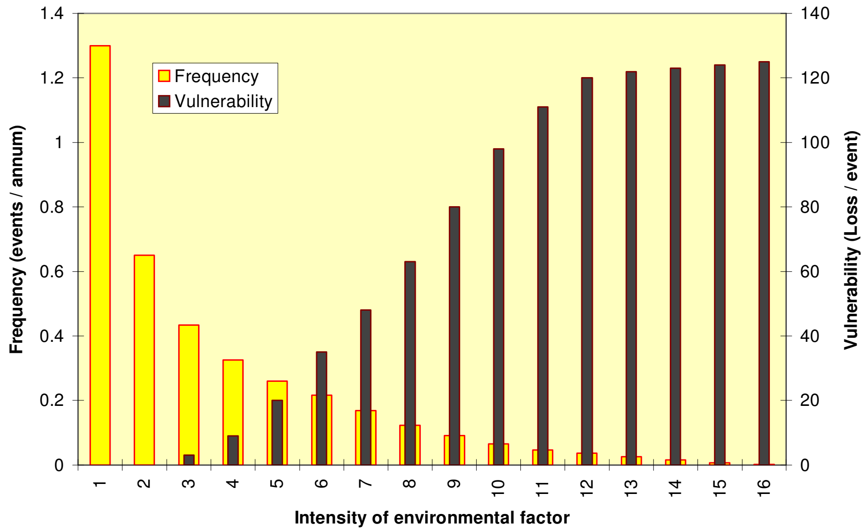
The risk, as a function of the intensity of the environmental stress is shown in Figure 2.

The total risk, for the factor under consideration, is the sum of the risks associated with each intensity. Again, the asymmetrical curve is typical. Most real world examples would be considerably more skewed than shown in figure 2, resulting in the largest portion of risk (losses) being due to relatively low-intensity factors (chronic risk), while extreme factors, i.e. by definitions those with a low probability of occurrence (major risks), have a relatively minor impact in absolute terms[2].

---

[2] "Structural risk", as in "structural food deficit" is equivalent to "chronic risk". The risk associated with low probabilities and high intensities would be "conjunctural risk".

Figure 1: variation of vulnerability and frequency as a function of the intensity of an environmental factor.



1.2 Discussion of concepts

This section examines to what extent the concepts above are relevant in an agricultural and a climate/climate change context.

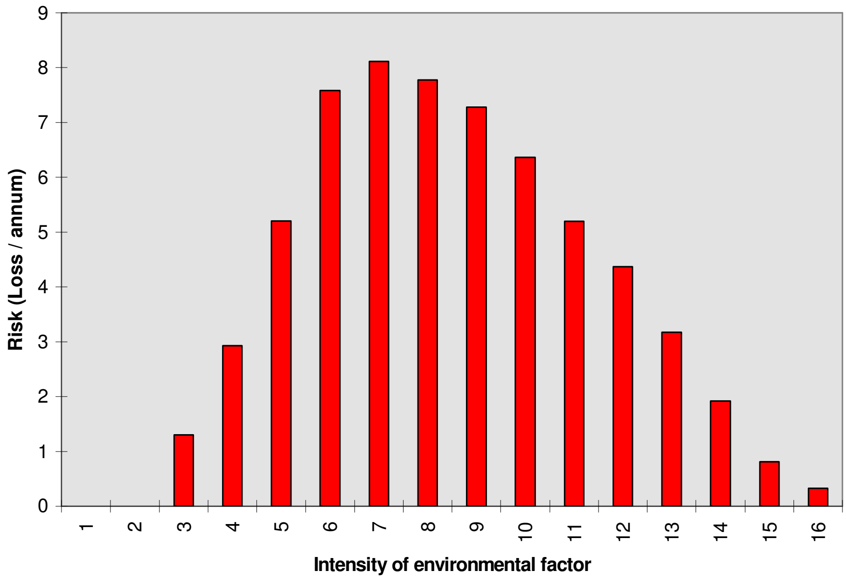
To start with, the system being impacted must be relatively well defined if "risk" and "vulnerability" are to be meaningful. As in most agricultural modeling, things tend to be theoretically satisfactory at the very local scale only (plant and field). When moving to regions or countries, many concepts become rather fuzzy, for instance "soil moisture" or "crop yield response to rainfall", etc., which is one of the reasons why the classical crop models are of little help in global studies.

