Final Report

A system of drought insurance for poverty alleviation in rural areas

A feasibility study of a practical method of drought insurance that is self-sustaining and ready for use by poor farmers, NGOs or other development organizations

Authors

Jacqueline Diaz Nieto
Simon Cook
Mark Lundy
Myles Fisher
Diego Sanchez
Edward Guevara

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung

CRS
CATHOLIC RELIEF SERVICES

Table of Contents

List of Figures

List of Tables

Acknowledegements

This project was carried out with funding from the German Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (BMZ), Project number 03.7860.4 – 001.00, Contract number 81076317, *A system of drought insurance for poverty alleviation in rural areas*. We gratefully acknowledge that support.

Executive summary

Introduction

Agriculture is inherently risky. Drought is a particularly troublesome hazard that has a documented adverse impact on agricultural development. A long history of decision-support tools have been developed to try and help farmers or policy makers manage risk.

The poor have little access to risk-minimization methods used by others. They therefore seek to avoid risk by minimizing their exposure to it. In the case of poor small-holder farmers, this means minimizing investment in the main risk they confront, growing a crop, such as not applying fertilizer to it. Although risk is lessened, the potential to generate profit is also lessened. Risk avoidance is thus inefficient and using it locks poor small-holders into poverty.

Insurance is a well-established method to share risk by people and organizations in all walks of society. In general the poor have typically had little access to insurance to help them manage risk. However, there is evidence that insurance can work for the poor and there are examples of schemes directed to the poor that do work. They help the poor avoid risk and they can also make a profit.

Insurance is widely used by farmers in developed countries to protect them against weather risk. In the case of drought, insurance works by encapsulating the best available scientific estimate of drought probability at a site within a single number – the insurance premium. The premium allows insurers to offer insurance to insurable parties in a transparent risk-sharing agreement. However, weather insurance has rarely been offered to poor small-holder farmers in developing countries.

Case study: Weather insurance for drybean farmers in Nicaragua

Drybeans in Nicaragua are widely grown by poor small-holder farmers in small plots with little technological input. Mostly they are grown both to eat and for sale.

Nicaragua has three geographical regions. The Pacific lowlands are a broad, hot, fertile plain that supports most of Nicaragua’s population. The sparsely-populated Caribbean coast is hot, low-lying and humid. The north-central mountains have a cooler climate and it is here that most beans are produced on hilly to steep slopes.

The rainy season in Nicaragua is June to November, allowing two successive drybean crops, with the second typically yielding better. The opening rains can be chancy, so sowing the first crop is risky. Most varieties are small- and medium-seeded blacks and reds that mature in 60-75 days. Rainfall, particularly the timing of water stress, determines final yield. Drybeans require well-drained, deep, fertile soils, although they are often grown on suboptimal soils.

Catholic Relief Services (CRS) partners several micro-finance organizations[1] (MFOs) by lending to them at low interest, and providing crop marketing infrastructure and expertise. Typically MFOs lend to groups of growers of irrigated vegetables. They lend little to drybean farmers because they classify rainfed drybeans as unacceptably risky and not a cash crop. This is changing, although emphasis is still on some irrigation. The group of 4 or 5 farmers must provide collateral with preference to those with diversified crops.

Drybean farmers were canvassed in workshops in 2005 to rank risks that cause greatest yield losses. The results depended on the farmers' climate; in humid climates, excess rain and erosion were problems, in drier climates, drought and occasionally excess rain. Farmers coped with risk by limiting investment and labour input, but if good weather was assured, they would increase the area of production.

Considerations for developing rainfall insurance for drybean farmers in Nicaragua

A weather-insurance scheme must show causal relation between the insured weather event and crop loss, ideally based on long historical records of weather and yield. But there are few data for drybean yields in Nicaragua. We developed methodology to establish the relation in the absence of actual weather and yield data.

A weather index is a way to reduce a complex relationship between rainfall (in the case of drought) and crop yield to a single figure. Primarily the scheme must have a positive impact on farmer livelihoods. Technically the index must:

- Be easily understood and the trigger event for payment be clearly defined;
- Take account of crop sensitivity at different growth stages such as flowering;
- Take account of the effect of soil texture on the effectiveness of rainfall;
- Be tailored specifically to the crop variety;
- Define a protocol that reflects the actual planting date as closely as possible;
- Ensure that the insured pays the price of the spatial variation in risk; and
- Enable accurate estimation of the probability of the risk event.

Financial and administrative aspects that are important require the scheme to:

- Have a reliable rainfall station network;
- Be corruption-free and transparent;
- Be a product adapted to small-holder farmers' needs; and
- Provide communication and training.

Methodology for designing a payout index based on rainfall: converting the relationship between yield and rainfall into a payable index

A major obstacle to insurance for agriculture in developing countries has been the absence of data on which to estimate probabilities, hence premiums. We describe a robust method that couples generated weather data to crop simulation. The procedure consists of three stages, generation of the weather data, simulation of crop yields using the generated

[1] In the literature, authors commonly use the term micro finance *institutions* with the acronym MFIs. In Nicaragua the word *institution* requires that the particular entity have institutional status accorded by the government, which entities we are referring to do not have. We therefore use the term organization here.

weather data and estimating the minimum water (rainfall) needs of the crop at fixed intervals during its growth and development.

We rely on the weather generator MarkSim, which interpolates on a multi-dimensional weather surface with a resolution of 10 arc minutes (about 18 km at the equator). The surface is based on observed data from 9 200 stations in the tropics and subtropics. For a particular site it interpolates on that surface to obtain estimates of monthly mean temperature and range and monthly precipitation. Alternatively, one can input actual data where they exist, or obtain data from another data base such as the WorldClim data set, with 30 arc seconds resolution (about 1 km at the equator). Either one of these three inputs can be used with MarkSim. The routine inputs these data to a third-order Markov model to generate daily data of maximum and minimum temperatures, rainfall and solar radiation for as many years as the user requires, up to limit of almost 500 000 years.

We generated 99 years' data for 153 pixels covering the drybean-growing area of Nicaragua, a total of 15 147 years' data. We used the generated data as input to the Decision Support System for Agrotechnology Transfer (DSSAT) drybean model. Briefly, the DSSAT CROPGRO series of models use the detailed understanding of crop biochemistry, physiology and agronomy to simulate crop water balance, photosynthesis, growth and development on a daily time step. They require input of the soil water characteristics and genetic coefficients of the crop cultivar, plus any relevant agronomic inputs such as fertilizer and irrigation, together with the daily temperature, rainfall and solar radiation.

For each pixel we used four combinations of soil texture (sand, sandy loam, silty loam and silty clay) on either flat or sloping topography with drybean cultivars of 70-day and 80-day maturity. For each of these 16 combinations we had a set of 99 years' data of daily rainfall and crop yield, comprising a "run".

For each simulation we divided the growing season into 10-day blocks, which we call a dekad. Within each soil-topography-variety combination we established the minimum water requirement (MWR, as rainfall) for each dekad below which there was a yield reduction. Initially we estimated plausible values for the MWR for each dekad and subtracted them from the observed rainfall to calculate deficits, that is, we ignored positive values. The total rainfall deficit for the growing period is therefore the sum of the deficits for each dekad. We selected the lowest quartile of each run and calculated total rainfall deficits from day -10 to day +70 for each simulation within this subset and calculated the correlation coefficient for the regression of total deficit on crop yield. We then optimized the estimates of MWR for each dekad to maximize the correlation coefficient.

We applied this method to each of the study cells and within each to each soil-topography combination. In each cell the procedure gave only slightly different values. The results for each soil by topography combination were therefore averaged over all cells.

A crop-insurance scheme based on weather is concerned with weather events that lead to severe yield losses. One possible type of insurance instrument would allow farmers to choose the level of yield below which they are not prepared to accept as normal variation. For each of these there would be a corresponding rainfall deficit, called a trigger for which the farmers could buy insurance. This would require a range of instruments whose premiums are actuarially adjusted for the corresponding risk. Another method is to sell a fixed trigger, which is actuarially easier to formulate.

In years when the trigger deficit, whether fixed or variable, is reached the scheme makes indemnity payments. The level of the trigger naturally affects the cost of the coverage. A modest trigger aimed at insuring a lower level of yield loss would obviously cost more.

The exercise described here, including the correlations and trigger points are based entirely on yield simulations using generated weather data. We are forced to take this approach because as we have already pointed out, sufficient hard data do not exist for drybeans in Nicaragua.

Sample contract

We proposed a weather-insurance contract based on the rainfall-deficit index that we developed based on minimum rainfall requirements for dekads throughout the growing season. The start and end date should reflect the most likely sowing date and should end at crop maturity. A simple sowing date rule seems the fairest method.

A sample contract is shown in Box 1 on page 42 and Tables 5-3 and 5-4 on page 43 are examples of how this hypothetical scheme would be calculated.

Site specific probabilities of a trigger event

Once a weather index has been established on which an insurance policy pays an indemnity, the probabilities of the payable weather event needs to be calculated to determine the pure risk, which is the main part of the price of the insurance premium. Standard insurance practice relies on historical data and careful extrapolation take account of any possible extreme events. Here we have described a method to produce data on which to estimate risk where few exist.

Figure ES-1 illustrates the potential of using weather generation coupled with a crop simulation model to estimate the probabilities of reaching a trigger levels of water deficit in drybeans in north-central Nicaragua.

Practical issues of distributing insurance

The success of a financial instrument for small holders is dependent upon the mechanisms put in place to ensure that the product is made accessible. One obvious channel of distribution is via MFOs that already have access to small-holder scale farmers, and additionally such an instrument complements the portfolio of products MFOs already offer. Nonetheless there are many limitations that limit MFOs from effectively managing and distributing weather-insurance products. Prudent links with experienced insurers and reinsures are essential components.

Re-insurance is essential to ensure the continuity and viability of any insurance scheme. In weather insurance re-insurance is necessary since weather risks are highly covariant,

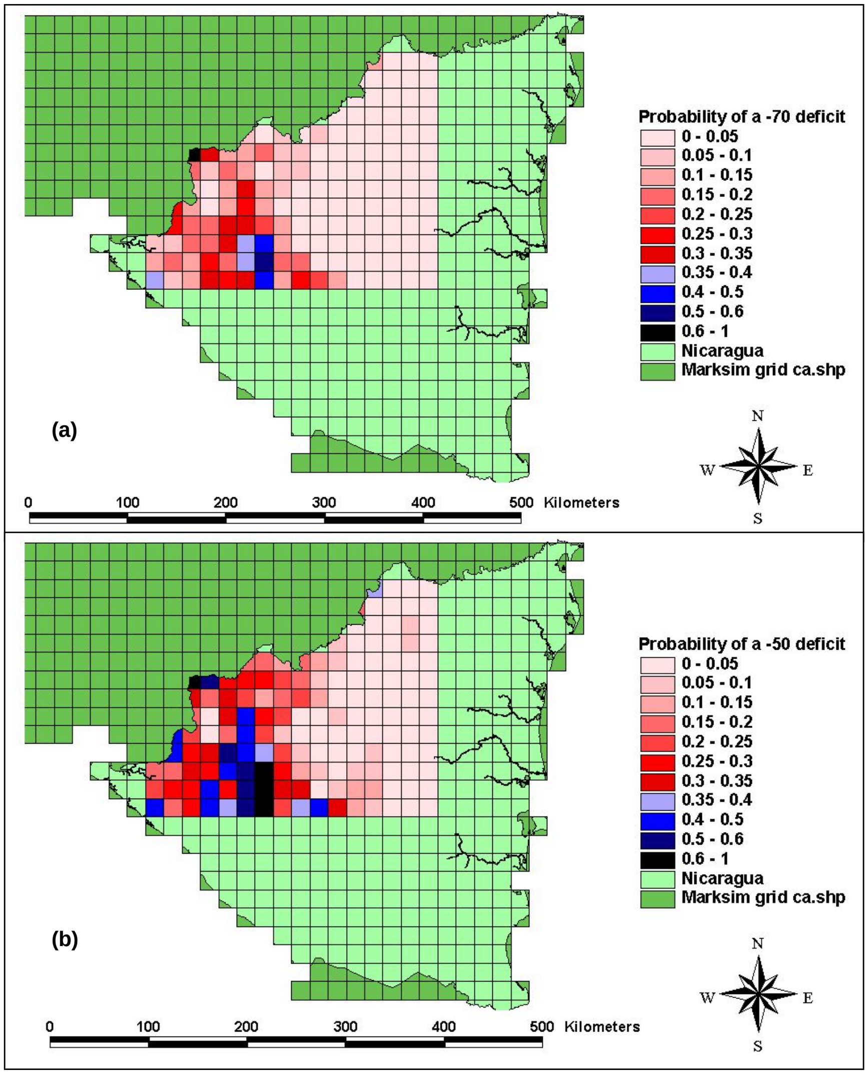


Figure ES-1 Probability of a (a) 70mm rainfall deficit and (b) 50mm rainfall deficit occurring in drybean crops during the *primera* cropping period in north-central Nicaragua.

yet at the moment are their biggest challenge. Re-insurance companies have very strict climate-data requirements and at this stage it is unknown how re-insurers would react to the scheme proposed here. Initial responses have been encouraging.

It is generally accepted that the weather data should be managed by an independent source. The role of the independent weather data provider is therefore critical to guarantee the data quality and take responsibility for the timely collection and distribution of the data.

Consultation with farmers

We asked farmers how much rain they thought they needed to grow a crop of drybeans. Farmers' opinion was congruent with our results.

Few farmers knew how insurance works or had experience with it, but quickly grasped the concept and became enthusiastic. They understood the concept that premium prices would depend on their location, that is, according to the risk. Farmers provided valuable feedback on administrative and operational aspects of such a scheme. Most farmers found the possibility that the MFOs would be local agents an attractive idea.

Crop insurance combined with micro finance has the potential to help poor smallholder farmers break out of the poverty trap. But these products were denied to many people because lack of information and infrastructure provided no information on which to formulate them. The work we describe here provides the scientific tools that allow the expansion of micro finance and insurance to people who have hitherto been denied them.

1

1. Introduction

1.1. Poverty and risk

Agriculture is inherently risky. Production risks include, but are not limited to climatic hazard, which of all the hazards agriculture faces is perhaps the most difficult one for agriculturalists to manage. Drought is the most serious of the natural hazards globally in terms of loss of life, accounting for 44% of reported deaths globally in the period 1974-2003 (EM-DAT, 2004[2]).

In Central America, drought is the major cause of crop loss. Droughts can have serious implications for small-scale producers who usually do not have access to irrigation, for example, in Nicaragua only 8% of the land is irrigated (World Bank, 2001). Droughts cause food and income insecurity through both acute and chronic effects. Acute effects are the loss of crops and of the livestock that depends on them, and in extreme cases drought leads to hunger and even starvation. Chronic consequences of drought include secondary effects such as increases in local interest rates due to a rise in the number of households seeking credit, a decline in the demand for farm labor, a reduced local wages due to greater numbers seeking off-farm employment, drops in livestock prices due to distress sales and increased food prices coinciding with reduced financial resources (Sakurai and Reardon, 1997).

Numerous studies have shown a strong link between risk, vulnerability and poverty (Dercon, 2001; Mosly and Krishnamurthy, 1995; Rosenzweig and Binswanger, 1993; World Bank, 2000). Poor households lack resources with which to absorb the shocks of natural hazards. Even small disruptions in the flow of income can have serious implications for poor households. Because they lack resources with which to absorb the shocks of natural hazards, poor farmers commonly avoid risk by using informal and self-insurance measures. While these measures can help survival (Webb and Reardon, 1992), most studies conclude that they are not the best tools for risk management. This is because they reduce the impact of a hazard at the expense of more profitable activities (Barrett *et al*, 2001; Morduch, 1995; Morduch, 1999).

1.1.1. Self insurance as a detrimental mechanism for coping with risk

Most modern risk-avoidance measures are not readily available in developing countries (Wenner and Arias, 2003), hence farmers in these regions are obliged to adopt traditional informal mechanisms for coping with risk (Table 1-0). Many argue that self-insurance measures not only present a barrier to poverty alleviation but reinforce poverty (Barrett *et al*., 2001; Brown and Churchill, 1999; Rosenzweig and Binswanger, 1993). They do this because firstly they use resources inefficiently and secondly they fail to exploit those investments and technologies that in the long term would give more productive systems (Hazell *et al*., 2000; World Bank, 2001). For example, when faced with the possibility of losing an entire crop due to drought, farmers may lessen risk by minimizing investment

[2] Source : EM-DAT : The OFDA/CRED International Disaster Database. http: //www.em-dat.net , UCL - Brussels, Belgium.

in the crop by not applying fertilizer. They do this because making the additional investment increases their loss should the crop fail.

Likewise, selling of family assets at a time when everyone is also trying to sell their assets will lower prices. As a result such assets of little use in smoothing the effect of the drought shock. Worse, if the asset was bought at a time when prices were buoyant, as in a time of plenty, selling will incur a net loss (Skees, 2003). Furthermore if an animal dies of starvation, all investment in it is lost.

Another common risk coping mechanism is seeking off-farm income. This may be effective for idiosyncratic risks[3], but the tactic is less effective when a geographically extensive risk event, such as drought, which is typically wide-spread, occurs. This is because the amount of labor on offer increases so that conditions become more competitive and wages fall. Moreover, as economic conditions worsen, the amount of work available typically lessens as employers seek to cut costs. Informal insurance is therefore a relative ineffective strategy so cope with covariant risk events such as drought. Repeated shocks further undermine it as a coping strategy (Dercon, 2003).

A survey in India found that 30% of respondents cited loss of wages, income or work as a major impact of a risk event (Hess, 2003*a*). Forty five percent said that they would borrow money to tide them over the crisis, leading to increased indebtedness. In reality the option to smooth consumption by borrowing is generally not available to small-holder farmers with low incomes. Financial institutions are unwilling to lend to these borrowers precisely because of their vulnerability to drought risk and the consequential likelihood of default on loan repayments (Hess, 2003*a*). Indian banks, who lend to farmers in irrigated areas, are constrained by the risk of drought from extending credit to farmers in non-irrigated areas (Mishra, 1994).

Goes and Skees (2003) argue that *ex post* disaster relief plans can have unintended negative impacts on economic development. In the worst-case, *ex post* relief can increase risk exposure in the long-term by promoting dependence on charitable relief. In addition, government assistance has to be very careful not to encourage new economic activity in areas that are unreasonably vulnerable to natural disaster (Skees *et al*., 2001).

1.2. Insurance as an effective tool to manage risk

1.2.1. Why insurance in a more effective risk management tool

The purpose of formal risk-management strategies is to enable investment in more profitable activities through transparent sharing of risk. For the reasons above, the informal risk-aversion mechanisms that poor households use mean that they are unlikely to invest in new technologies that could likely lead to increased wealth. For this reason, poor people exposed to risk find it difficult to break out of the poverty cycle.

[3] By idiosyncratic risks we mean those that affect a small number of people, often in a pseudo-random way.

Table 1-1 Risk management tools.

Self insurance measures	**Modern risk avoidance measures**
Crop diversifications	Production contracting
Maintaining financial reserves	Marketing contracting
Reliance on off-farm employment	Forward pricing
Other off farm income generation	Futures options contracts
Selling of family assets (e.g. cattle)	Leasing inputs
Avoidance of investments in expensive processes such as fertilizing (especially in high risk years)	Custom hiring
Accumulation of stocks in good years	Acquiring crop and revenue insurance
Removal of children from education to work on farm	

(Source:, 2003; Hess, 2003*a*; Skees *et al.*, 2001; Wenner and Arias)

Formal insurance has provided benefits to individual consumers for centuries and in the last few years has also been suggested as a pro-poor tool for managing risks (van Oppen, 2001). A growing number of micro-insurance products (products offered to insure items in the range of a few hundreds of dollars) are now being offered in poor countries in the areas of life, health and property insurance and in some cases, schemes for crop insurance. This growing interest in micro-insurance products as development tools is associated with the expansion of micro-credit schemes (Morduch, 1999). There is also the growing recognition of the mutual benefits of risk management as a tool for poverty alleviation. Micro-insurance is not only justified on the basis of humanitarian need. Properly designed, it also makes economic sense for the organization offering it (Dercon, 2003).