The scale problem obviously also applies to the "intensity of environmental factor" used in Figure 1 and Figure 2. If we consider that climate behaves as a set of coherent and correlated variables, we can obviously replace the "intensity" with an indicator, which will incorporate most of the variations of climate as far as they are relevant for regional agriculture. This approach was used in a study of African food security where the "intensity" was replaced by a "national rainfall index" biased towards agriculture (Gommes and Petrassi, 1994; Gommes, 1998).

The question to be answered is thus: what indicators can be used in the current context? Their desirable features include that they must be synthetic, generic and normative (refer to Bakkes et al., 1994, for a good overview of indicators).

<u>Synthetic</u>: the indicator must incorporate most of the factors which are known to be of relevance for agricultural production, for instance crop water consumption, a key factor in production, and dependent on water supply, radiation, CO2 concentrations... The word "synthetic" insists on the fact that the indicator reduces the dimension of the problem, i.e. the number of variables actually to be dealt with.

Figure 2: risk as function of the intensity of an environmental factor.



<u>Generic</u>: this feature points at the fact that the indicator should be robust enough to be applicable outside its original context. If it performs correctly in different areas and years, it may remain meaningful in the future as well.

<u>Normative</u>: can indicator is said to be normative if it can be compared to some reference value, which implies that

- the sensitivity of vulnerability to the indicator should be roughly linear or, at least, that the variation of vulnerability as a function of the indicator should not behave unpredictably. In Figure 1, vulnerability is approximately linear up to an intensity of 12, after which the response levels off;
- the reference value (possibly the average) does have a physical and statistical significance.

The IPCC definition of **vulnerability** as *the extent to which climate may damage or harm a system. It depends not only on a system's sensitivity but also on its ability to adapt to new climatic conditions* (IPCC, 1995) is consistent with the approach above, if we take "extent" quantitatively.

Many difficulties are, however, associated with the notion of vulnerability. They include the following:

- vulnerability can be determined empirically through impact assessments. Since extreme conditions tend to be rare, the statistical base for such assessments is bound to remain weak. In addition, the intensity of the stress factor is not always known;
- vulnerability depends on the history of the impacted system. An excellent example is provided by the Sahelian droughts in the seventies, the impact of which was far more dramatic than in 1984, when the drought actually peaked;

- vulnerability changes over time, under the influence of numerous factors, for instance population pressure and the resulting short fallow and horizontal expansion of agriculture into marginal areas. In Asia, for instance, FAO studies (FAO, 1989) indicate that some countries have reached the limit of available agricultural land, completely modifying the vulnerability profiles;
- the main difficulties are again linked with the scale, in the case of stresses that originate (spatially) outside the area covered by the impacted system (pest and disease outbreaks, for instance).
- vulnerability can be reduced through adaptation[3] (to stresses as they occur) or through mitigation (measures aiming at reducing future vulnerability), including structural and non-structural measures.

2. Variability of agricultural production

2.1 Causes

Although it is generally agreed that, under normal circumstances[4], weather variability remains one of the main factors behind the inter-annual variability of agricultural production, it is very difficult to estimate how much production is lost due to variability.

This is due to several factors, among others the fact that agricultural statistics are reported by administrative areas, which are rarely homogeneous from an agricultural and agro-ecological (including climatic) point of view.

In addition, weather can impact agricultural production systems at many levels (production, harvest, storage, transportation...) both directly and indirectly through diseases, pests, damage to infrastructure, etc. This subject has received a lot of attention and it is not necessary to repeat this here.

We simply underline that climate variability impacts agricultural output (production) through its effects on yields and areas planted. Yields are affected, as indicated, by weather as the main “random” factor, but also by mostly continuous technological trends (including new varieties and management), innovations (including management innovations), agricultural policies (mostly national policies) and extreme factors of various origins.

Areas are more dependent economic factors. Areas planted vary according to labour availability, level of mechanisation and expected return (prices). Areas harvested are often strongly linked to environmental conditions, including poor weather during the cycle, damage to infrastructure due to extreme conditions, or simply very low yields for which it is not economical to harvest at all.

---

[3] ***Adaptability*** *refers to the degree to which adjustments are possible in practices, processes or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned, and can be carried out in response to or in anticipation of changes in conditions.* (IPCC, 1995)

[4] Thus excluding war, major epidemics, etc.

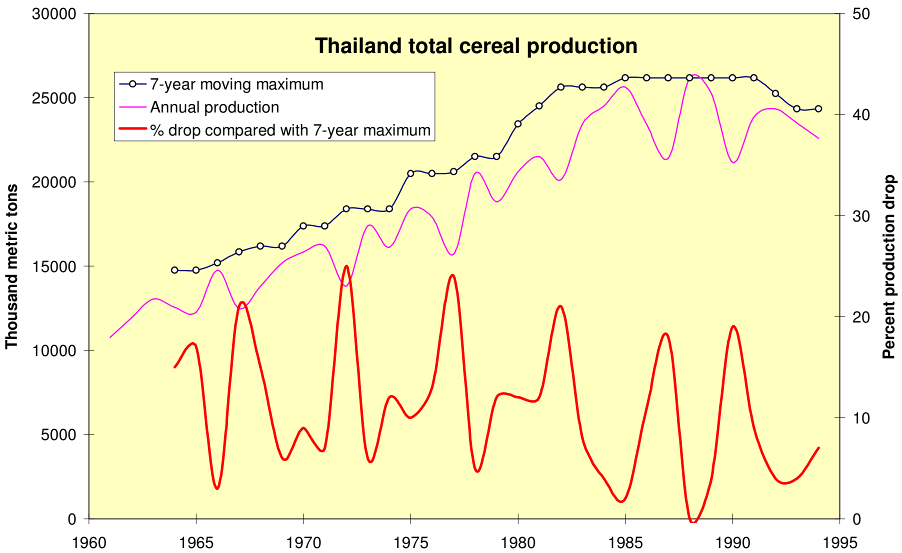
2.2 Quantification of loss due to variability

An attempt can be made to estimate how much production is lost currently because of the variability of climate. The following methodology was followed:

- take a national production time series
- for each year Y, take the maximum production value Pm in the 7-year interval from Y-3 to Y+3
- compute the difference between the production P of year Y and Pm, and express it as a percentage "loss": (Pm-P)/Pm*100%.

The approach assumes that no marked technological progress took place in the seven-year period. An example for Thailand is shown in Figure 3: the "loss" varies between 0 and about 25% and shows a slight downward trend probably due to stagnating productions since 1980.

Figure 3: total cereal production and production loss due to inter-annual variability in Thailand between 1961 and 1994 (based on FAO statistics). The 7-year moving interval used for defining the "maximum yield" becomes an asymmetrical interval at the end of the series, i.e. 1991 (1988-94) is the last complete interval, followed by 1989-94 for 1992 etc.



The same approach can be applied to areas harvested and to yields, leading to Figure 4. Logically, production undergoes the largest fluctuations. The comparison of areas and yields is interesting, as the two curves keep crossing, suggesting that, according to the years, areas planted (i.e. mainly socio-economic factors) or yields[5] (i.e. mainly environmental factors) have played the main part.

[5] If reported areas correspond to harvested ones rather than to planted ones, the effect of weather variability on yields is artificially depressed.