Micro-insurance is one of a number of products that can be sold under the collective title of micro-finance and an initial question to consider is whether insurance is the most appropriate of these tools to address weather risks (Brown *et al*., 2000). Insurance needs to be evaluated against other tools such as savings, mutual plans or credit.

Formal strategies such as insurance are most effective where there is a high degree of uncertainty and when there is a lot to lose (Brown and Churchill, 1999; Zupi, 2001) (Figure 1-0). Weather risks naturally fall into this category: Large uncertainty remains since long-range weather forecasting cannot yet predict events with precision; the losses can be severe because depending on the nature of the event it may lead to an entire crop failure or worse. For example, hurricane Mitch in Central America that wiped out entire plantations, which take years to establish.

Insurance can be thought of as exchanging the irregular uncertainty of large losses for small regular premium payments. A general rule, the larger the potential loss in assets and income to a household posed by a given risk, the fewer alternatives there are to recover from the loss (Brown and Churchill, 1999). Insurance constitutes one of the few viable options for poor people to manage uncertain events that can result in large losses.

In general, the few micro-insurance schemes operating in poor countries have reported encouraging results. In an empirical study of a crop-insurance scheme, Mishra (1994) found that there were many socio-economic benefits for both farmer and insurer. The

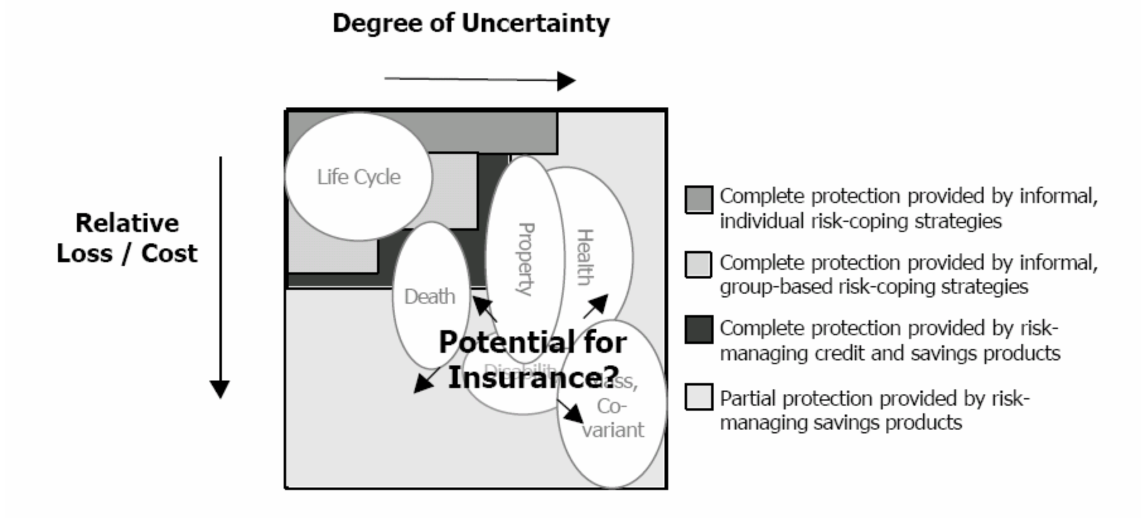


Figure 1-1 Illustration of the potential for the insurance in managing situations where there is high uncertainty and a lot to lose. Informal strategies become less effective in these situations. (Source: Brown and Churchill, 1999)

farmers benefited from insured production, which led to increased investment and wealth and the insurers benefited from a wider base of credit-worthy customers. Unfortunately the scheme was not financially viable. If, the financial weaknesses of crop insurance in developing countries can be overcome (Bryla *et al*., 2003), these socio-economic benefits could flow more generally amongst poor smallholder producers. Insurance instruments can be tailored to the needs of poor farmers while taking account of their financial limitations. If this can be done, the scheme could be financially viable without losing its pro-poor benefits.

1.2.2. Reasons for failure of previous agricultural insurance schemes (not weather insurance).

Most crop-insurance schemes in the past have failed mainly because they covered multiple perils or provided all-risk coverage (Skees *et al.*, 2001). This has meant that virtually any cause of crop failure was insured, resulting in excessive indemnity payments. Because private insurance companies will not insure risks that are widely correlated, such as multiple crops, these schemes were either fully publicly-owned or had large government subsidies. Also because they were all- or multiple-risk they incurred substantial moral hazard in which the insured has no incentive to take all prudent care to avoid crop losses.

Related to moral hazard is the problem of asymmetrical information, where the farmer knows more about the likelihood of crop failure than does the insurerA successful insurance scheme requires symmetrical information between both parties. Hidden and asymmetrical information is fundamental to the failure of crop insurance (Skees, 2003). They encourage both moral hazard and adverse selection, which is where farmers facing lower-than-average risks opt out of the scheme leaving only farmers with higher-than-average risk.

Miranda and Glauber (1997) argue that crop insurance schemes fail because crop risks are systematic or co-variate, that is they occur over geographically extensive areas. The normal solution for co-variate risk is re-insurance or other long-range risk sharing mechanism, which is unlikely to be offered except at prohibitive cost.

1.3. Weather insurance as a solution

Weather micro-insurance has been proposed as a viable tool to help poor farmers manage weather risk that affects crop production. The principles underlying weather insurance have been widely discussed (Bryla *et al*., 2003; Hess, 2003*a*; Skees *et al*., 2001; Stoppa and Hess, 2003; Varangis *et al*., 2003). A review of the principles and experiences of the insurance processes follows.

1.3.1. Principles of weather insurance:

Probabilities of occurrence can be calculated for those adverse weather events that cause crop losses. However, the probability of occurrence of an adverse weather event varies in space, so that some areas are riskier than others. In an insurance scheme the probability of occurrence must be identified for specific areas both parties (symmetry).

Two broad principles govern the viability of insurance. First, risk-sharing can only occur when both the insurer and the insured have accurate information about a hazard and its likelihood, which has been the basis of insurance for over three centuries. Moreover, a sound insurance product is both transparent and symmetrical, so eliminating both moral hazard and adverse selection (Skees, 2003). Second, risk-sharing must be broad enough to sustain the potential impact of co-variate risk, especially given that a major weather event such as drought is strongly correlated over any given area.

1.3.2. Weather-insurance products

Crop yield indices. This is a relatively new method that has been applied in US, India, Sweden, Mongolia and Quebec, Canada (Skees *et al.*, 2001). Farmers in a given area are entitled to indemnity payments when the area-average yield for a particular season falls below a predetermined long-term area average. The index in this case is the long-term area average yield. Although these schemes avoid the traditional problems of adverse selection and moral hazard, they may not be appropriate for developing countries where long and reliable yield data may not be available (Skees *et al.*, 2001). Yield data for developing countries normally come from research stations, whose location may not be representative of the area in which they are located. Furthermore, yields for research station yields overestimate farmers' yields by as much as 30% or even more (Davidson, 1965).

Weather index insurance: Indemnities are paid on specific weather events, not yield reduction. Weather insurance is a relatively recent development. In the 1990s weather markets started developing in North America mainly as a result of privatization of the energy sector in the US, which encouraged producers to hedge against fluctuations in revenue caused by variable weather (Turvey, 2001). Agricultural applications appeared as a spin-off from this development, since many of the weather risks the energy sector confronts also affect the agricultural sector through crop losses.

Compared to area-average indexes, weather-based indices have the advantage that weather data are generally more accessible and more reliable than yield data. This is especially the case in developing countries (Skees, 2003). Weather-related insurance products succeed or fail on their ability to present accurate information about weather-related risks that are specifically associated with yield loss. The critical step is to identify the causal relationship between an insured weather event and consequent crop loss.

A key attribute of weather-based index insurance is its simplicity. This not only increases profitability of the insurer, but also makes reinsurance of the relevant products more attractive to the global markets (Miranda and Vendenov, 2001). Weather insurance provides a hedge against the cause of the yield loss, rather than its cost, as is the case with traditional crop insurance, which removes the need to estimate prices. Traditional yield-triggered insurance schemes are criticized because although they help farmers to smooth out the impacts of risk, they do not protect the rest of the community (Turvey, 2001; Skees *et al*., 2001). From a developmental context, this is important, since it is not only farmers who suffer during droughts. Weather-index insurance can address this issue as it can be offered to anyone who considers themselves to be at risk from drought (Skees *et al*., 2001).

1.3.3. Functioning weather insurance schemes

Table 1-2 Examples of existing weather insurance schemes around the world.

Location	Comments	Source and further information
Ontario, Canada.	Farmers in Ontario were the first to be offered weather-based insurance for forage production. The program protects farmers against forage crop losses using rainfall readings at local weather stations. Agricorp, an agency of the Ontario government, provides the insurance. Indemnities are paid if the rainfall May to August is less than 80% of the long-term average. Customers are allowed to choose the rainfall station that best represents rainfall at their farm. The insurance scheme was fully subscribed in the first year, however it must be acknowledged that it was introduced after a major drought.	Hess (2003*a*) Stoppa and Hess (2003) Turvey (2001) Agricorp website[1] University of Guelph website[2]
Alberta, Canada	The Agricultural Financial Service Corporation (AFSC) developed an insurance instrument based on satellite imagery. Wavelength data are used to estimate growth conditions for native pasture. Producers are compensated when the wavelength-based index falls below a predetermined value.	Stoppa and Hess (2003)
Spain	Since 1978 there has been a public-private crop insurance scheme. The ministry for agriculture conducts studies, designs and provides reinsurance, pays a fraction of farmer premiums and provides subsidies to insurers. Indemnity payments and administrative costs have exceeded the premium payments.	Wenner and Arias (2003)
Mexico	In 2001 Mexico was the first developing country to experiment with weather indices. Agroasemex (a Mexican agricultural insurance program) used weather markets to reinsure part of the multiple crop insurance programs. This appeared to be more effective than traditional insurance. Agroasemex is a government insurance company, started in 1991 that only reinsures local private insurance companies and mutual insurance funds (FONDOS). FONDOS are located in low-income regions and they cover risks like drought, excess moisture, frost, hail and wind. It is a voluntary program (unlike the predecessor ANAGASA) and it seems to be more cost effective. However the coverage is lower than with ANAGASA.	Hess (2003*a*) Stoppa and Hess, (2003) Wenner and Arias (2003)
South Africa	Genbel Securities Limited (Gensec), an investment bank, offers weather derivatives to producers of deciduous fruit in the western Cape against early spring frost. This began in October 2002. It is a temperature-based insurance. Insureds are paid for days when the temperature is equal to or below 0°C during the budding phase.	Hess (2003*b*)
India	National Agricultural Insurance Scheme (NAIS) is an area-index scheme offered through state owned companies.. Premium rates are 1.5 to 3.5% of the loan amount. It has been unsuccessful with a claims ratio of 200 percent in a normal year. Failure is attributed to the fact that premiums and claims were not equitably distributed across crops and states.	Hess (2003*a*)
Argentina	A private insurance company in Argentina offers rainfall-based insurance contracts to milk-producing co-operatives. The scheme is based on a positive correlation between rainfall and milk yields.	Skees *et al.* (2001)

[1] http://www.agricorp.com/en-ca/about/history.asp
[2] http://www.uoguelph.ca/research/news/articles/2002/insurance_plan_farmers.shtml

1.3.4. What are the main challenges in developing weather insurance

The main challenges involved in developing good weather insurance schemes are summarized in Table 1-0. We shall then discuss the separate issues below.

Table 1-3 Summary of main challenges that need to be addressed and possible areas of action.

Challenge	**Possible solution**
Basis risk.	Careful design of index insurance parameters. Selling via micro finance institutions that understand the risks.
Precise actuarial modelling.	Requires historical data and actuarial models. If no data is available then this is where weather generators come in useful.
Reinsurance – Without reinsurance correlated weather insurance is likely to fail.	Re-insurance. CAT-bonds (Skees, 2003)
Security and dissemination of measurements, the insurance ultimately depend on the objectivity and accuracy of the measurement.	Install tamper proof rainfall stations.
Education – Customers may not understand this new generation of products	Need some education to help customer assess whether it will benefit them or not.
Marketing – For the product to be successful it is critical to think carefully about how, when and where the insurance product will be sold, including marketing at a higher level i.e. reinsurance markets.	
Payment of the premium – Expecting the poor to pay a premium could be quite difficult.	It might be possible to address this via charity (Goes and Skees, 2003). For example charities are always ready to provide support after a disaster, so why not provide support before disasters occur. Or the premium could be purchased by the charity and the indemnity also administered by them. The premium could be included as part pf a micro-finance package.

(Source: Skees, 2003)

1.3.5. Basis risk

Basis risk is when the basis of the insurance instrument, in this case the weather index, does not accurately represent the risk when either the weather index does not trigger a payment when there has indeed been a loss or it triggers a payment when no serious loss has occurred. Basis risk is the greatest challenge weather-based insurance products face (Miranda and Vedenov, 2001; Skees, 2003; Skees *et al*., 2001; Turvey, 2001; World Bank, 2001). If customers think that the basis risk is too high, they will not buy the insurance (Skees *et al*., 2001).

Basis risk can be caused by the need to model incorporate complex heterogeneous systems within a single index. There are three sources of basis risk (Table 1-0)

Table 1-4 Three types of basis risk

Basis risk	Details	Solutions
Temporal risk	The level of impact of a weather phenomenon will vary according to the time at which it occurs during the crop cycle. E.g. a shortage of rainfall at just before maturity may kill a crop, whereas just after seedling may have little effect.	Indices that represent the temporal variability in sensitivity to rainfall deficit.
Spatial risk	A rainfall deficiency may occur at one location causing crop losses, but this rainfall deficiency did not occur at the recording location and so no payment is triggered.	Offset the risk by offering site-specific contracts that account for spatial variability.
Crop specific risk	A rainfall deficiency may kill a drought sensitive crop, whereas a drought resistant crop will survive through longer periods of drought.	Offset the risk by tailoring the insurance to specific crops.

(Source: World Bank, 2001)

In Nicaragua, at least one set of meteorological data in each department differed from the remainder, leading to the conclusion that a single index could not represent the spatially-variable risk within departments (World Bank, 2001). A short study by using simulated data for Honduras also revealed that the (proposed) single weather index was not appropriate for a country the size of Honduras (Díaz Nieto *et al.*, 2006*a*). Moreover, there were significant differences in rainfall over short distances.

Specialized instruments can be designed to take account of much of the temporal, spatial and crop-specific risk (Miranda and Vedenov, 2001), however doing so will likely increase administrative costs and more importantly increase the complexity of marketing and distributing a wide range of products. An alternative is to design a myriad of standard contracts and allow the insured to select the contract they consider most appropriate. Other challenges arising from basis risk are discussed below

Establishing the correlation between crop yield and rainfall index

The fundamental requirement of a rainfall index is that the rainfall pattern must explain a large proportion of the variation in yield of the crop under consideration (Skees, 2003; Skees *et al.*, 2001; Stoppa and Hess, 2003; Turvey, 2001;). Moreover it is essential to establish a cause and the effect relation (Turvey, 2001).

It is not sufficient to propose that a rainfall deficiency of 30% of the long-term mean will trigger payments. The indices developed must represent rainfall deficits at those critical times during the crop's development that account for crop losses. Defining those weather events that cause the most serious losses and covering defining the consequences of as many of the loss events as possible requires a considerable investment in research (Skees *et al.*, 2001). Furthermore it is of prime importance that both the insured and the insurer agree that the indexed weather variable adequately explains the variation in crop yields (Stoppa and Hess, 2003). Few customers would be inclined to purchase insurance that they did not perceive protected them against risk. On the other hand, no insurer would offer insurance that indemnified against non-risky events.

Limited availability of yield and climate data on which to base indices

In an effective weather-insurance instrument the weather variable must be easily measurable and adequate historical weather data must be available from which to estimate probabilities (Stoppa and Hess, 2003). Ignoring this fundamental requirement, many studies into the feasibility of using weather-based indices in developing countries have proposed indices based on relatively few data. Indeed, reliable data of sufficiently history are very limited in developing countries and this presents a major challenge It is noteworthy that those countries with poor infrastructure are those where an effective insurance product could have a large impact. The danger is that poor countries, which have greatest potential demand for insurance, are those that are excluded, precisely for reasons of poor infrastructure associated with poverty.

Fortunately a viable alternative approach is available, which we describe in more detail below and which we used to develop drought indices to provide the basis for insurance instruments for drybean producers in Nicaragua. Briefly, the approach uses statistical models to generate weather data, which are then used as input to and process-based crop-simulation models. The crop simulation models are based on hundreds of scientist-years of studies to understand the biochemistry, physiology and agronomy of crop growth and development. This procedure can be used to generate 'pseudo-historical' data of climate and yield. Where possible, any weather data that may be available for a specific site can be included (Díaz Nieto *et al.* 2006*b*).

<u>The pricing of weather-insurance contracts</u>

An actuarial challenge that arises from the various types of basis risk is that of equitable pricing of premiums. Turvey (2001) in particular has highlighted the importance of considering spatial variation. Many feasibility studies have also found that premium prices must vary from place to place (Hazell *et al*., 2000: Hess, 2003*a*). However a question that remains to be answered is how can premium prices be set across regions, especially in the face of a lack of appropriate historical records?

Turvey (2001) argued that pricing weather-insurance contracts based on the average weather of a large area would be foolish. Comparing three locations in Canada, Turvey (2001) found that pricing must be location specific, since the risks at each location are obviously different. Higher-risk areas require higher-cost premiums. However, in the Ontario context, setting site-specific prices requires further research into the use of triangulation of three of more weather stations to interpolate rainfall for more accurate estimation of actual rainfall for a particular site Turvey (2001). As a comment, this seems to be a rather archaic approach. A more modern method would be to fit a multi-dimensional surface to all the available weather data and interpolate on that surface using the GIS approaches that are now readily available. The recently-available WorldClim database (Hijmans *et al*., 2005) would be even more precise. It has a resolution of 30 arc seconds with a longitudinal dimension of about 1km and a latitudinal dimension of about half that at this latitude.

If the issue of site-specific premium rates is not addressed, then there is a risk of the product suffering from asymmetrical information, in which the insured have a better knowledge of which areas experience higher risk. This information asymmetry can only be resolved if the insurers have sufficient information to be able to assign premium rates properly (Skees, 2003). Another key limitation is the lack of a universal pricing method, which reduces market transparency and therefore increases the challenges involved in marketing the product (Stoppa and Hess, 2003)

Premium prices are based on estimates of the probability of future claims, so it is essential to know accurately what the probabilities are (Brown *et al.*, 2000). In respect of weather insurance it is essential that the insurance provider has sufficient information to be able to estimate the probability of the weather events accurately.

In the past, many micro-finance organizations have lacked the expertise to price products effectively, and this has often led to the failure of schemes. For example, found that the Indian crop insurance scheme referred to above was financially unviable due to the inappropriate pricing (Manojkumar *et al*., 2003). Many other crop insurance schemes have also been unsuccessful due to inappropriate pricing of premiums, which has led to indemnity payments far outweighing premiums collected (Skees *et al*., 1999), and the schemes' collapse.

<u>Probabilities change as the season approaches</u>

Farmers with limited resources may not be able to purchase insurance policies in advance of the season. Cutoff dates therefore to be flexible to the extent possible without incurring adverse risk. However, the way the season is likely to develop becomes clearer the closer it gets. This requires that the insurance premiums to be updated to reflect this. Information and communication technology have important roles to play in the development of effective weather-based indices (Stoppa and Hess, 2003). Insurance products can become increasingly sophisticated by using satellite technology. Indeed, as the accuracy of seasonal forecasting improves it will be a simple matter to use the technology to adjust premiums according to the forecasts. However, this may lead to information asymmetry where the insurer knows more about the approaching season that the farmers (Skees, 2003; Stoppa and Hess, 2003). Moreover, farmers may not understand how satellite imagery works and be deterred from buying a product based it. Furthermore the asymmetries implicit in seasonal forecasting may discourage potential buyers who fear they may be cheated by a technology that is not well understood even by well-educated people.

1.3.6. Reinsurance

Some risks, most notably drought, are highly correlated spatially, that is they affect broad regions. Primary insurers may not accumulate sufficient funds to cover the losses should a catastrophic event occur in the first few years after establishment. A higher-level safety mechanism, reinsurance, is required to protect primary insurers against events such as these. Miranda and Glauber (1997) go so far as to say that without reinsurance any private crop insurance scheme is doomed to fail.

<u>The case for involvement of global capital markets</u>

Most traditional insurance text books assert that catastrophic risk is uninsurable. Conversely Jaffee and Russell (1997) argue that sharing of catastrophic risk is viable if insurers take a long term view, which implies some form of reinsurance. Recent innovations in financial capital markets have introduced instruments that will provide a back stop for spatially-correlated weather-based insurance schemes (Miranda and Vedenov, 2001). Wenner and Arias (2003) defined this as risk securitization, that is bringing together capital markets and the re-insurance markets as a way of securing the risk involved. This is possible because weather risks are uncorrelated with global capital market fluctuations; capital markets provide more financial resources than is available in insurance markets and private capital reduce the cost of catastrophes to governments. The main technical challenge is to estimate premiums for-low frequency, high-intensity events.

There are a limited number of options that can be used to 'secure' a weather-based insurance. However Morduch (2001) points out that reinsurance also has its disadvantages, such as the global re-insurer may require the local insurer to conform to its political or social policies. From the point of view of the local insurer the premium for reinsurance must accurately reflect the risk; else it is merely a form of profit sharing. Global re-insurers are unlikely to be attracted by small local insurers, especially micro-insurers because of the additional administrative overhead.

1.3.7. Agent-partner model

If weather insurance is to reach the poor, it must do so in a micro form. Agent-partner models are widely advocated for this to be implemented successfully (Brown, 2001; Zupi, 2001). The model consists of an agent with strong links to customers and a partner whose role is the design of the insurance product and to provide the capital input. The agent is responsible for marketing and delivery of the insurance product. Micro-finance organizations (MFOs) are obvious agents because they have natural links with the target customers through existing micro-credit schemes.

One of the biggest challenges in setting up an agent-partner model for micro-insurance is that there are few national insurers willing to enter this market (Brown and Churchill, 1999). Therefore micro-insurance organizations (MIOs) need to highlight existing successful schemes in order to win over the interest. Pilot schemes such as the weather insurance proposed by Díaz Nieto *et al.* (2006*a*) are needed to illustrate to insurers that micro-insurance schemes can be viable.

National insurers are likely partners because of their experience in the design of contracts and their capability to provide capital for large payouts in the event of a co-variate risk event. Many micro-insurance institutions are too small to pool risk sufficiently (Brown *et al.*, 2000). Of the 32 institutions offering micro-insurance, Brown and Churchill (1999) found that the most successful were those operating in a partner-agent model. A major weakness therefore of many micro-insurance schemes is the lack of connection channels between companies providing the insurance and the existing micro-finance organizations (Zupi, 2001). One possibility would be for micro insurers to use national insurers in the role that they themselves use re-insurers.

National insurers have experience in actuarial analysis, underwriting and claims management, so that micro-finance institutions have much to gain from establishing partnerships with them. The national insurer is able to provide the initial capital, while the micro finance organization may is able to negotiate a commission based on sales of insurance. Finally the risk involved starting a new business is undertaken by the insurer (Brown *et al.*, 2000).

2. Case study: Weather insurance for drybean farmers in Nicaragua

2.1. Drybean production in north-central Nicaragua

Drybeans in Nicaragua are widely grown by small-holder farmers, who are usually amongst the poorest rural people. Drybeans were therefore selected as the crop for this pilot study since they offer the greatest scope for impact on rural poverty. Drybeans in Nicaragua are typically produced in small plots with little technological input. Many farmers in Central America produce drybeans for both consumption and to generate household income by selling part of the harvest (Mather *et al.*, 2003).

2.1.1. Where are drybeans produced?

Figure 2-1 Map of Nicaragua (Source: INETER, Nicaragua. http://www.ineter.gob.ni/Direcciones/Geodesia/SeccionMapas/MapaNicaraguaPolitico1.html).

Nicaragua has three geographical regions, the Pacific lowlands to the west, the north-central mountains and the Mosquito Coast facing the Caribbean in the east. The Pacific lowlands are a broad, hot, fertile plain that supports most of Nicaragua's population. The Mosquito Coast is hot, low-lying, humid and only sparsely populated. The north-central mountains are an upland region away from the Pacific lowlands with a cooler climate.

Although drybeans are an important staple and are grown in many regions of Nicaragua (Tapia and Garcia, 1983) the main drybean-producing departments are Matagalpa, Jinotega, Estelí and Nueva Segorvia (MAGFOR, 2001) in the north-central mountains. Most drybeans are produced on hilly to steep slopes (Quintana and Caceres, 1983).

San Dionisio, in Matagalpa Department is the baseline study site for CIAT-Nicaragua and is one of the major drybean producing areas of Nicaragua (Baltodano, 2001). At San Dionisio drybeans and maize are generally grown at the altitudes between 500 and 800 meters while coffee is grown above 800 meters. San Dionisio is a good example of where drybean crops are grown on steep slopes; 67% of the area has slopes greater than 30%.

2.1.2. When are drybeans produced

Nicaragua, as with many other parts of Central America, has a well-defined dry season from December to May and a rainy season from June to November. Because the potential for irrigation is very limited, rain fed agriculture during the rainy season dominates in Nicaragua. The rainy season is long enough to allow two successive crops to be grown known as the *primera* and *postrera*, separated by a short drought that usually occurs in July or August (Magaña *et al.*, 1999) called the *canicula*. Some favoured areas allow a third crop, termed the *apante*. The main characteriscs of these three crops are summarized in Table 2-0. Johnson and Klass (1999) report that in Honduras yields of drybeans are higher in the *postrera* crop, which can be expected to the case in Nicaragua as well.

Although the *primera* and *postrera* cropping periods are well defined, the onset of the rains is highly variable so that sowing date is of great importance. The farmer has to decide when the rainy season has begun and sow at this time to make the best use of both the *primera* and the *postrera* cropping periods. The farmer therefore generally waits for several rainfall events to indicate that the rainy season has definitely begun. These first few falls of rain are also crucial for recharging soil water in preparation for sowing.

Nevertheless the farmer does not want to wait too long for the appropriate rainfall, for doing so carries the risk that the mid-season drought may start before the crop has matured, or alternatively, planting too late may not permit a second (*postrera*) crop. Deciding when to sow is therefore a gamble with the weather. When the rainy season has not begun by the first or second week in May, many farmers take the risk and sow into dry soil in the hope of rain, because if they do not, the chance of growing a second crop diminishes rapidly. According to the reports of CRS micro-finance partners, most of their drybean customers plant both a *primera* and *postrera* crop, however a common crop sequence is a *primera* crop of maize followed by a *postrera* cop of drybeans.

2.1.3. Drybean varieties

The drybean varieties grown in Nicaragua are adapted to temperatures of between 17 and 24ºC (Quintana and Caceres, 1983). Many of the drybean varieties adopted in Central America have a life cycle of between 60 and 75 days. Excluding drybeans for exportation, Central American farmers generally prefer small- and medium-seeded drybeans of the black and red types (Voysest and Dessert, 1991).

2.1.4. Climate and drybean production

Temperature and solar radiation are the two factors that exert the greatest influence on drybean yields (Ríos and Quirós, 2002). However since temperature and solar radiation vary little during the growing season for any particular site in Nicaragua, it is rainfall that has the greatest climatic influence on drybean production. According to White (1985,

Table 2-1 Cropping periods for drybeans in Nicaragua.

Cropping period	Dates	Characteristics
Primera	Sow: May/June Harvest: July/August	This crop marks the beginning of the growing seasons. Farmers sow when soil-water levels are replenished and when they are sure of the onset of the rainy season. The aim is to harvest during the dry *canicula* in July/August.
Postrera	Sow: September Harvest: November	In many regions this is the main crop. Beans harvested in this crop season are typically of a higher quality as they are almost always harvested in a very dry period.
Apante	Sow: December Harvest: February/March	The *apante* crop is only possible in the northernmost mountainous regions in the direction of the Caribbean coast.

quoted by Ríos and Quirós, 2002) 60% of drybean crops in the developing world suffer from water shortage. Drybeans readily wilt when water is limited (White, 1985 quoted by Ríos and Quirós, 2002) while extended droughts, especially during flowering and grain fill, cause serious yield reductions (Stoker, 1974, Abarca *et al*., 1988 and White and Izquierdo, 1989, all three quoted by Ríos and Quiros, 2002; White and Izquierdo, 1991). Furthermore under stress conditions nitrogen fixation is reduced (Rios and Quiros, 2002). The optimum rainfall is between 300 and 400 mm while Jaramillo (1989 quoted by Rios and Quiros, 2002) found that the maximum yields were obtained with 400mm precipitation distributed according to the water requirements of the crop.

The timing of any water stress determines the impact of the stress and the final yield (White, 1985; White and Izquierdo, 1989; Abarca *et al*., 1988; Stroker, 1974 all quoted by Ríos and Quirós, 2002). Therefore the index developed for identifying low yields based on weather patterns, and thus for triggering insurance payments, should place great emphasis on the timing of rainfall.

2.1.5. Soils

For maximum yields, drybeans require well-drained, deep, fertile soils that have no compacted layers in the profile to restrict root development. Drybeans grow best in loamy soils, although they also grow well in slightly heavier silty soils. Best soil textures range from silty loams, slightly sandy to loamy clays (Quintana and Caceres, 1983; Rios and Quiros, 2002). Many of Nicaragua’s soils are volcanic in origin (Quintana and Caceres, 1983) with clay laoms and clays the predominant soil textures in Matagalpa, Estelí and Jinotega departments (MAGFOR, 2001). Although these are not the ideal soils for drybean crops, they are nevertheless satisfactory. Other soils in these regions include heavy clays and sandy loams. According to the FAO soil classification the predominant soils in the drybean-producing areas are dystric cambisols, followed in order by dystric nitosols and orthic acrisols. Many of these soils are indeed characterized by a clay horizon.

2.2. Rural micro finance in Nicaragua

Catholic Relief Services (CRS) works in partnership with several micro-finance organizations[4] (MFOs). CRS lends funds to MFOs at very low interest rates. Other activities that link CRS to many of the MFO partners are crop storage and crop commercialization activities. At the moment CRS (and its MFO partners) and CIAT have very strong links in Nicaragua through the learning alliances network. Briefly the learning alliance network is a global initiative that seeks to advance learning processes jointly between development organizations, researchers, international aid agencies, state institutions and private industry. The objective is to help growth of rural industry, improve research and promote sound policies that contribute to optimize the quality of life or rural populations in developing countries (see www.alianzasdeaprendizaje.org). The links with the MFOs for the present study arose from the learning alliances network.

An initial meeting was held between CIAT, CRS and MFO partners to discuss interest in a weather insurance tool. The discussions with the MFO partners revealed that although their agricultural customers are involved with a wide range of crops, they saw the greatest potential for weather micro-insurance with drybeans, which is a crop that is widely grown by small-holder farmers. Other crops that could benefit from weather insurance were potatoes and vegetables such as tomatoes and lettuce. CRS partners stated that for a drybean weather insurance to have the greatest impact it would need to cover both rainfall deficiencies and rainfall excesses since both cause low yields. As a general rule low rainfall is the predominant problem in the *primera* crop and excess rainfall is a problem in the *postrera* crop.

Several more discussions were held with representatives from the CRS MFO partners, in November 2004 in Managua with all of them, and in mid-2005 individual meetings with many of them. The aim of the discussions was to confirm the need for insurance coverage against weather risk and also to define the operational aspects of providing credit to drybean farmers. This section and the following sub-sections are based on those discussions.

Through the learning alliances network, CIAT and CRS are analyzing drybean market chain. Since the current project is also focused on drybean farmers, the interview and farmer workshops (described below) were organized and carried with strong support from the learning alliances network. These efforts are focused on the northern Nicaragua drybean-producing areas in three departments; Matagalpa, Estelí and Jinotega. Many of the MFO partners are part of larger networks, for example FIDER or CARITAS. The following sub-sections describe the micro-finance environment.

2.2.1. Characteristics of loans

Traditionally, MFO's have only offered credit to groups of farmers, but group credit is now seen as an outdated concept and credit is increasingly being offered to individual farmers. However, FIDER-Estelí's portfolio is still 80% group credit and only 20% for individuals. The costs that farmers pay for credit are made up of fees specific to each

[4] Essentially a synonym for micro finance *institutes*. See footnote [1] on page vii.

MFO (CARITAS-Estelí (2005) levies an 8% payout charge) plus interest, the rate of which is set by the Central Bank of Nicaragua.

2.2.2. Access to loans – who qualifies?

Most of the rural loan portfolio in Nicaragua goes to farmers growing high-value crops such as vegetables under irrigation. Drybean farmers receive very little of it because the MFOs (apart from Aldea Global) have not regarded drybeans as a cash crop but a low tech staple for home consumption. MFO's have also regarded drybeans as unacceptably risky because they are rain fed and moreover drybean growers are small-holders that are widely dispersed, so increasing transaction costs. Fortunately these perceptions are starting to change.

External funders of MFOs such as the DAP project and CRS formerly did not permit them to make loans to drybean farmers. External funders have now lifted their restriction due in part to buoyant prices for drybeans, which seem to be sustainable. MFOs only loaned 50% of production costs when they relied on their own internal resources; they now lend 100% with external support. CRS provides support in the form of certified seed, storage and commercialization support in the wider drybean market.

The basic prerequisite to qualify for a loan is that the farmers must live and work on a permanent basis in the community. Farmers must then show that the economic activity for which the loan in made should generate income and they must organize themselves into a credit group of three, four or five (i.e. it is group-based credit). Once the basic requirements are met, the credit group must provide a credit guarantee in the form of livestock or property or a person who will act as guarantor. If the farmers cannot provide an acceptable credit guarantee (usually for twice the value of the loan), credit is denied.

Once the credit guarantee is accepted, the next step is a farm inspection on which a decision is made to approve or deny credit. The inspector, usually an agronomist, assesses what possibilities the farmer has for irrigation. Often credit will be denied if irrigation is not possible. In a drought-prone area such as Estelí, access to a source of water, even if very basic, is essential to qualify for credit for any crop (CARITAS-Estelí, 2005).

Preference is also given to farmers who produce a variety of crops. Even if the primary loan is to grow drybeans, most MFOs require some form of diversification as a safety net. However in drier regions, such as Estelí, only about 20% of farmers can grow crops other than drybeans because it is too dry for vegetable production. The remainder will at most have livestock, which may qualify as diversification.

Approximately 70% of the farmers that approached FIDER-Estelí (2005) seeking credit for agricultural production were approved. Thirty percent of applicants were denied credit most commonly because their credit guarantee was not acceptable. Of the MFOs surveyed, FIDER-Estelí (2005) offers the largest proportion of its credit portfolio (10%) to drybean producers. Of this 10%, approximately 60% are small scale producers with 2 or 3 *manzanas*[5] for production. CARITAS-Estelí (2005) offers about 65% of their loan portfolio to agricultural credit and of this only 2% is for drybean production. However for the year 2006, of the total amount that CARITAS-Estelí (2005) manages (approx US$55,000) US$5683 is projected for credit to drybean producers, a huge increase. Only 5 - 7% of FIDER-Jinotega's (2005) total loan portfolio was for drybean production, made up some 48 farmers and 110 *manzanas*. Agricultural micro-finance accounts for 75% of the total loan portfolio in Jinotega and is mostly for vegetable production.

2.2.3. Defaults

MFOs gave the following reasons for farmers defaulting on their loans:

- Farmers were provided with seeds unsuitable for their environmental conditions,
- Lack of fertilizer,
- Inadequate crop management,
- Unexpected climatic conditions, and
- Variations in market prices.

Many of the MFOs commented that climatic risk was not the main reason for farmers defaulting on loans since most of the farmers they currently lend to have some form of irrigation. The possibility to extend credit to non-irrigated producers was seen by the MFOs as a possibility if their loans were covered by insurance. This is discussed briefly later in Section 7.1.2. FIDER-Jinotega (2005) commented that in a year when drybean prices fell drastically, only 2 of the 30 drybean producers with loans made their repayments on time.

When a farmer is unable to make payments, the MFO usually gives an extension and restructures the loan. Although CRS and other funding bodies recommend against giving extensions, the MFOs often have no option, especially if the reason for the default is beyond the farmer's control, such as adverse weather or market variations. The longest extensions granted were for 2 or 3 growing periods and in very extreme cases 5.

MFOs invest considerable time and effort in monitoring crop production and use this information to determine whether a farmer qualifies for loan restructuring. MFOs will usually lend again to a farmer who defaults once provided the reason for default was beyond the farmer's control. When loan restructuring fails, the MFOs have no option but to call the credit guarantees. Loan restructuring is costly for MFOs; although they still charge interest on the outstanding amount, turnover of funds is slow.

2.3. Exposure of small-holder drybean farmers to weather risk and its impacts

2.3.1. What do farmers think about weather risk

Farmers' workshops were held in May and June, 2005 in four contrasting regions. Using a proportional piling methodology, farmers were asked to rank production risks that cause greatest yield losses. Briefly, each possibility is identified as a cell on a large piece of paper laid flat on a table. The farmers are given the same number of objects (beans in this case) and asked to place them in the cells in accordance with their agreement (or not)

[5] 1 *manzana* = 1.73 acres or 7000m^2

with the available options. The number of objects in each cell indicate participants' preferences. The results varied considerably between workshops, so the subsequent discussion is divided according to the four regions.

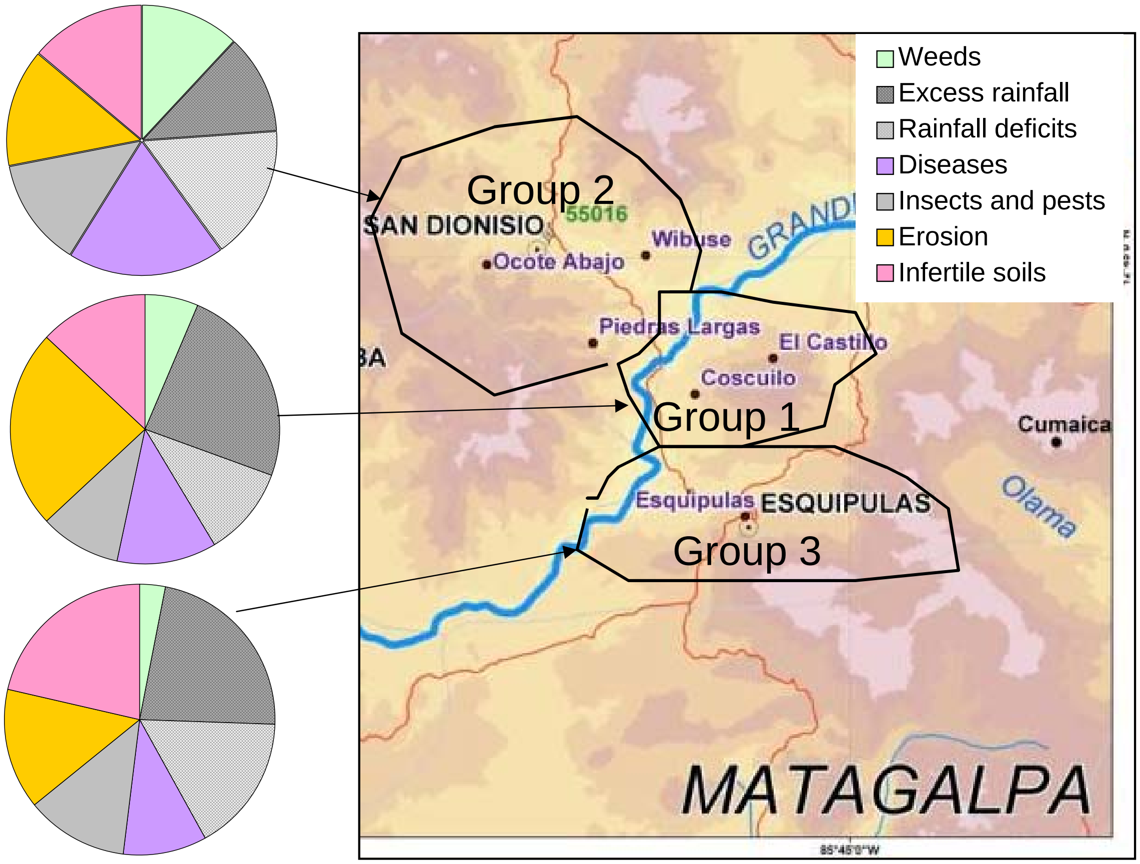


Figure 2-2 Results of the proportional piling exercise for each group in Matagalpa.