It can be **assumed** that a large fraction of the "losses" thus put into evidence is **directly** ascribable to weather.

Figure 4: percent loss of cereal production, yield and areas in Thailand between 1961 and 1994 (based on FAO statistics).

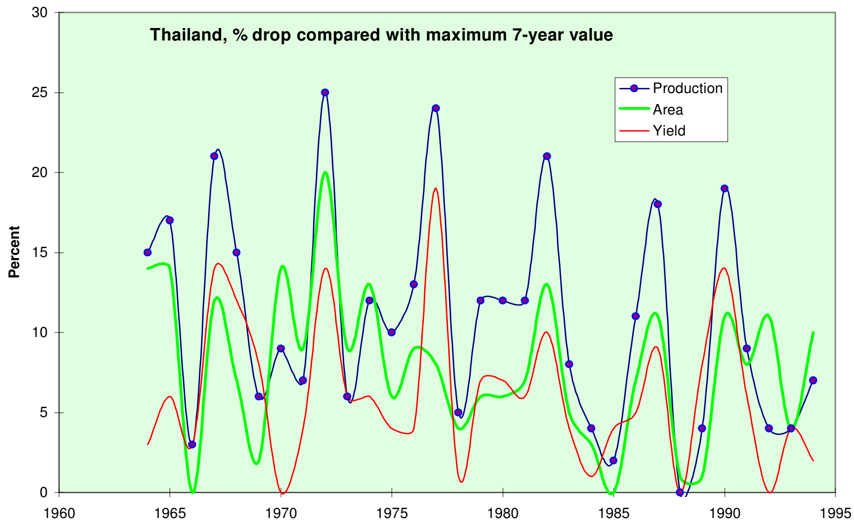


Figure 5: percent "loss" of total cereal production in Niger as a function of National Rainfall Index (mm). R=0.63 for the figured regression line (heat capacity model)

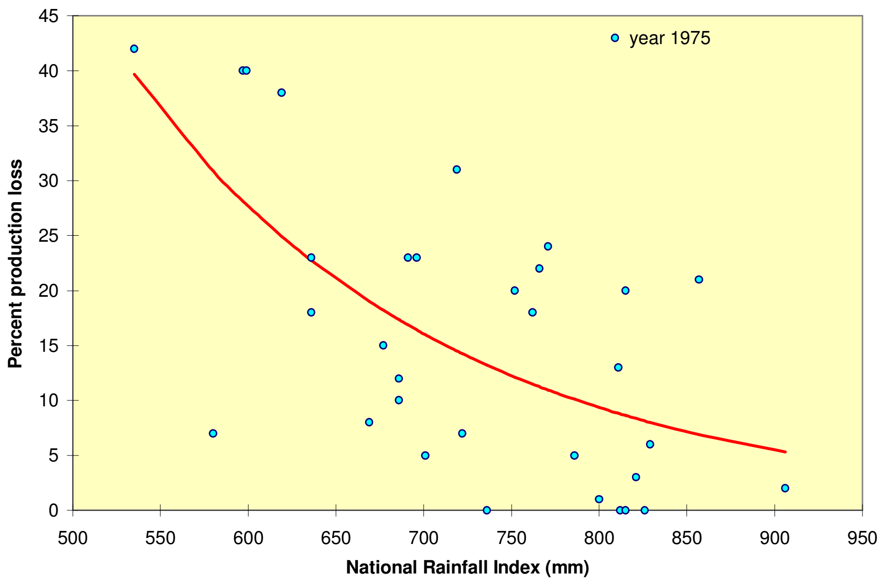


Figure 5 indicates that, in the case of Niger, the crude above-mentioned National Rainfall index accounts for about 25% of the loss. This is clearly an underestimate, as rainfall was affected by a negative trend during much of the period under consideration. The second example below (wheat in Italy) shows a marked dependence of yield on radiation (solar energy) which accounts for about half the non-technology variability.