Matagalpa

In general the region has a mild and semi-humid climate, which makes it suitable for coffee production. Farmers in El Castillo, and Coscuilo and Esquipulas considered excess rainfall as their most significant risk followed by erosion caused by high rainfall intensity (Figure 2-0). Rainfall deficits were not a high priority.

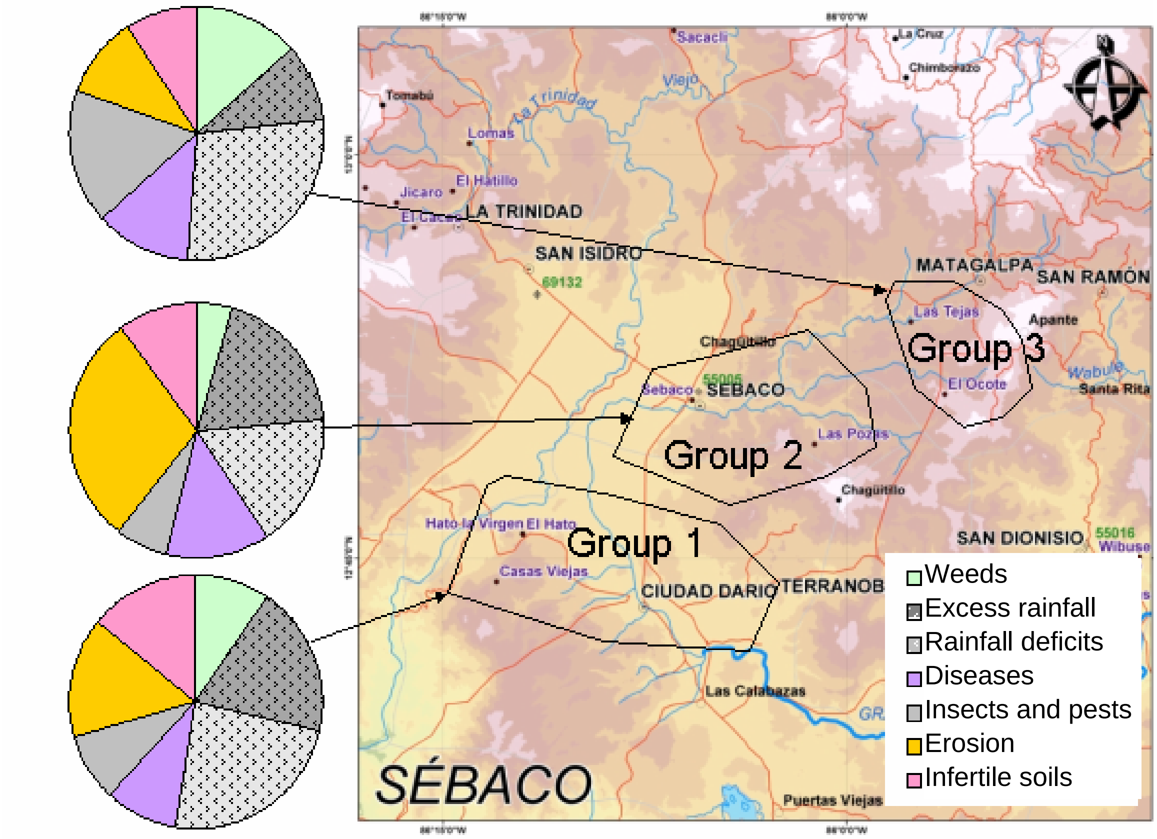


Figure 2-3 Results of the proportional piling exercise for each group in Sébaco.

Table 2-2 Answers given by producers at Sébaco.

	Adequate rainfall	Lack of rainfall	Excess rainfall
Group 1	Double production areas. Request larger loans.	Sow fewer seeds, request small or no credit amounts,	Sow in high areas. Request small credit amount.
Group 2	Sow sufficient seed quantity for a good harvest. Sow high quality seed. Apply good management to crops. Request credit.	Sow a small amount of seed, sow in areas likely to give a harvest, and do not request credit.	No sowing that season or look for highland areas.
Group 3	Doubling crop production area, requesting credit and technical assistance, sowing certified seed.	Sow a small quantity of seed. Ask for a small loan	Look for arid areas in which to sow. Sow on the slopes.

Sébaco

Groups 1 and 3 attributed greater yield reductions to rainfall deficits, followed by excess rainfall. Group 2 attributed the largest proportion of yield reduction due to soil erosion (Figure 2-0)

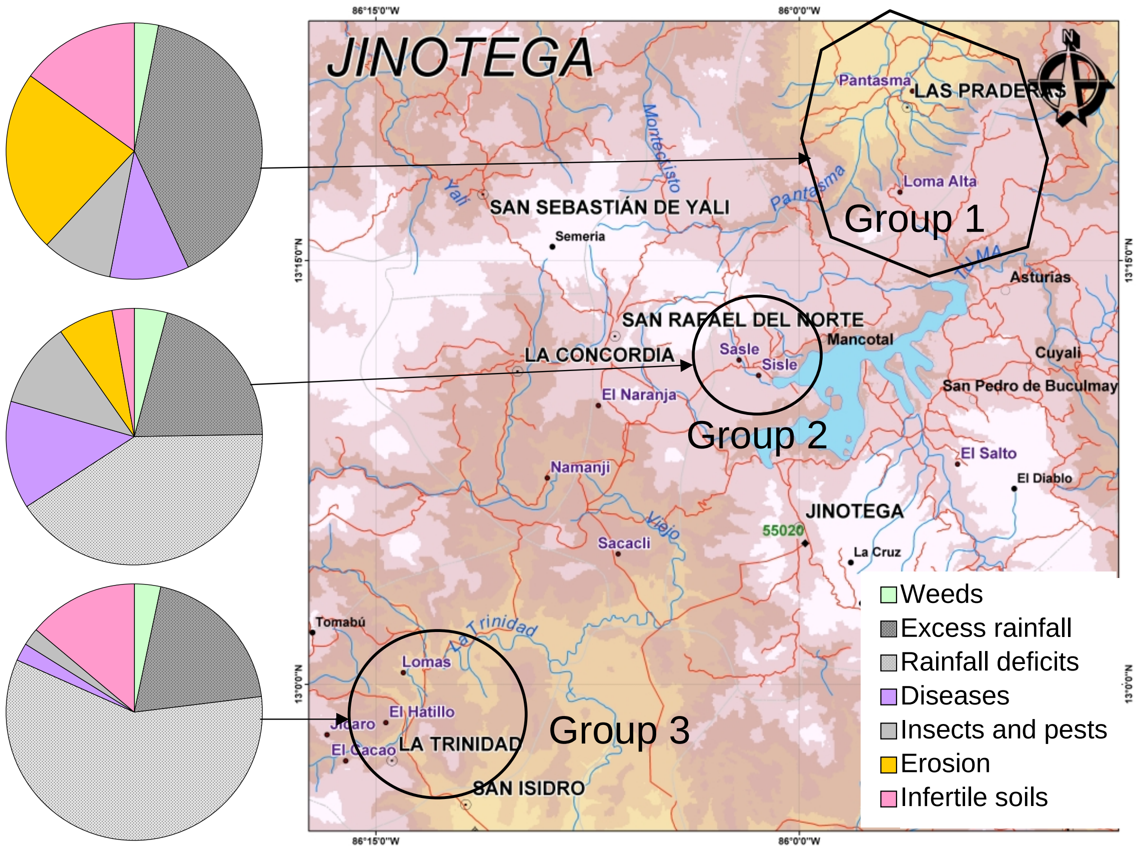


Figure 2-4 Results of the proportional piling exercise for each group at Jinotega.

Table 2-3 Answers given by producers at Jinotega.

	Strategies used to deal with climatic variation	How would your strategies change?
Group 1	Sow other crops such as maize that are more resistant to rainfall deficits. This reduces costs as less family manual labour is required. Create reservoirs, drainage systems. Least cost investment. Small production area.	Increase production areas. Sow higher yielding varieties. Crop diversification. Soil management and conservation. Higher investment.
Group 2	In the *primera* period sow on the hillsides with minimal investment. Plant associated crops. Use resistant varieties with higher cost. Soil management. Drainage techniques.	Use appropriate technology with a higher cost. Irrigation systems. Crop diversification (crop rotation, associated crops). Introduce improved varieties. Sow more vegetable crops.
Group 3	Soil conservation. Short growing season varieties. Foliage in dry period. Fertilize on sowing. Sow on fertile soil. Level sowing. Plowing soil before rainy season. Low plant density.	Increase production – higher seed population and over greater area. Sow high yielding varieties. Crop diversifitacion. Greater investment in the crop.

Jinotega

There are three local climates in Jinotega; dry, semi-dry and humid. Groups 2 and 3 associated rainfall deficits with the largest proportion of yield losses. Group 1, from the humid zone, did not attribute rainfall deficits as responsible for any yield reductions, however rainfall excess, closely followed by soil erosion, which leads to loss of soil fertility were said to be responsible for over 60% of the yield reductions (Figure 2-0).

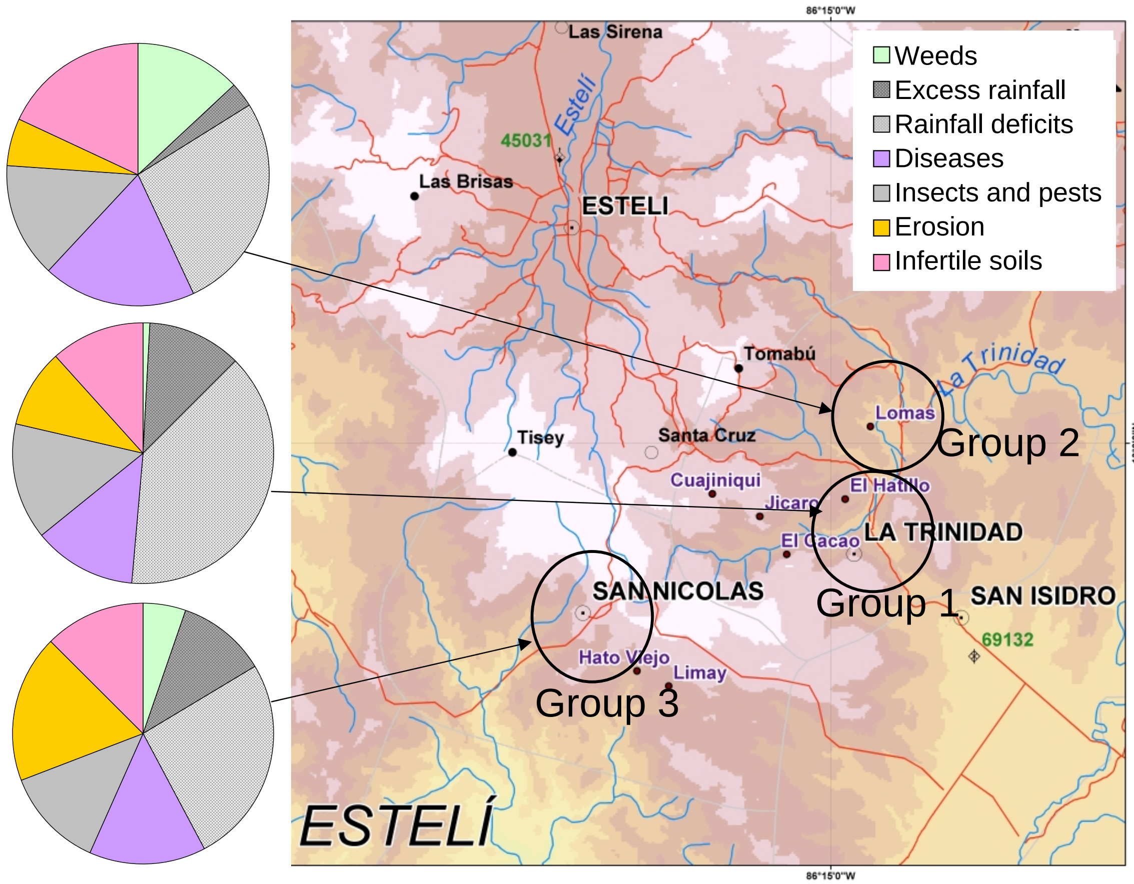


Figure 2-5 Results of the proportional piling exercise for each group at Estelí.

Estelí

This region is characterized as being extremely dry. Rainfall deficits were found to be the main productive risk encountered. In all cases more than 25% of drybean yield losses are attributed to lack of rainfall, and in group 1 this was found to be 40% (Figure 2-0).

2.3.2. Coping strategies

The objective of the farmers' workshops was to establish the coping strategies farmers use to deal with climatic risk. Table 2-0, Table 2-0 and Table 2-0 are summaries of the answers they gave. Frequent responses when asked about coping strategies include a reduction in the production area, reduction in all sorts of costs such as fertilizer, manual labor and seed costs, selecting where to sow based on the expected weather and crop diversification (staple crops). We also sought to determine how the presence of risk affects behavior. To get some notion of this, we asked farmers how their strategies would change, or what would they do differently if they had complete certainty that there would be adequate rainfall in every crop period. The most common replies included an increase in the production area and plant population, use of improved and certified seed, request for larger loans, crop diversification to high value crops and in general an increase in investment.

Table 2-4 Answers given by producers at Estelí.

	Strategies used to deal with climatic variation	**How would your strategies change?**
Group 1	Pray, group 1 is located in a semi high zone and they suffer due to excess rainfall, in the *postrera* period they use less fertilizer and reduce the production area, in the *primera* period they produce as much as they can and invest as much as possible, in the *postrera* period they reduce costs by reducing the area, using less fertilizer, less manual labour. Before Hurricane Mitch they used to invest equal amounts in the *primera* and *postrera* periods.	Sow longer growing varieties in order to have higher yields, sow greater quantities in the postrera season, invest more in fertilizer and foliage sprays.
Group 2	Reduce fertilization costs, use resistant seeds, avoid buying improved seeds, investment in production principally for home consumption, diversification with livestock and vegetable crops	Increase costs, buy improved seeds, apply fertilizer, increase production area, look into producing other crops, request loans.
Group 3	Keep up to date with weather forecasts, soil conservation, use of drought or excess rainfall resistant seeds, monitoring for the need to apply fungicides, be prepared with covers to protect the beans, daily observation of the crop.	Use appropriate soils, team work, work on soil conservation, organic agriculture, sow certified seed, adequate drainage.

These producers are risk averse; most of the strategies they use to cope with climatic risk result in reduced investment. The most common response of reducing the production area implies a reduction of actual costs and labour input. Their response to lessened risk was to make greater investment, most commonly by increasing the area of production.

3

3. Considerations for developing rainfall insurance for drybean farmers in Nicaragua

3.1. Technical considerations for the design of an effective weather insurance scheme

A weather-insurance scheme should ideally take account of the following technical/scientific details:

3.1.1. The payout index must be highly correlated with yield loss

In a weather-insurance scheme it is not the actual crop loss that is insured, but the loss-causing event, which in the case of drought is a specified adverse-weather event. Thus the way in which the relationship between weather and crop losses is expressed in an insurance index needs to be carefully thought out and appropriately designed. Farmers will be interested in a weather-insurance scheme that is highly likely to pay out when they do indeed suffer loss of crop yield. Ideally, the relationship between weather and crop yield is based on long historical records of both data sets. In the case of Nicaragua and drybean yields however, data are very scarce. It was therefore necessary to develop methodology that allowed the relation to be established in the absence of actual weather and yield data. This methodology development is discussed in detail later in this report.

3.1.2. Payable index

Several series of crop simulation models exist which can be used to simulate crop yield (see, for example, Jones *et al.*, 2003). These models synthesize many hundreds of scientist-years of research to understand the biochemistry, physiology and agronomy of growth and development of crop plants. Climate variables are the key drivers of these models. In principle, such models could be used to determine whether farmers receive an indemnity or not, by inputting the current weather data as they become available for a particular site into the appropriate crop model. Although scientifically sound, this approach is unlikely to be thought transparent by either the insured or the insurer. The requirement of a weather index simply means that a complex relationship between one climatic variable, such as rainfall in the case of drought, and crop yield must be converted into a simple index. Moreover, the index must be easily understood by all parties so that the trigger event for an indemnity payment is clearly defined.

3.1.3. Temporal specificity

In the case of rainfall insurance, it is not only the quantity of rainfall during the growing season that affects crop yield, but the combined effect of the timing and quantity of rainfall. It is a well-known that crops are more sensitive to water deficits at certain critical stages of their development, particularly during flowering and pod fill. A payment index therefore must take the temporal rainfall requirements of the crop into account.

3.1.4. Soil specific

The effectiveness of rainfall is strongly influenced by soil characteristics. In soils that have low water-storage capacity, the impact of rainfall shortages will be felt much sooner than in the case of soils with high water-storage capacity. This is a key factor that needs to be taken into account in an effective insurance scheme. Conversely, when soils are dry, small falls of rain can be more effective on sandy soils compared with clay soils, which require more water to "wet up". Soil texture, soil depth and water-holding capacity are key factors to take into account in designing an effective insurance scheme. Farmers growing crops on very risky soils will be in need of an indemnity payment more often than farmers on less risky soils, which must be reflected in both a soil-specific payout structure and in the cost of the insurance coverage.

3.1.5. Cultivar specific

Rainfall requirements will also vary greatly from crop to crop and within the same crop depending on the cultivar. Drought-tolerant varieties will naturally withstand rainfall deficits more successfully than drought-sensitive varieties. Therefore in order to increase the relationship between the rainfall weather index and crop losses, the rainfall indices should be tailored specifically to the crop variety.

The implications of this for modeling are that the genetic coefficients must be known for the cultivar or cultivars in question. Ideally these should be the outcome of carefully-designed experiments. Nevertheless, it is possible to make some informed guesses as to what the coefficients should be, based on phenological data from different latitudes for the cultivar in question. But the guessing should only be undertaken by experts with a clear understanding of how the particular model represents physiological factors such as photoperiod response and the thermoregulation of plant development.

3.1.6. Planting date

In rain-fed agriculture, which is implicit in designing a drought index, sowing date varies from season to season depending on the onset of rain at the start of the growing season. Since weather insurance schemes will be sold in advance when there is no information about what the weather will be, a transparent system is needed that incorporates variable planting dates into the insurance products. Both insurer and insured will need to know the exact start and end dates within which the observed rainfall will be taken into account for determining indemnity payments. To maximize the effectiveness of the insurance product, the method used to establish the sowing date used in the product must reflect the actual planting date as closely as possible.

3.1.7. Site specificity

Weather risk varies significantly in space. To reflect this spatial variation of risk in the premium; methods to estimate it in risk evaluation are needed so that the insured pays the price of the risk they actually confront.

3.1.8. Accurate estimation of payment probabilities

Insurance companies will need to know how often they will be paying out indemnities based on each of the weather stations they are using as a reference for payments. In some cases these weather stations will not have the necessary historical data to determine the probabilities required. A method therefore needs to be established that will enable accurate estimation of event probability at points where the historical data are inadequate or lacking.

3.2. Non-technical considerations for the design of effective weather insurance.

The positive impact that weather insurance is expected to have on farmer livelihoods is one of the main drivers for the development of these tools. It is therefore important to consider some of the factors that will determine their effectiveness to alleviate poverty. It is also opportune to consider briefly some financial and administrative aspects that are important to the success and acceptability of an index-based scheme.

3.2.1. Need for a reliable rainfall station network.

An adequate network of pluviometers (devices to measure rainfall) is needed. These should be part of a network adequately distributed spatially to allow farmers to select a weather station that best represents the weather of their farm. A sparse network will not adequately serve farmers located a substantial distance from the pluviometer. Although recording pluviometers are now much cheaper and reliable than they were some years ago, there are a number of considerations to take into account. Provisions need to be made to provide maintenance of the pluviometers, particularly their calibration and the integrity of the data, and the procedures to be followed when there are disputes over the data or when a pluviometer fails.

3.2.2. Corruption-free, transparent scheme.

Although many of the types of corruption that occurred in traditional insurance schemes cannot occur in weather-index schemes, possibilities still remain. Tampering with weather stations or weather station data is always a possibility. Measures need to be put in place to prevent physical tampering. Data tampering can be made less likely by making the data freely available to all interested parties as quickly as possible, preferably daily. Another option is to use statistical relationships between the data from different locations to flag anomalies. It may be prudent that a disinterested third party be charged with overseeing data collection, verification and quality control. The cost should be factored into the premium structure.

3.2.3. A product adapted to small-holder farmers' needs.

Income is highly variable throughout the year for poor rural customers. For this reason, they will find it difficult to pay an insurance premium at the same time as investing in planting, compared with when they sell their crops at harvest. Cut-off dates for sale of policies must be flexible enough to accommodate these patterns of rural incomes (Cohen and Sebstad, 2003). Manojkumar *et al*. (2003) found that poor people were able to pay the premium, but not in the early stages of the cropping season when their limited resources were committed to planting. Furthermore Indian farmers were reluctant to pay a premium out of their own limited resources. Therefore linking insurance to a credit facility may be inevitable for success (Manojkumar *et al*., 2003; Ahuja and Jütting, 2004). Nevertheless there still should be provision for farmers who do not require credit to buy the insurance.

3.2.4. Communication and training

Clearly the field officers and the administrators of the institutions offering the insurance require adequate training. Sales representatives particularly need adequate training for marketing insurance and communicating to communities about insurance. But the farmers also need to understand the concepts and some of the technical aspects of insurance. If they do not, their lack of knowledge can be a serious obstacle to expanding micro-insurance (Cohen and Sebstad, 2003). Cohen and Sebstad (2003) cite some examples from east Africa, that show that much distrust by micro-insurance customers was caused by communication failures:

- Some FINCA-Uganda non-subscribers did not join Microcare because they, 'had heard that even if a cycle was completed without falling sick, one was not given a refund of the money and it was not carried forward.' *(Sebageni, 2002 in Cohen and Sebstad, 2003).*
- A lady in one of Nairobi's poorer districts insured her business against fire, paid premiums of 600 Kenyan shillings per month for two years and then, "All that money! I stopped." Many people are not sure they are getting value for money if "the risk does not happen" *(Millinga, 2002 in Cohen and Sebstad, 2003)*

Key to addressing this issue is for the MFO to assign adequate staff training, materials, knowledge and time required to sell to and communicate with clients.

4. Methodology for designing a payout index based on rainfall: converting the relationship between yield and rainfall into a payable index

An effective weather-index insurance scheme will pay an indemnity when an event occurs that causes low yields. This requires that the complex relationship between rainfall and yield needs to be converted into a simple index. One possibility is to synthesize the published data of crop water requirement and irrigation budgets and corresponding crop yields. Unfortunately these data are available for only a limited number of crops and rarely for the tropics. An alternative would be to use expert consultation, that is, seeking the informed opinion of scientists and farmers regarding the rainfall patterns that cause low yields. This method can work, but it lacks rigor.

Here we describe an objective methodology to determine the relation between precipitation patterns and yield in drybeans. The primary objective was to develop a weather index on which to base insurance for poor small-holder farmers. Since many poor countries have few observed data, the method had to be independent of data. The only way to do this is to generate simulated weather data and use these as input to a crop simulation model.

4.1. Precipitation data: MarkSim

MarkSim is a weather-generation tool specifically to generate data of tropical weather (Jones *et al*., 2002). MarkSim simulates rainfall and temperature data for any point in the tropics at a resolution of 10 arc minutes (about 17km*18km in the Central American region). For any particular pixel, MarkSim interpolates on a multi-dimensional surface of weather data from stations (about 10,000 in Latin America, Jones *et al.*, 2002) with long data runs ranging from 14 to 100 years (Jones and Thornton; 1999, 2000). It then applies a third order Markov model to the monthly mean data derived from the interpolation to generate daily data for maximum and minimum temperature, rainfall and solar radiation. MarkSim generates data for up to 99 years for any one run. Each run for the same pixel with the same random number seed is identical. Although the random number seed is four digits, the internal procedures only use odd numbers. Thus for any particular pixel one can generate a total of 4999*99 or almost 500,000 years' data.

Ninety nine years' data were generated for 153 cells in north-central Nicaragua using MarkSim. The nomenclature of these cells is shown in Figure 4-0. Weather data were generated using the default elevation for each cell and this was taken as the modal elevation (Figure 4-0). A total of 15 147 (99 years x 153 cells) weather files were generated, each containing daily values of solar radiation, maximum and minimum temperature and precipitation for the year. The cells NIGS, NIDV, NIDT, NIDS and NIBS (Figure 4-0) contain parts of the Matagalpa, Sebaco, Jinotega and Estelí municipalities described earlier, but were selected to cover the broadest range possible of altitudes.

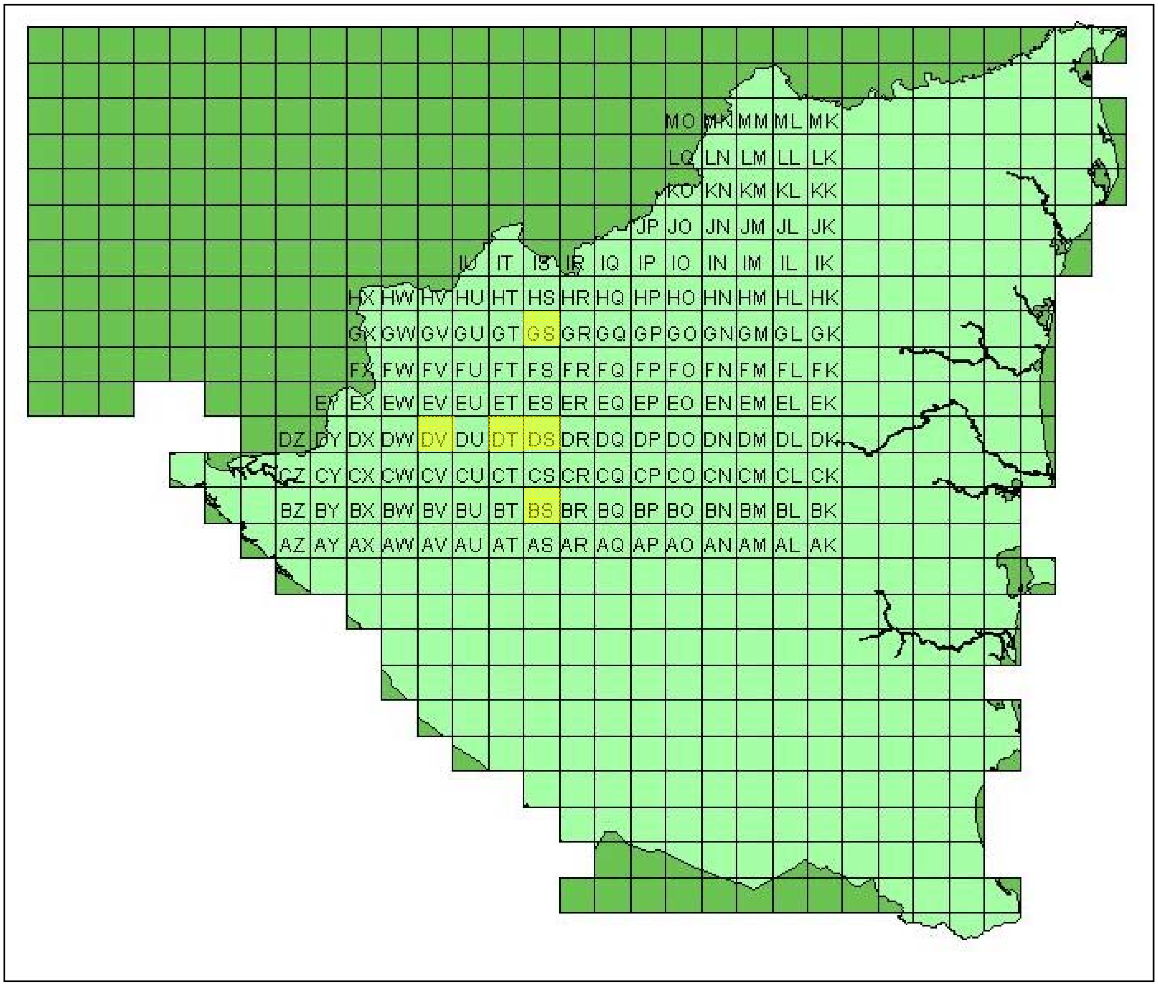


Figure 4-1 Two letter codes of each pixel used to identify the generated weather data.

4.2. Yield data: DSSAT

The MarkSim data for each pixel were used as input to the Decision Support System for Agrotechnology Transfer (DSSAT) drybean model (White *et al.*, 1995). This gave 99 years' data of climate and yield for each of the 153 cells. DSSAT also requires that the soil and crop genetic coefficients be specified. We chose four generic soils, sand, sandy loam, silty loam and silty clay, whose data are included in the DSSAT package. We used the data for the soil profiles modified to reflect the shallow soils typical of Nicaragua and also both sloping and flat land (Appendix 1), for a total of 8 soil combinations. In all cases we allowed the DSSAT procedure SOIL BUILD to generate the coefficients for surface runoff coefficient according to the US Soil Conservation Service tables. We used the same slope (30°) for each soil.

Two cultivars, typical of the drybeans grown in Nicaragua, were selected from those whose genetic coefficients are provided in DSSAT; Rabia de Gato and Bat477 (Appendix 2). The latter is slightly more drought tolerant, but matures ten days later. Other inputs

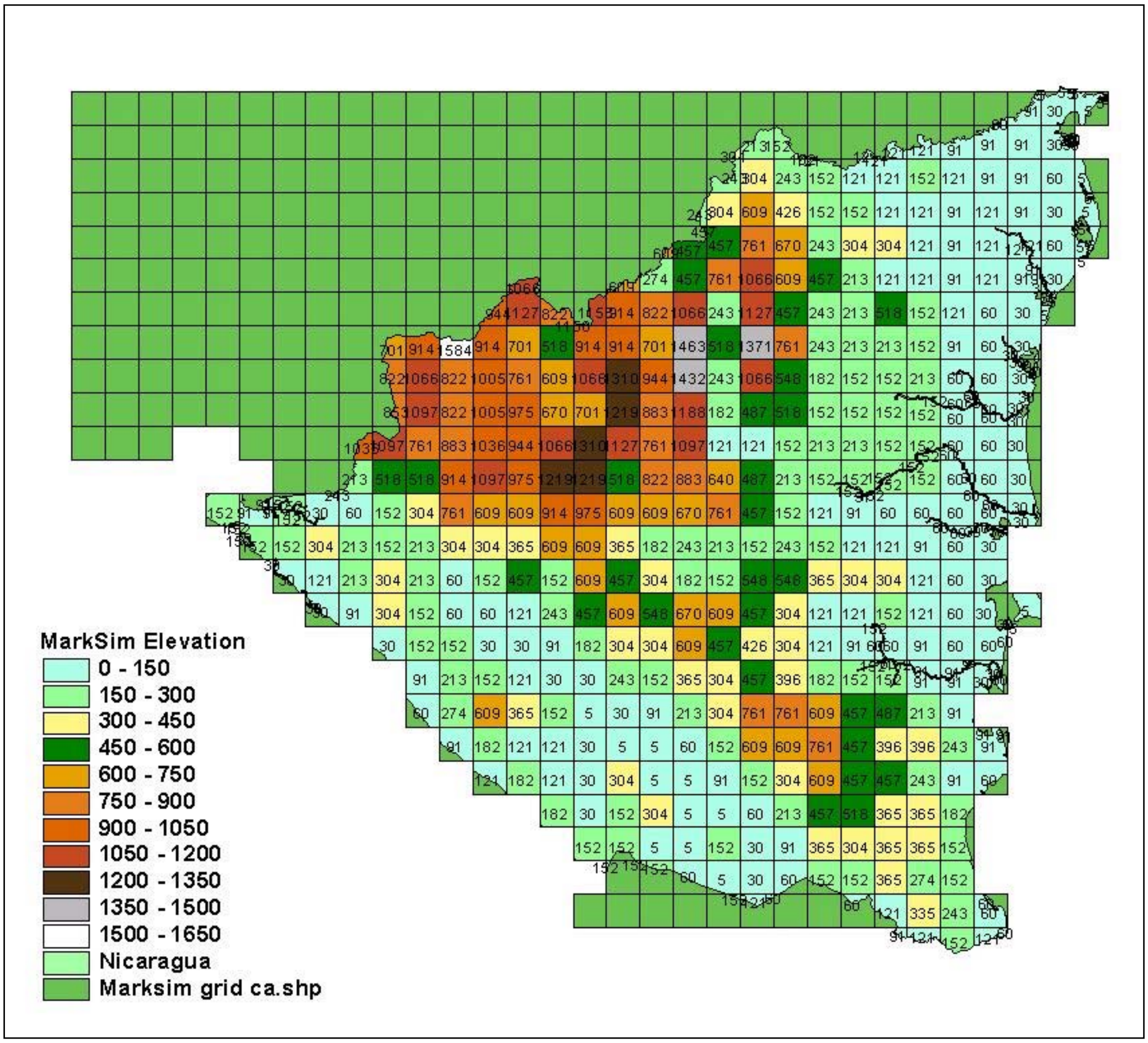


Figure 4-2 Default elevation used in the MarkSim simulations.

and options needed to run the DSSAT drybean model are in given in Appendix 1. For each of the 153 pixels there were then 2 cultivars *x* 4 soil types *x* 2 topographies. We simulated each of these combinations for 99 years. From here on, we shall call these 99 years' simulation data for each of the 16 combinations a "run"[6].

4.3. Identifying precipitation needs

For each simulation we divided the growing season into 10-day blocks, which for simplicity we shall call a dekad[7]. Following some exploratory work, we decided to use rainfall deficits. Within each run we established the minimum water requirement (MWR, as rainfall) for each dekad below which there was a yield reduction. Since rainfall

[6] The term "run" is not entirely arbitrary because MarkSim generates 99 years' data in one operation and we ran the DSSAT drybean model to use these data in batch mode.

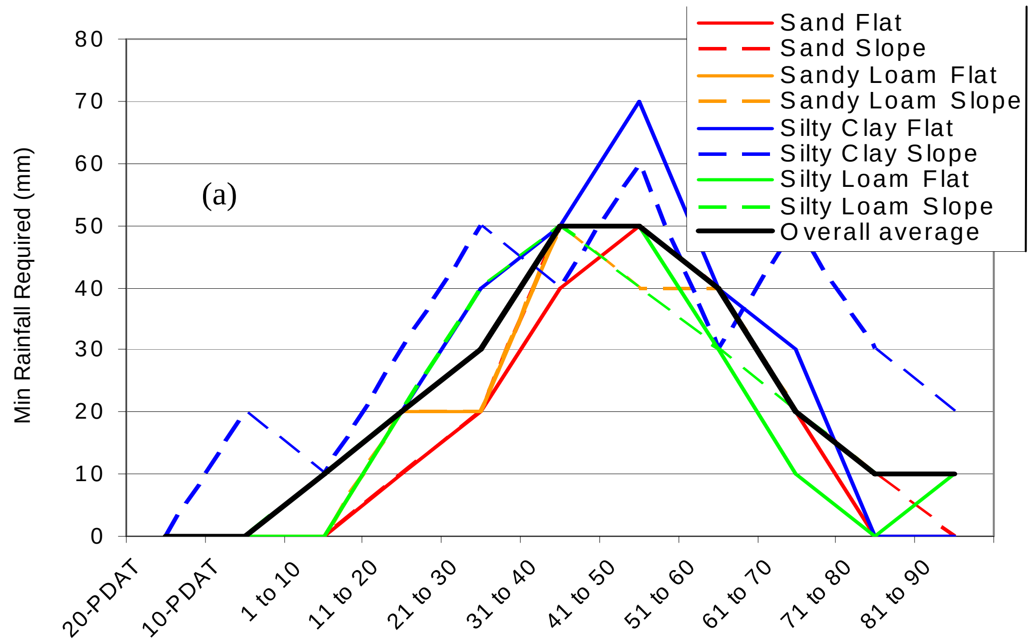
[7] Decade is commonly used to refer to periods of ten years so we coined the word "dekad" to refer to periods of 10 days.

requirements vary considerably with soil texture, MWRs were established for each of the soil by topography combinations.

The procedure we used was as follows: we estimated plausible values for the MWR for each dekad. We subtracted these MWRs from the observed rainfall for each dekad to calculate deficits, that is, we ignored positive values. The total rainfall deficit for the growing period is therefore the sum of all the deficits.

We selected the lowest quartile of each run and calculated total rainfall deficits from day -10 to day +70 for each simulation within this subset. We then calculated the correlation coefficient for the regression of total deficit on crop yield. We optimized the estimates of MWR for each dekad to maximize the correlation coefficient using the Solver procedure of Excel with the constraint that MWR for each dekad ≥ 0. The upper and middle quartiles of yield have rainfall deficits of zero, and therefore were not relevant to establish MWRs.

This method was applied to each of the study cells and within each to each soil topography combination. In each cell the procedure gave only slightly different values. The results for each soil by topography combination were therefore averaged over all the cells (Figure 4-0).



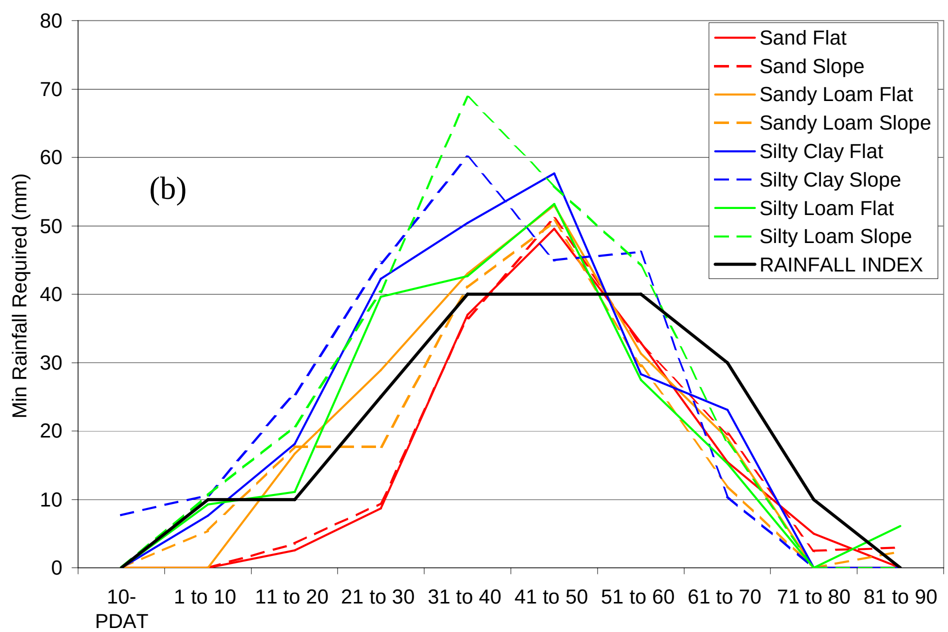


Figure 4-3 Averaged results of the algorithm: minimum rainfall requirements for (a) the *primera* and (b) the *postrera* cropping periods.

The highest rainfall requirements are between days 30 and 50, which correspond to the flowering period. Other general points are:

- Bat477 has later peak water requirement compared with Rabia de Gato. It flowers later because it matures ten days later.