Although this is only an assumption, it seems thus that at least 50% of the variability of agricultural production is due to weather, in developing and developed countries alike.

Yield (a) is the average, (b) is the 0.90 percentile (i.e. the value exceeded 10 years out of 100) and (c) is the average of the 3 highest values.

Table 1 and Table 2 illustrate the "average loss" (as defined above) over the period from 1964 to 1991 in several countries and groups of countries.

Figure 6: detrended national wheat yield[6] in Italy (1951-86) as a function of estimated September-March global radiation, together with quadratic trend.

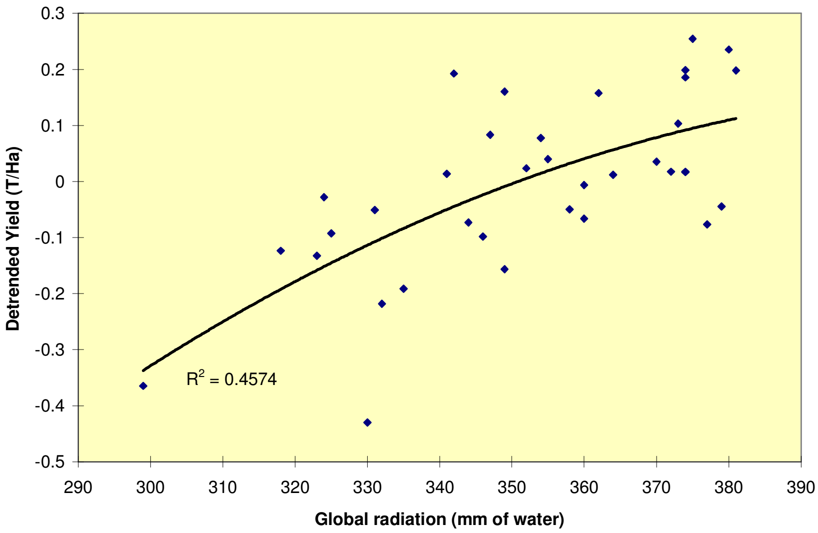


Table 1: average loss of production, area and yield of total cereals between 1964 and 1991 in several countries. Three values are given for yields: (a) the average ;(b) the 90% percentile (the value exceeded on average 1 year out of ten) and (c) the average of the 3 highest losses during the period. Based on FAO statistics.

	Thailand	Tanzania	Niger	Mexico	France	Canada
Production	12	20	18	13	12	14
Area	8	13	13	8	2	6
Yield (a: average)	7	17	16	9	11	11
Yield (b: p90)	14	29	31	15	20	23
Yield (c: 3 highest)	16	34	64	18	23	28

As noted above in the case of Thailand, production shows the highest average losses, while the relative importance of area and yield varies, with area being usually highest. It is also worth observing that some very high values occasionally occur in developing countries. At the global scale, values tend to be lower due to the averaging effects.