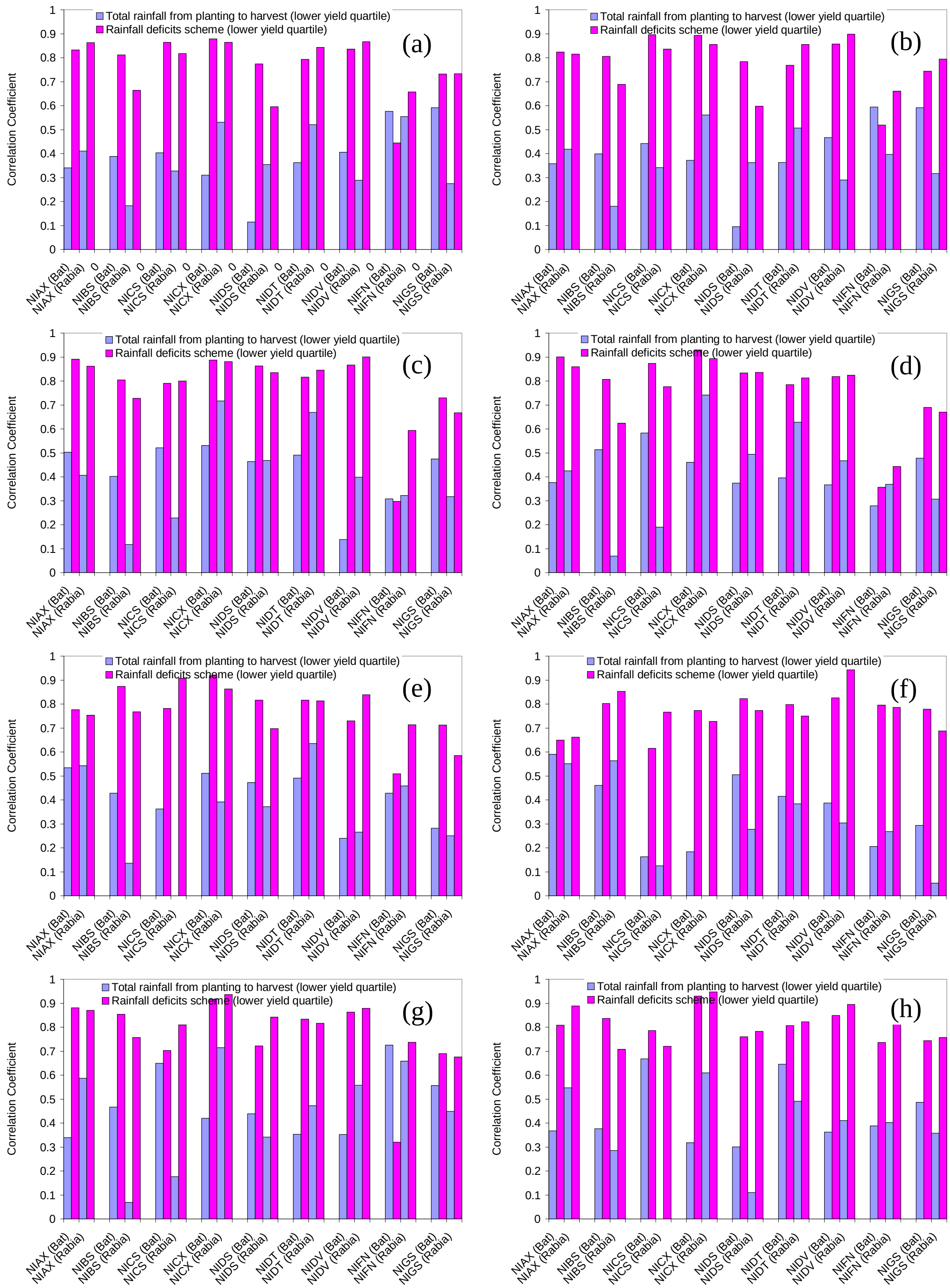


Figure 4-4 Correlation coefficients of total rainfall deficit and rainfall on yield of drybeans simulated by the DSSAT drybean model on contrasting soils and slope for a selection of sites in north-central Nicaragua. Soil textures: sand, (a) and (b); sandy loam, (c) and(d); silty loam, (e) and (f); silty clay, (g) and (h). Flat land, (a), (c), (e) and (g); sloping land, (b), (d), (f) and (h). The rainfall for each cell was generated using the MarkSim procedure.

- The correlation coefficients vary considerably from cell to cell, indicating that rainfall alone is not always the main determinant of yield. Cell NIFN is in a high rainfall area so that the relationship between yield and rainfall is weak. Similarly in cell NIDS, with an altitude of 1000m, yield correlation with rainfall is weak because a low temperature due to high altitude exerts a stronger influence over yield.
- Both the silty clay and silty loam on sloping land had higher water requirements than on flat land. Although both silty soils have high water-holding capacities, more of the rainfall is partitioned to runoff due to the higher runoff coefficient for these soils to account for their lower infiltration rates (see above).

Using minimum rainfall amounts needed in each dekad (Figure 4-0) to calculate rainfall deficits for the crop period gives much better correlations with yield than the simple measure of total rainfall (Figure 4-0). This justifies using rainfall deficits to develop a weather index on which to base an insurance instrument as described in the succeeding sections of this report.

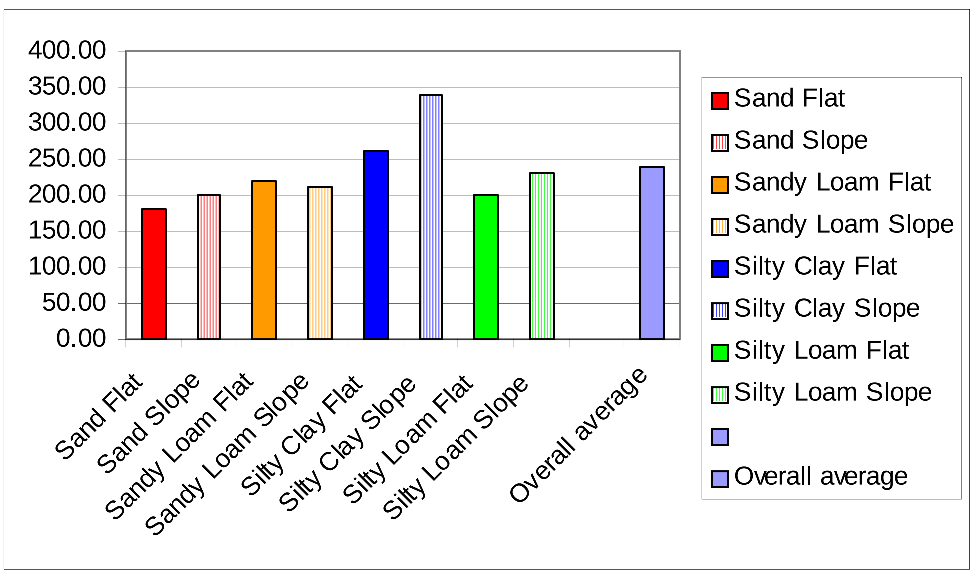


Figure 4-5 Total minimum rainfall requirements for each soil texture-slope combination. The data are means for six typical pixels.

4.3.1. *Areas for further methodology development*

This is a methodology in development so that there are several areas that need further research. Figure 4-0 shows the minimum rainfall requirements summed over all dekads for each soil texture-slope combination. The totals vary between 200 and 400mm. The sandy soil has the lowest total minimum rainfall requirement, which appears anomalous. However, it takes less water to wet up sandy soil compared with the sandy loam, which can account for the relatively small difference of about 40mm. The silty soils are a different matter. Although they too require more water to wet up than either of the sandy soils, they also have different infiltration rates, so that they lose more rainfall as runoff.

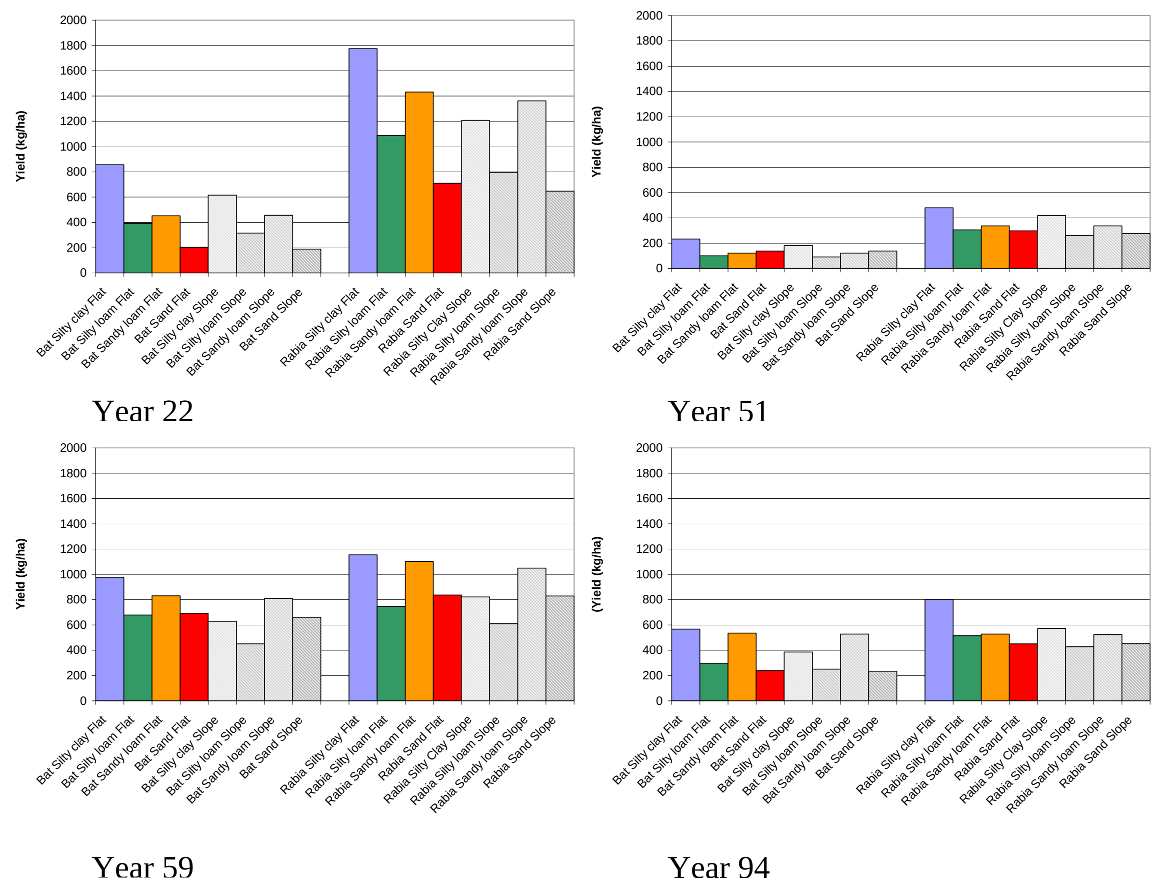


Figure 4-6 Yield results for several soil types for four of the worst weather years (*postrera* cropping period for the pixel NICS).

The methodology is based on the DSSAT crop simulation, which gives voluminous output including daily soil-water balance. These allow us to identify rainfall requirements specific to soil texture-slope combinations. According to Figure 4-0 the pattern of rainfall required for soils of differing textures is very similar, it is the absolute amounts that differ (Figure 4-0). However, inspection of yields for individual years across runs shows that yields differed markedly on different soils in drought years (Figure 4-0 and Figure 4-0)

In the four years that gave some of the lowest yields, Rabia de Gato always yielded better than Bat477 (Figure 4-0) except in year 94 for the sandy loam-slope. This justifies developing cultivar-specific indices in addition to soil-specific indices.

The DSSAT drybean model gives daily indices of water stress with values ranging from 0 (no stress) to 1 (extreme stress). There is a clear relationship between the sum of the daily stress indices and yield (Figure 4-0). Although attractive at first glance, the procedure would require daily input of actual data to the DSSAT model, which would be unlikely to be thought a simple transparent index that could be easily marketed either to farmers or to insurers.

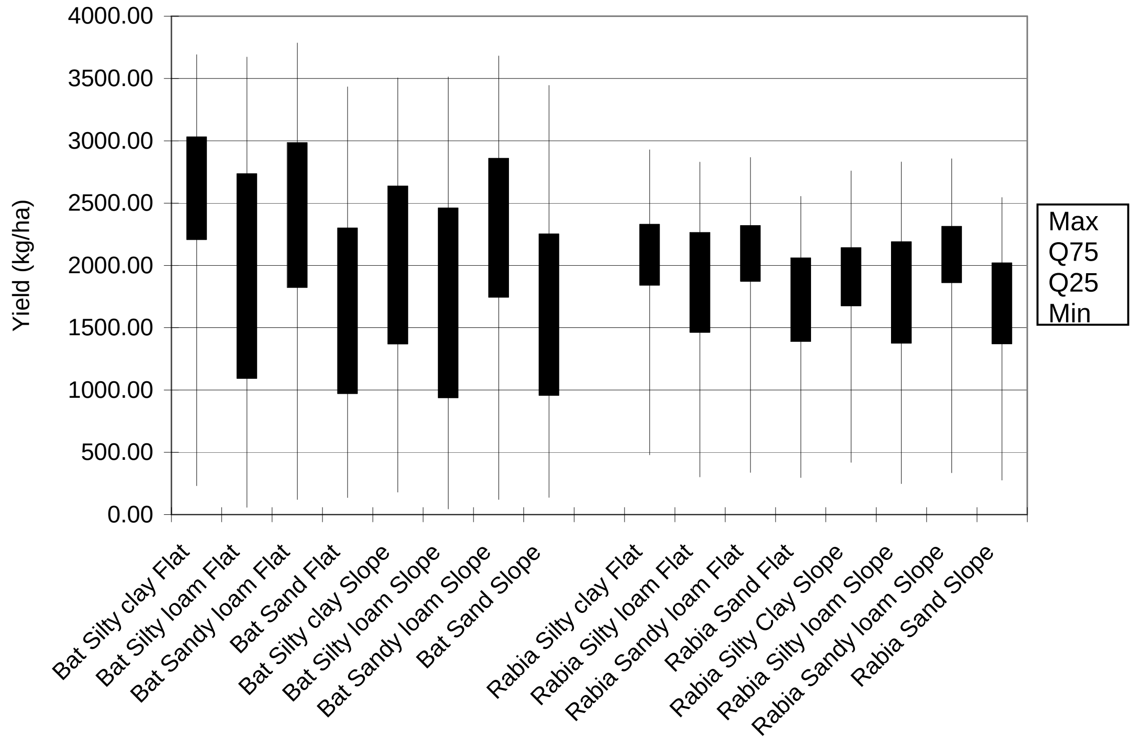


Figure 4-7 Summary statistics for yields obtained with the same weather on different soils and topography.

Plants experience water stress at different periods and to different extents under the same weather pattern depending on both the soil texture and the cultivar (Figure 4-0). To illustrate further, in year 51 stress starts in Rabia de Gato on day 20, but does not start in Bat477 until more than a week later. Also in year 51, rain on day 61 immediately reduces stress to zero on the sandy soil, both slope and flat. In the other soils, stress is reduced but not to zero. This further illustrates differences of the effectiveness of rainfall events between soils, and the need to incorporate these soil-specific differences into the drought index on which insurance instruments will be based.

Because heavier soils have low infiltration rates, a high proportion of rain runs off intense precipitation events. For this reason crops on the silty soils experienced higher levels of stress than the lighter soils in years 94 and 59, for example.

Cultivar characteristics are another key issue. In these studies, Rabia de Gato is about ten days earlier than Bat477, and is the reason for its higher yields in years of low rainfall. Weather indices must therefore be cultivar specific, based on the duration of the life cycle. While it is clearly not feasible to design an index for every one of the large number of cultivars and land races that exist, it is possible to group cultivars into maturity types which can be expected to give similar responses to rainfall deficits.

As expected, lower temperatures cause lower levels of water deficit (Figure 4-0). It is therefore necessary therefore to incorporate a temperature factor into the rainfall index, because temperature is in the primary determinant of water requirements of a crop.

Because temperature is largely determined by altitude, adjustments can readily be made using the Shuttle Radar Topgraphic Model (SRTM)-based WorldClim database (Hijmans *et al*., 2005). Altitude resolution of the SRTM is accurate to 16m with a spatial resolution of 90m, more than adequate for crop simulations even in mountainous areas.

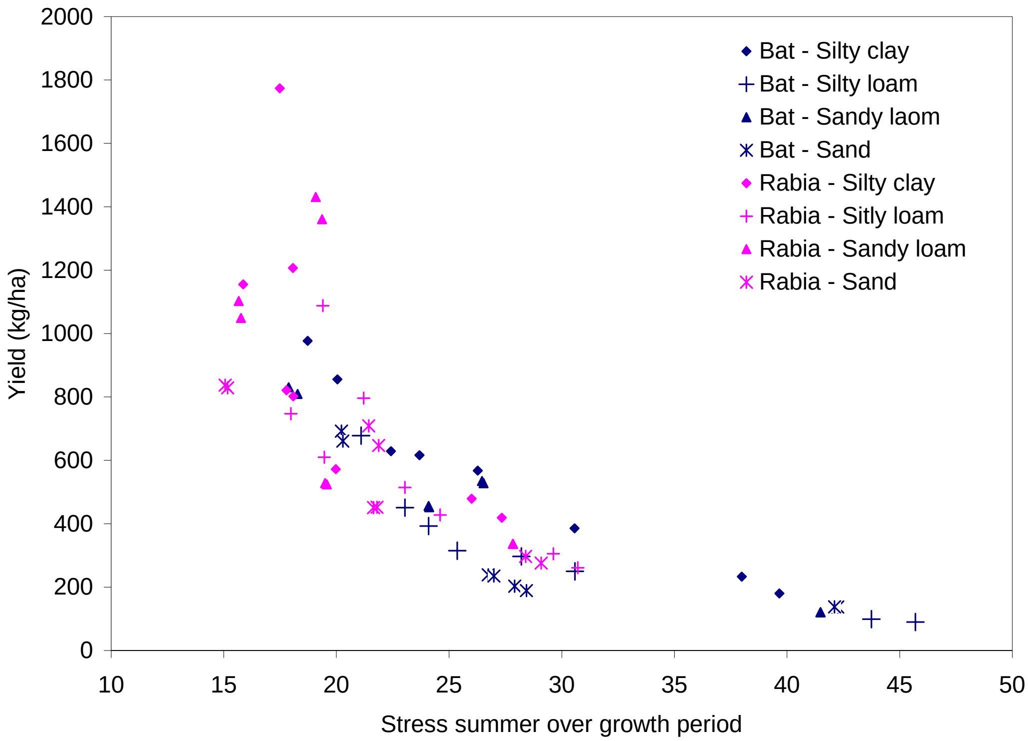


Figure 4-8 Sum of the water stress value plotted against yield for various soil types.

4.4. Identification of payable events

Hitherto we have focused the discussion on the design of an index that is closely correlated with yields. We have defined a rainfall-deficit index that does this satisfactorily. However a crop-insurance scheme based on weather is concerned with weather events that lead to severe yield losses. One possible type of insurance instrument would allow farmers to choose the level of yield below which they are not prepared to accept as normal variation. For each of these there would be a corresponding rainfall deficit, called a trigger for which the farmers could buy insurance. This would require a range of instruments whose premiums are actuarially adjusted for the corresponding risk. Another method is to sell a fixed trigger, which is actuarially easier to formulate.