---

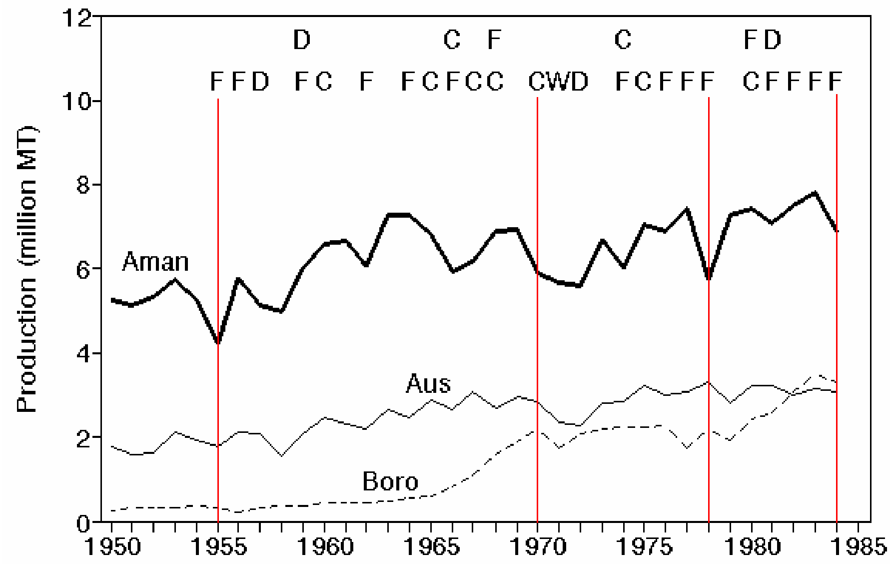
[6] The detrended yield is the departure of yield values from the time-trend, assumed to take into account the technology and management component of yield. Like in many developed countries, radiation, not rainfall, is the main limiting factor to agricultural production. The time-trend accounts for about 80% of the total variation of yields, leaving about 20% to be accounted for by other factors.

Table 2: average loss of production, area and yield of total cereals, total roots and total pulses between 1964 and 1991 in Africa and the world as a whole. Refer to Table 1 or the definition of the different yield loss statistics. Based on FAO statistics.

	Cereals		**Roots**	**Pulses**
	Africa		World	
Production	10	8	5	7
Area	6	2	2	4
Yield (a: average)	8	7	4	5
Yield (b: p90)	16	10	8	11
Yield (c: 3 highest)	19	12	10	11

Regarding extreme factors, their impact can be shown to have marked effects **at the national level** only in some particularly disaster-prone countries, like Bangladesh (Figure 7) where the losses due to the extreme conditions can reach 2.5 million tons (in 1988, according to Hofer and Messerli (1997)), or about 15% of the total rice production[7]. In comparison, factors like hail, frost or fires are only of marginal significance.

Figure 7: Production of three rice typologies in Bangladesh. *Boro* is a dry season (winter) irrigated crop; *aus* is a pre-monsoon crop (Apr.-Aug.) and *Aman* is a late-monsoon crop (June-Dec.). Extreme conditions are indicated as F for floods, D for drought, C for tropical cyclones and W for war. After Gommes, 1992.



In summary, it appears to be rather difficult, to quantify the impact of climate variability on agricultural production. This is mainly because agricultural statistics are spatially aggregated values, and because of some traditional practices of national services, like for instance the reporting of harvested rather than planted areas.

In agreement with Palm and Dagnelie (1993) and Palm (1997), it may be concluded that, **at regional scale**, the largest fraction of inter-annual variability of crop yields and

[7] Hofer and Messerli see the erosion of river banks (loss of land) as one of the main problems in Bangladesh.

production can be ascribed technology and management in developed countries[8]. In Europe and for annual crops, non-weather factors account for more than 50% of the variance in 75% of the cases studied, and for more than 75% in 40% of the cases. Roughly 20% of the variability is due to other factors, of which at least half is weather dependent.

In developing countries, particularly in semi-arid areas, the fraction of variability due to weather is at least of the same order of magnitude, but because trends tend to be much less marked, the actual role of climate appears to be much larger, up to 100% in extreme cases of virtual complete crop loss due to generalised drought. .

3. Risk management

3.1 Some differences between developing and developed countries

Most farmers in developing countries live at subsistence level. This not only means that their production is low and precarious, but indicates, by definition, that they grow their own food and that they actually market only a small part of their production. According to UN (1996) figures, the 2000 rural population will be only 24% in developed countries, and 75% in the least developed ones[9].

In developed countries, only a fraction rural population is actually involved in farming, and the population relies on markets for their food supply.

This is to say that the strategies of farmers, and their perception of risk, are vastly different: a subsistence farmer aims at stabilising his production, while farmers in developed countries aim essentially at maximising their economic return.

There are many other differences: developing countries usually make a clear difference between food crops and cash crops, while all crops in developed countries are "cash crops". In developing countries, most cash crops are industrial export crops (coffee, sisal...), and some of them are grown as an "insurance against good years"[10].

An attempt of a more systematic treatment of the subject is given in Table 3 below. The listed differences entail large differences in strategies.

3.2 Risk management sensu stricto

There is little doubt that one of the main problems facing the individual farmer in developing and developed countries alike is the unpredictability of weather at a seasonal scale.

---

[8] For perennial crops, the trends account for between 25 and 75% of the variance in about half the countries studied by Palm and Dagnelie. 36 % show no trend at all.

[9] The corresponding figures projected for 2030 are 17 and 56 %, respectively.

[10] Farmers market a small part of their food crops. During good years, prices tend to drop, in which case the government still buys cotton or sisal, thereby ensuring some cash income.

Even under traditional farming conditions with no inputs other than labour, several management decisions have to be taken: choice of crops and varieties to be planted either in isolation or mixed, choice of land where there id sufficient land to chose, choice of planting dates, etc.

Table 3: some differences between farmers in developed and developing countries

	Subsistence farmer	**Developed farmer**
Strategy	Stabilise food production	Maximise income
Maximum loss	Life and out-migration	Debt and cessation of activity
Source of risk	Weather	Weather, markets and policies
Non-structural risk avoidance mechanisms	Virtually non existent	Insurance, credit, legislation
Inputs	Very low, with little and slow evolving technology component.	Very significant; fast evolving (varieties, mechanisation, pesticides etc.)
Farm assets	Insignificant (some tools)	Very significant
Price of food crops	Local: depends mostly on local markets and production. Very steep spatial gradients of prices can be observed in the same country; prices are often government controlled	Global: they depend on national and international markets and production, and on government policies
Price of industrial crops	Global to some extend, but government agencies or other buyers are often in a position to pay farmers less than the actual values of their crops	As above, but with much less interference of policies
Role of cattle	Banking system[11] (cash reserve); source of animal products for direct consumption, but mostly from small cattle and poultry	Cash production

Subsistence farmers sometimes make use of bewildering spectrum of traditional varieties, of which they know and understand the eco-physiological response. Diversification is thus one of the most basic risk management approaches used at the subsistence level as well. It should also be stressed that traditional systems can be very robust because of their low water consumption (as compared with improved varieties) and low input requirements (fertilisers too increase water consumption and the risk of agricultural drought!).

[11] This is sometimes referred to as "contemplative herding".

It remains that subsistence farmers will be gradually forced out of their traditional farming, willingly or unwillingly, mainly because of land shortage, urban demand and general development.

Climate risk management techniques in agriculture can be categorised as below. All the techniques listed assume that long-term data are actually available to properly assess the risks and statistically most efficient response mechanisms.

Structural measures that reduce the variability of climate resources at plant level

They include irrigation, water harvesting, windbreaks, frost protection, artificial and controlled climates (greenhouses...), microclimate manipulation... Most of them entail significant costs that actually require government participation when they are implemented in developing countries.

Non-structural measures

Again, most non-structural measures include a cash component that is non-existent or difficult to implement at the subsistence level. Credit to farmers, for instance, is still the exception rather than the rule. Crop insurance can be resorted to only when there is sufficient spatial variability of the environmental stress (e.g. with hail), but remain extremely difficult to implement for some of the major risks, such as drought, which typically affect large areas, sometimes whole countries. They are certainly not feasible without government intervention. One of the techniques which have been adopted with credit and insurance is to make them conditional to the adoption by farmers of improved, risk-reducing practices, like early planting.

Improved legislation, if it can actually be implemented is probably one of the measures that has the best potential in the long run. This includes watershed protection (for instance by preventing grazing in some forest areas), and all the measures aiming at improving farming efficiency under a no-regrets approach.