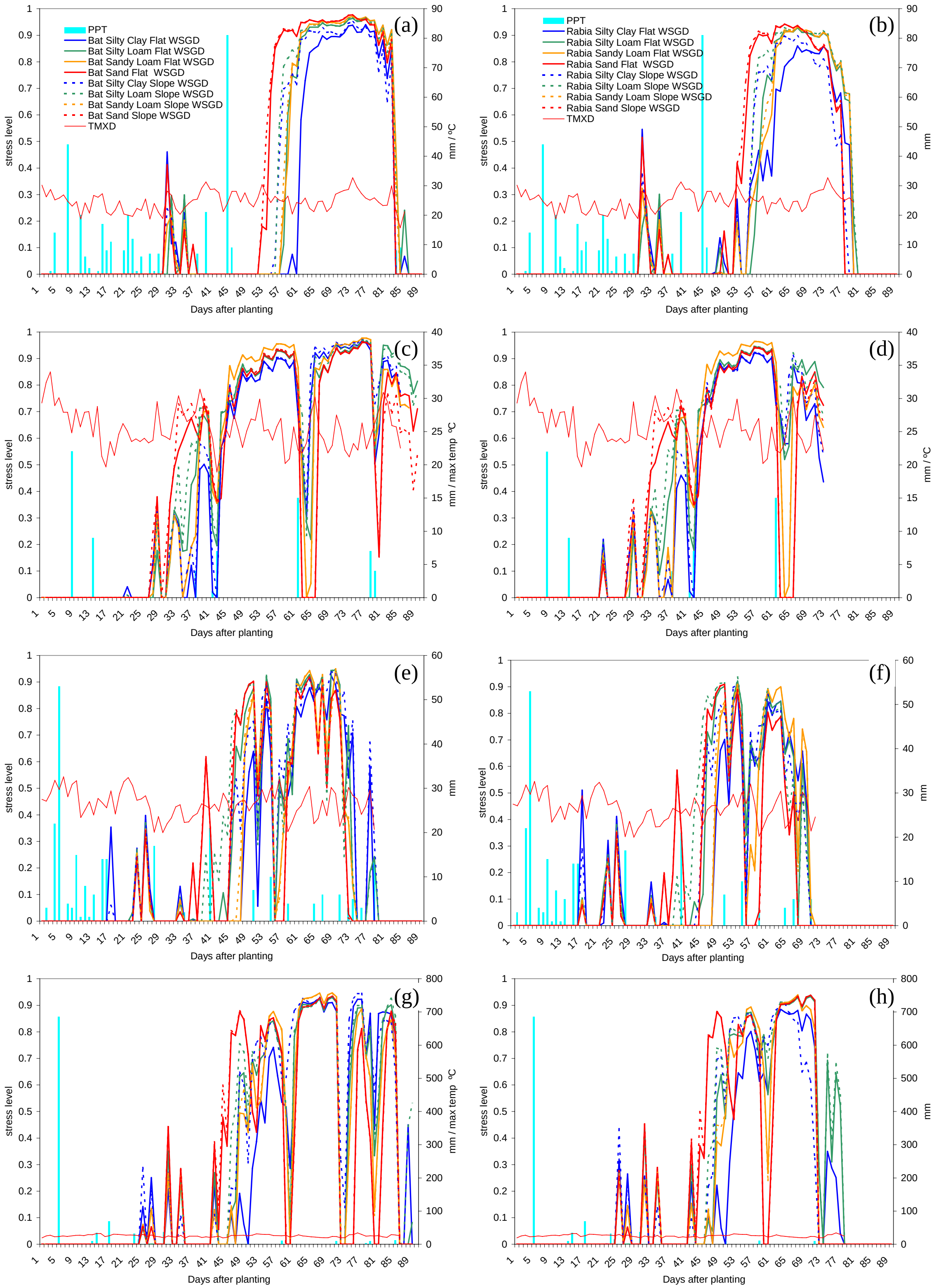


Figure 4-9 Water stress output value plotted with precipitation, temperature and the available soil water for various soil types. Years: 22, (a), (b); 51, (c), (d); 59, (e), (f); 94, (g), (h). Cultivar: Bat447, (a), (c), (e), (g); Rabio de Gato, (b), (d), (f), (h).

In years when the trigger deficit, whether fixed or variable, is reached the scheme makes indemnity payments. Farmers may need technical advice to help them select an appropriate trigger, such as assessing the risk probability for their soil-cultivar-slope-altitude combination and assuming transparent symmetry. But the level of the trigger naturally affects the cost of the coverage. A modest trigger aimed at insuring a lower level of yield loss would obviously cost more.

The relationship between the rainfall deficit index and yields varies spatially in that a given rainfall deficit causes different yield reductions depending on the pixel, which seems primarily to be an effect of altitude. This is illustrated in Figure 4-0 where the relationship is shown for two contrasting pixels. In pixel NICX yields below 500 kg/ha are associated with rainfall deficits of only 40mm, while in cell NIAX yields below 500 kg/ha are associated with deficits of 80mm. It is possible that some generalizations can be made for a given location based on its geographical characteristics. This aspect was not considered further and is an obvious area for further investigation, especially with the greater altitude precision that is now available (see discussion of SRTM above.)

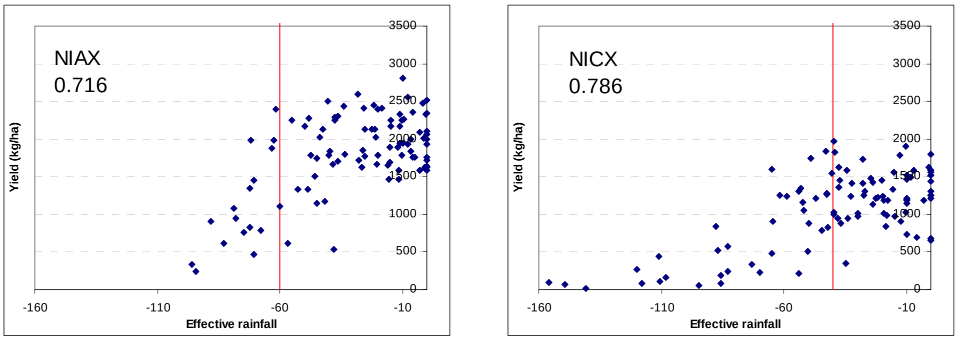


Figure 4-10 Correlation between rainfall deficit and yield in pixels NIAX and NICX in northern Nicaragua.

The exercise described here, including the correlations and trigger points are based entirely on yield simulations using generated weather data. Even the farmer interactions described in section 8 were to seek their opinions, expert opinion certainly, but still opinion. We are forced to take this approach because as we have already pointed out, sufficient hard data do not exist for drybeans in Nicaragua.

We are confident that the DSSAT drybean model accurately represents the behaviour of drybean crops in the field (White *et al.*, 1995) . We are also confident that the generated weather data represent field reality, although we had some worries with the data for the Somoto site, as we discuss and resolve later in Section 6.1. The new WorldClim data set (Hijmans *et al.*, 2005) with its resolution of 30 arc seconds (about 1km) provides us with even greater levels of confidence.

5. Sample contract

Here we outline a weather-insurance contract based on the rainfall-deficit index that we developed in the previous section. Like that analysis, the index is based on the establishment of minimum rainfall requirements for 10-day windows or dekads throughout the growing season. (Table 5-0, see section 4.3 for details).

Table 5-1 Minimum rainfall requirements on which to base weather insurance contract. The MIN values are for flat sandy soil in several representative cells and cultivar Rabio de Gato.

	Day -10 to day before planting	**Day 1 to 10**	**Day 11 to 20**	**Day 21 to 30**	**Day 31 to 40**	**Day 41 to 50**	**Day 51 to 60**	**Day 61 to 70**	**Day 71 to 80**	**Day 81 to 90**
Minimum rainfall (mm) for satisfactory growth (MIN)	0	10	10	25	40	40	40	30	10	0

The start and end date of the contract must be specified so that both parties know the exactly when the contract starts taking rainfall into account. Ideally the start date of the contract should reflect the most likely sowing date and should end at crop maturity.

In Nicaragua the sowing date is highly variable (see Section 2.1.2). Since weather insurance contracts should be sold when neither party is able to forecast the likely weather for the coming cropping period, it is not possible to set a given calendar date for sowing. For this reason, we believe that a simple sowing date rule is the fairest method.

Farmers will usually have their own rules-of-thumb about when to sow, so one option would be to obtain consensus and formalize such rules so that they could be incorporated into the contract. A refinement would be a sowing-date window within which a simple rule is applied. Expert consultation is the key to specify what the rule might be, since this is also an effective mechanism for communicating information about suitable sowing dates to farmers. Examples of sowing date rules could be:

- In the window 15 May to 15 June, the sowing date is taken as the first day after 5 consecutive days with a minimum rainfall of 5mm each.
- In the window 15 May to 15 June, the sowing date is taken as the first day after a total of 30mm rain in a 5 day period.

Sowing date rules could also be specified according to soil type, since the amount of rainfall needed to wet up a soil will vary with soil texture and slope. Table 5-0 is an example of a sample contract and Table 5-3 and Table 5-4 are examples of how this hypothetical scheme would be calculated.

Table 5-2 Sample insurance contract.

RAINFALL INSURANCE CONTRACT	
Reference weather station	*(e.g.) San Dionisio INETER weather station*
Crop	*(e.g.) Dry beans – drought tolerant type*
Reference soil type	*(e.g.) Sand*
Sowing window	*(e.g.) 15th May to 15th June*
Sowing date rule	*(e.g.) First day after 5 consecutive rainy days over 5mm each*
Trigger value	*(e.g.) -70mm*
Premium price	*(e.g.) US$3*
Indemnity	*(e.g.) US$5 for every mm of rainfall deficit after the trigger value*

Minimum rainfall requirements (given crop and soil stated above)

	Day 1 to 10	**Day 11 to 20**	**Day 21 to 30**	**Day 31 to 40**	**Day 41 to 50**	**Day 51 to 60**	**Day 61 to 70**	**Day 71 to 80**	**Day 80 to 90**
MIN	0	10	10	25	40	40	40	30	0
RAIN									
DEF									
TOTAL Rainfall deficit									

Calculation of indemnity payments

1. MIN is the minimum rainfall that is required for your crop in each of the 10 day windows.
2. RAIN is the rainfall observed at the reference weather stations (you may enter this into the RAIN box, however it is the official rainfall recorded at the weather station that determines whether you are entitled to an indemnity payment).
3. DEF is the rainfall deficit. This is calculated by subtracting MIN from RAIN (only negative values are taken into account).
4. Indemnity payments occur when the TOTAL rainfall deficit is equal to or less than the trigger value
5. The rainfall deficit is the sum of the 10 day rainfall deficits

Table 5-3 Example of a season not entitled to an indemnity payment (total rainfall deficit does not reach the trigger value of -70mm).

	Day 1 to 10	Day 11 to 20	Day 21 to 30	Day 31 to 40	Day 41 to 50	Day 51 to 60	Day 61 to 70	Day 71 to 80	Day 80 to 90
MIN	0	10	10	25	40	40	40	30	0
RAIN	*34.9*	*22.4*	*0.6*	*33.8*	*0*	*57.6*	*73.4*	*161.8*	*112.9*
DEF			*-9.4*		*-40*				
TOTAL Rainfall deficit									-49.9

Table 5-4. Example of season resulting in an indemnity payment (total rainfall deficit exceeds the trigger value of –70mm).

	Day 1 to 10	Day 11 to 20	Day 21 to 30	Day 31 to 40	Day 41 to 50	Day 51 to 60	Day 61 to 70	Day 71 to 80	Day 80 to 90
MIN	0	10	10	25	40	40	40	30	0
RAIN	*5.8*	*3.6*	*0*	*9.5*	*4.1*	*23.5*	*12.6*	*2*	*96.1*
DEF		*-6.4*	*-10*	*-15.5*	*-35.9*	*-16.5*	*-27.4*	*-28*	
TOTAL Rainfall deficit									-139.7

6. Site specific probabilities of a trigger event

Once an index has been established on which an insurance policy pays an indemnity, we need to calculate the probabilities of the payable weather events. This is known as the pure risk and is the principal component of the price of the insurance premium. Under standard insurance practice, this is usually done by a robust examination of the historical data and careful extrapolation to take account of any possible extreme events.

In most developing countries reliable and long-term historical weather records are not usually available. To overcome this deficiency, we have used MarkSim, a weather generation tool specifically for the tropics. There are a number of advantages to using a tool such as MarkSim. Firstly, it is possible to estimate the probabilities of payable events where no data exist. Secondly, the data generated by the model are free of inconsistencies and missing values, which are commonplace in observed data-sets. Since the data are interpolated and generated according to a muli-dimensional climate surface, it is possible that, at least for some sites, the generated data may be more reliable than any local data whose quality may be dubious.

Figure 6-0 illustrates the potential of using weather generation coupled with a crop simulation model to estimate yields of drybeans in north-central Nicaragua. Here the probability of the specified event (rainfall deficit of 50 and 70mm during the *primera* cropping period) is shown for every 10-arc minute grid cell. Using this methodology it is possible to see the spatial variation in the risk event and also identify areas where the risk is high, and therefore possibly not insurable.

6.1. Comparison of observed and simulated data

Any model must produce output that is demonstrably accurate and reasonably representative of reality before it is useful. In the specific case of insurance and reinsurance, many companies will require evidence that allows them a high level of confidence in the data before they are used as the basis for contracts.

In this study we carried out a brief comparison exercise. Standard statistics were computed for both observed and simulated data and then compared graphically. We obtained observed precipitation data from the Nicaragua Ministerio Agropecuario y Forestal (MAGFOR) for the locations shown in Figure 6-0 and described in Table 6-0. We emphasize that we did not check the data or correct them for inconsistencies; nor did we carry out any quality checks.

We eliminated station Bluefields on the Caribbean coast with annual precipitation of more than 4000mm as being irrelevant to this exercise. We also eliminated data sets from stations with less than 20 years' data (Boaco, La Paz Centro, Hacienda el Apante and Estelí) as being too short to make useful comparisons.

We generated MarkSim precipitation data for 99 years using the option to input the mean monthly precipitation data for each of fourteen stations (Table 6-1). For the purpose of comparing cumulative frequency data, the 99 years' data were used, restricted to the same range of annual precipitation as the observed data. For other comparisons the same of number of years were simulated as in the observed record Figure 6-0. to Figure 6-0 show

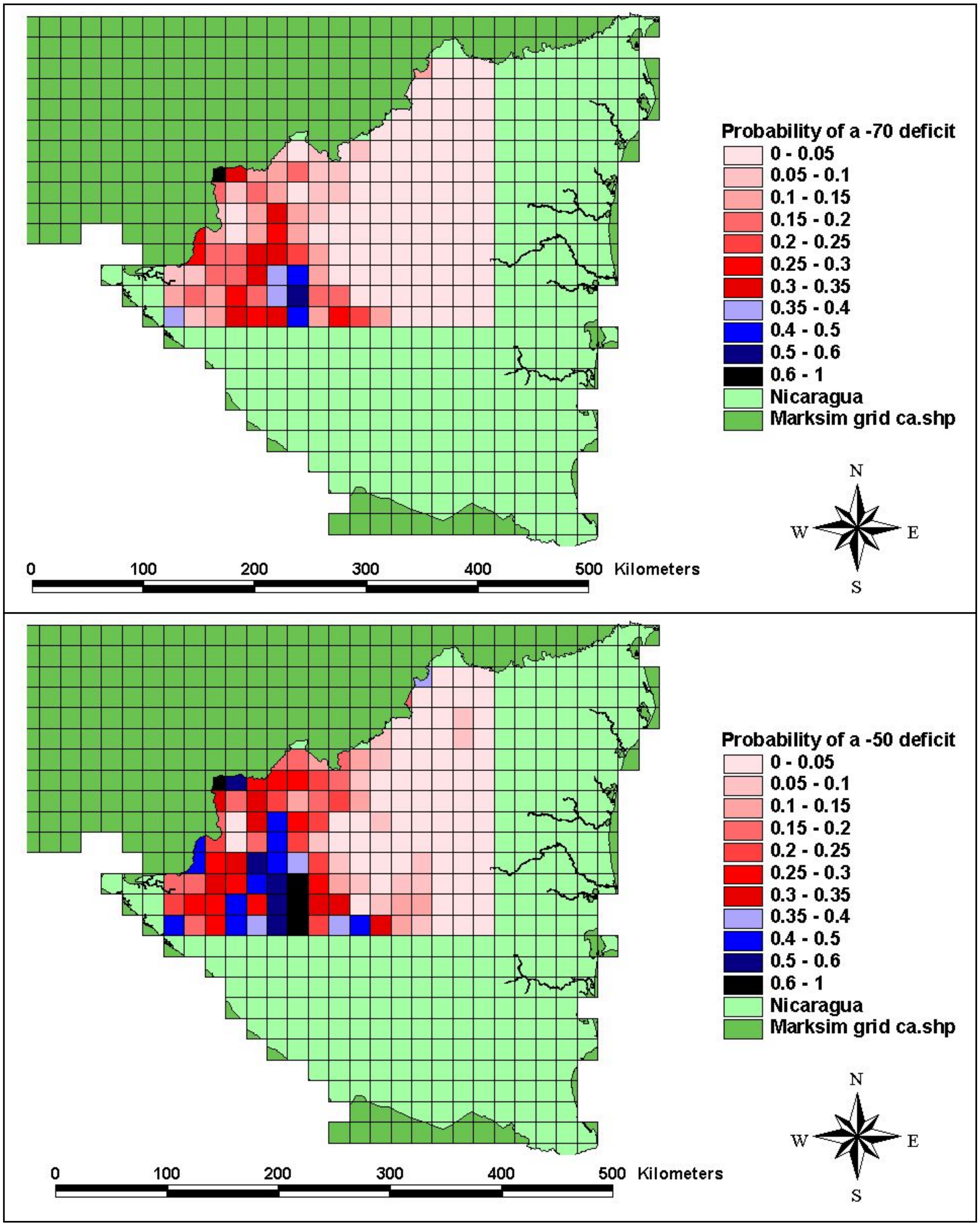


Figure 6-1 Probability of a (a) 70mm rainfall deficit and (b) 50mm rainfall deficit occurring in drybean crops during the *primera* cropping period in north-central Nicaragua. The data are for the sandy loam soil.

the results of the comparison exercise.

Table 6-1 Details of the weather stations used in the comparison.

Code	Name	Years	Start	End	Lat	Long	Elev[2]		Missing
NC01	Somoto	35	1963	2003	13.4733	-86.5850	737	6	1987-90,1997,2000
NC02	Sebaco	45	1952	2003	12.8533	-86.0919	487	7	1966,1979,1982,1990-1,1997,1999
NC03	San Dionisio	30	1971	2003	12.7583	-85.8500	371	3	1996-7,2000
NC04	Jinotega	47	1954	2003	13.0833	-85.9967	1034	3	1979,1989-90
NC05	Terrabona	28	1971	2003	12.7266	-85.9650	535	6	1979,1989,1990,1997-9,2000
NC07	Chinandega	38	1966	2003	12.6316	-87.1333	68	0	0
NC08	Ingenio San Antonio	43	1958	2003	12.5316	-87.0500	32	3	1993,2000,2001
NC10	Managua Airport	45	1958	2003	12.1416	-86.1636	61	1	1982
NC11	Juigalpa	32	1963	2003	12.0983	-85.3667	88	9	1967,1973,1976-80,1984,1989
NC12	Masatepe	36	1966	2003	11.9122	-86.1464	449	2	1976,1979
NC13	Rivas	36	1968	2003	11.4333	-85.8333	67	0	0
NC17	El Tuma	24	1971	2003	13.0567	-85.7433	371	9	1978-79,1981,1984,1988-90,1997,2000
NC19	Crucero Santa Rita	20	1966	1988	12.0183	-86.2308	357	3	1973,1981-82
NC20	Matagalpa	30	1954	1988	12.9133	-86.1917	471	5	1979-80,1982,1984,1986

In general the simulated data are comparable to those obtained in the observed data set. The results confirm that MarkSim does produce rainfall patterns and summary statistics that mirror the observed data sets. There are some indications that during the rainy season MarkSim slightly overestimates the monthly precipitation totals for some stations such as Managua Airport and Crucero Santa Rita, but this is not likely to be important in determining drought events. The length of dry spells is modeled well, with the exception of the month of January, which in several cases was drier than the actual data. But January is of little interest for drybean producers except those few who grow an *apante* crop. This is an opportunistic activity and almost certainly not one that would not attract insurance.

Any further development in the use of MarkSim as the basis for creating weather indices on which to base insurance products should include robust statistical validation of MarkSim. It is noted that in MarkSim it is also possible to input the observed monthly means for given sites and use these to generate daily data as we did here to compare with the observed data. We did not use this option in the general modeling exercise, but for specific sites it is certainly a valid approach.

A further option is to use as input to MarkSim data derived from the WorldClim database (Hijmans *et al.*, 2005) as we discuss below. This option was not available when we undertook the present study, but we made a comparison of total annual rainfall estimated by MatkSim and from the WorldClim database for each of the fourteen stations in the comparison reported above (Table 6-2). As a matter of interest, we did generate MarkSim data for Ingenio San Antonio using the WorldClim data for this site (Figure 6-0). The data speak for themselves.