Finally, preparedness plans are mentioned.

Improved use of climate knowledge and technology

This includes the development of monitoring systems and response mechanisms to current weather, both at farm and government level.

Under technology we include mainly the modelling of future impacts based on current weather (within season), and decision tools of varying complexity.

In practice, the decision tools are tables/flow-charts or software that assist farm-level management decision-making based three types of inputs:

- the knowledge of local environmental/agricultural conditions (reference data[12]);
- the measurement of local “decision parameters” by local extension officers or farmer;

[12] A simple example of this could be, for instance, a threshold of air moisture or sunshine duration to decide on pest risk, or a threshold of salt content of water to decide on irrigation-salinity risk. More complex applications require the use of models, which can usually not be run at the village level but require regular communication with a central office.

- economic considerations, e.g. Cost of inputs Vs expected output.

The major challenge facing all crop-weather modelling is the incorporation of qualitative changes deriving from complex interactions. For instance, the above-mentioned shortage of land in several countries will entail severe qualitative changes. Whether the resulting chain of interactions (social conflicts) can be modelled is rather dubious.

4. References

Arléry, R., H. Grissolet and B. Guilmet, 1973. Climatologie, méthodes et pratiques. Gauthier-Villards, Paris. 434 pp.

Bakkes, J.A., G.J. van den Born, J.C. Helder, R.J. Swart, C.W. Hope and J.D.E. Parker, 1994. An overview of environmental indicators: state of the Art and perspectives. UNEP/EATR.94-01, RIVM/402001001, RIVM, Bilthoven.

FAO, 1989. Rainfed agriculture in Asia and the Pacific region. FAO Regional Office for Asia and the Pacific, Bangkok, 224 pp.

Gommes, R. 1992. Current climate and populations constraints on agriculture, chapter 4 (p. 67-86) in Kaiser and Drennen, 1993.. Cornell University, Ithaca (N.Y.), 8-9 Oct. 1992: St. Lucie Press, Delray Beach, Florida.

Gommes, R. 1997. Prévision agrométéorologique des rendements: quelques moyens et méthodes utilisés par la FAO dans un contexte de sécurité alimentaire. In: Tychon and Tonnard, (Eds), 1997, 145-175.

Gommes, R. 1998. Some Aspects of Climate variability and food security in sub-Saharan Africa. Proc. Bull. Soc. Royale Sc. Outremer, Brussels. In press.

Gommes, R., and F. Petrassi. 1994. Rainfall variability and drought in sub-Saharan Africa since 1960. FAO Agrometeorology Series Working Papers N. 9 : 100 pp.

Hofer, T., and B. Messerli, 1997. Floods in Bangladesh. Report prepared for the Swiss Agency for Development and Cooperation by Inst. Geography, Univ. Bern. 32 pp.

IPCC, 1995. Contributions of working group II to the IPCC second assessment report, IPCC-XI/Doc. 4. IPCC Geneva.

Nash, J.C. and M.M. Nash, 1995. Managing Risks. Chance, 8(4):25-31.

Palm, R., 1997. Les modèles de prévision statistique: cas du modèle Eurostat-Agromet. In: Tychon and Tonnard, (Eds), 1997, 85-108.

Palm, R., and P. Dagnelie, 1993. Tendance générale et effets du climat dans la prevision des rendements agricoles des différents pays des C.E. Official Publications of the EU, EUR 15106, Luxembourg. 132 pp.

Tychon, B., and V. Tonnard, 1997. Estimation de la production agricole à une échelle régionale. Official Publications of the EU, EUR 17663, Luxembourg. 202 pp.

UN, 1996. World population prospects, the 1996 revision. Annex I: Demographic indicators. United nations Secretariat, Population Division, New-York. 253 pp.

White, D.H., 1994. Climate variability, ecologically sustainable development and risk management. Agric. Systems and Information Technology, 6(2):7-8.