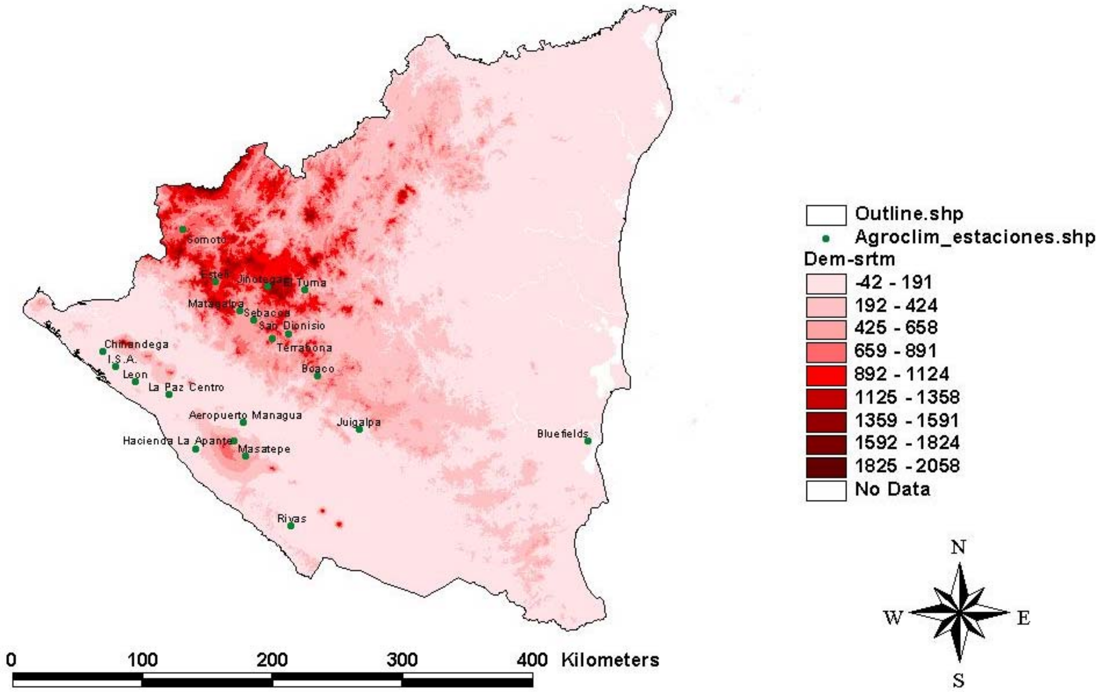


Figure 6-2 Location of weather stations for which observed precipitation data was obtained.

Table 6-2. Mean annual rainfall from the measured data compared with data derived from the MarkSim 10-arc-minute surface and the WorldClim 30-arc-second surface.

Station	Measured	WorldClim	MarkSim
	mm	mm	mm
Somoto	834	970	2890
Sebaco	844	921	947
San Dionisio	1301	1200	1213
Jinotega	1156	1564	1213
Terrabona	819	923	1213
Chinandega	1886	1849	1463
Ingenio San Antonio	1736	1724	1463
Managua Airport	1091	1134	1291
Juigalpa	1119	1246	1438
Masatepe	1456	1388	1473
Rivas	1396	1536	1431
El Tuma	1397	1733	2054
Crucero Santa Rita	1224	1299	1290
Matagalpa	1329	1464	1374

As expected, the 30-arc-second WorldClim data in general are closer to observed mean annual rainfall than are the data derived from the coarser 10-arc-minute MarkSim surface. Where there are discrepancies, as in Jinotega, for example, one would have to check the observed data carefully, which we did not do. We must also caution that mean data of annual rainfall are only part of the story, and tell us nothing about distribution within and between years. Nevertheless, one clear anomaly is the MarkSim data for Somoto, which were surprising and a little worrying[8]. The 30-arc-second data set (WorldClim) data agree with the actual data, giving mean annual precipitation of 970mm. We investigated further by examining both the 10-arc-minute and the 30-arc- second surfaces (Figure 6-0).

Two points arise. Firstly the 10-arc-minute surface has a much coarser representation than the 30-arc-second surface with twenty times the resolution. Furthermore, the three 10-arc-minute cells around Somoto all have very high rainfall, which skews the interpolation in that direction. Secondly, the 10-arc-minute weather surface is fitted using an inverse distance-weighting function on the data of nearby weather stations, including one from Somoto itself with mean annual rainfall of 769mm. But Potoste, just to the south of Somoto, shows mean annual rainfall of over 4,000mm. On the face of it this seems unrealistic, but if there is an error in the data, it was not obvious when we examined them. They show that the monthly precipitation throughout the year is constantly above 100mm. The problem could be a matter of a decimal point, with the true rainfall being 300mm, but that in turn would make the mean annual rainfall unrealistically low.

Because of the advanced algorithm that WorldClim uses to interpolate on the 30-arc-second surface, it discarded Potoste as an outlier. But the inverse distance weighting method that MarkSim uses to interpolate on its cruder surface would not have done so; hence the anomaly remained in the 10-arc-minute surface. But we emphasize that the problem is not Marskim per se, but in the data behind it. A pragmatic solution would be to discard the Potoste data from the 10-arc-minute surface, but this is not an option available to the user.

The magnitude of the discrepancy is such that a person with local experience would have noticed that the data were nonsense. Moreover, the error is such that no insurance would have been offered for this location, which would have led both farmers and agents to ask, why not? This would have led to an investigation such as the one we are reporting here.

The work reported here was a feasibility exercise to demonstrate MarkSim's ability to simulate weather data for any given site in the north-central Nicaragua. In any future statistical validation, quality checks of the observed data should also be incorporated into the analysis.

The obvious approach for the future is to use the WorldClim data set, and input these data into MarkSim using the appropriate option to generate the intermediate MarkSim CLX files. This is not as elegant as the automated procedures of MarkSim, which allow one to generate large runs of data in one operation to cover a wide geographical area. There are

[8] We thank Dr Andy Jarvis, CIAT Land Use Project for his prompt and helpful contribution to the resolution of this anomaly.

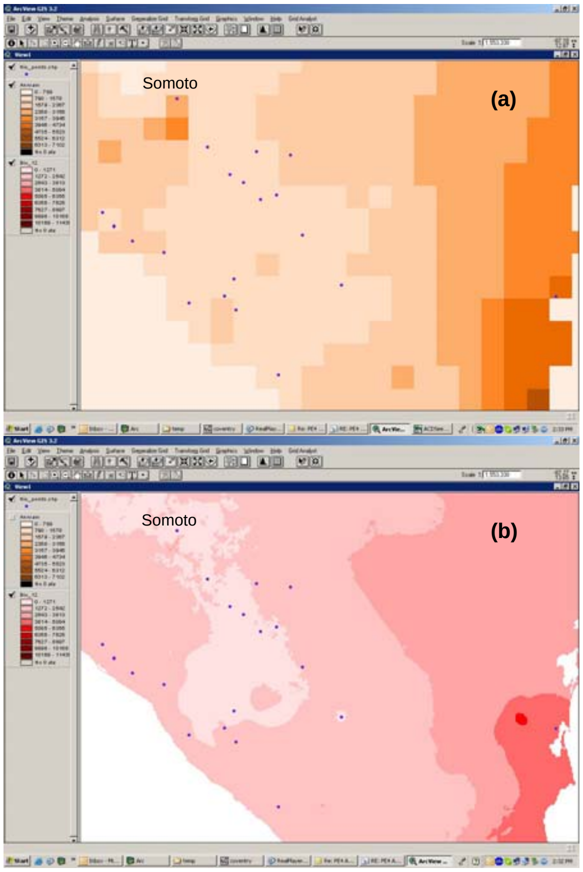


Figure 6-3. Fitted climate surfaces for Nicaragua (a) 10 arc minute resolution and (b) 30 arc second resolution. The dots are the locations of the sites used in the comparison, with Somoto identified in the extreme north. In (a), the high rainfall site Potoste lies in the pixel to the south of the one containing Somoto. Note that the anomaly does not occur in (b).

currently discussions about incorporating the 30-arc-second data surface into MarkSim, which would provide the ultimate solution (A. Jarvis, personal communication, 24 March, 2006; P. Jones, personal communication, 31 March, 2006).

6.2. Temporal error, estimating extreme events from short-run data.

It is common to think that 50 years' (or so) weather data are sufficient to estimate yield variation in crops. We caution that this is a dangerous assumption. Engineers design structures and other works to withstand a given frequency of extreme weather, for example, a river levy to withstand a one in 100 year flood, termed more simply a 100-year flood. Clearly, a short run of historical data (50 years or even less) is only a limited sample of a very large population. Using such limited data alone to generate probabilities of climate risk will lead to seriously underestimated risk since by definition, only the extremes encompassed by the actual data are represented.

To estimate the frequency of an event not represented in the data, engineers apply a log Pearson function to the yearly extremes within an historical data set. They then use the fitted Pearson function to predict the probabilities of extreme events that lie outside the range of the observed data. Obviously some variation of this approach must also be applied to short runs of historical data used to generate probabilities of weather-based risk events. This is also an issue in comparing short runs of actual data with similarly short runs of generated data.

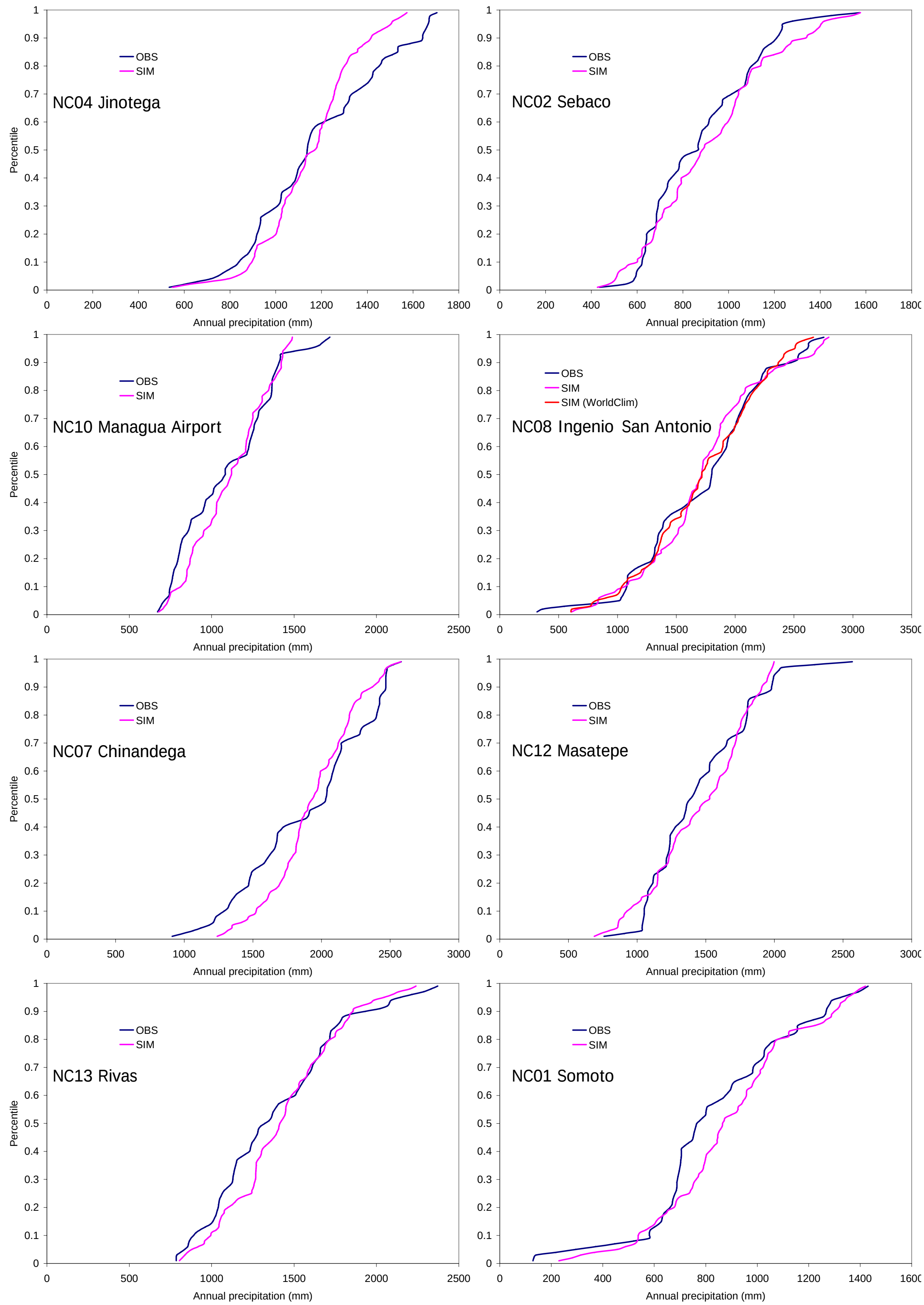


Figure 6-4 Cumulative frequency of precipitation for the observed and simulated data sets. For an explanation of the SIM (WorldClim) data for Ingenio San Antonio, see text.

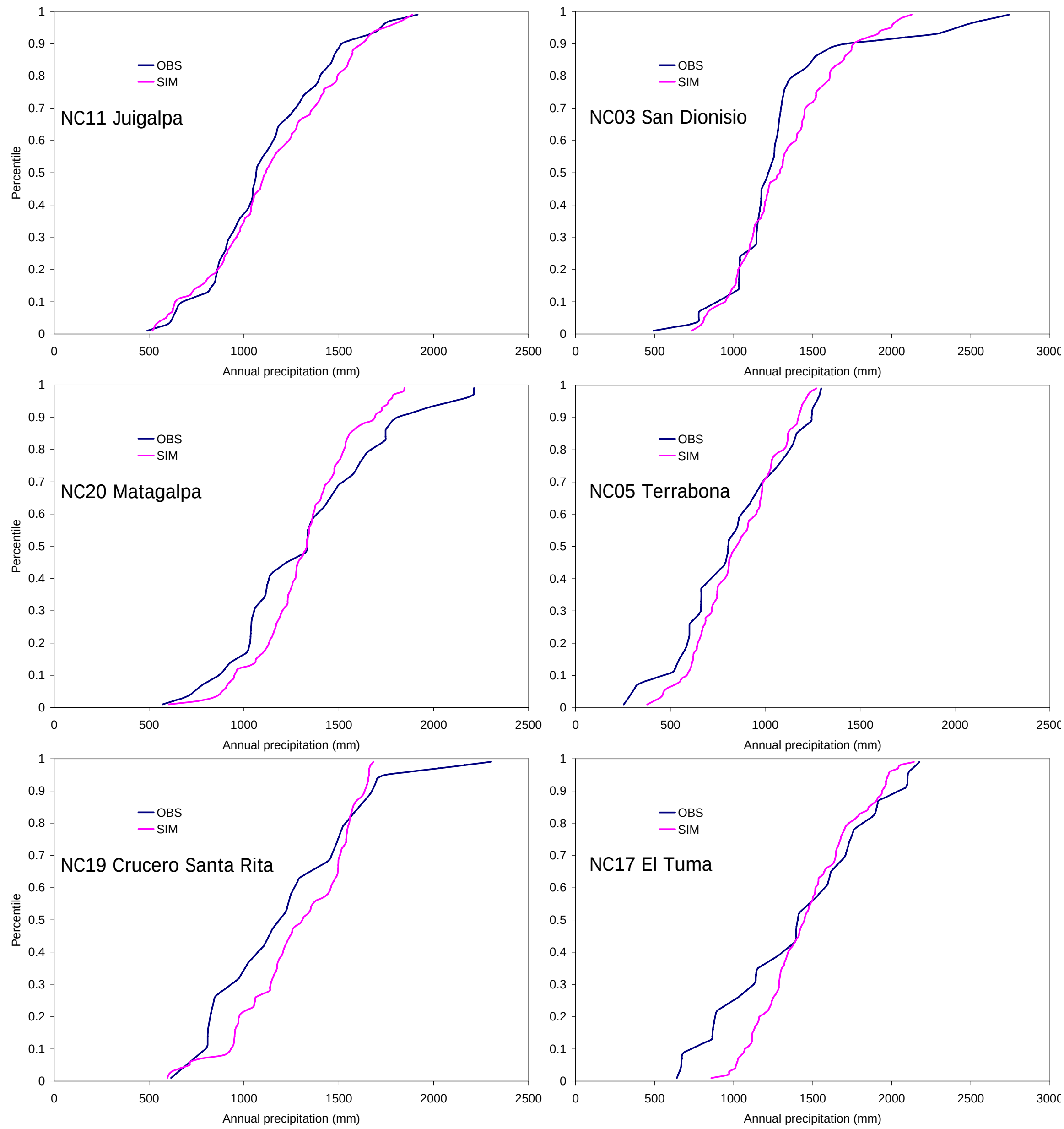


Figure 6-5 Cumulative frequency of precipitation for the observed and simulated data sets (continued).

Figure 6-6 Average monthly precipitation for the observed and simulated data sets.

Figure 6-7 Average monthly precipitation for the observed and simulated data sets (continued).

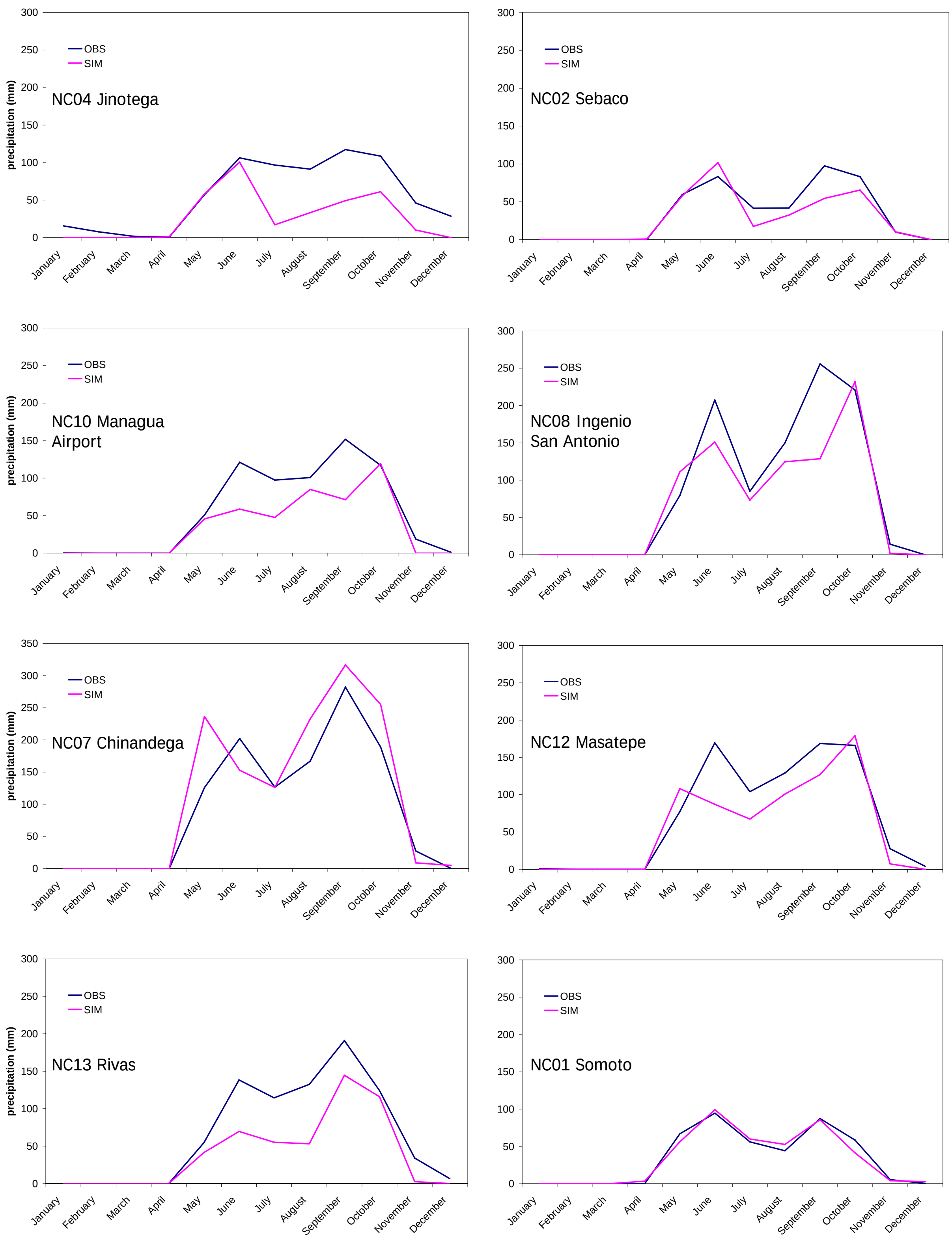


Figure 6-8 Average monthly precipitation in the lowest quartile for the observed and simulated data sets.

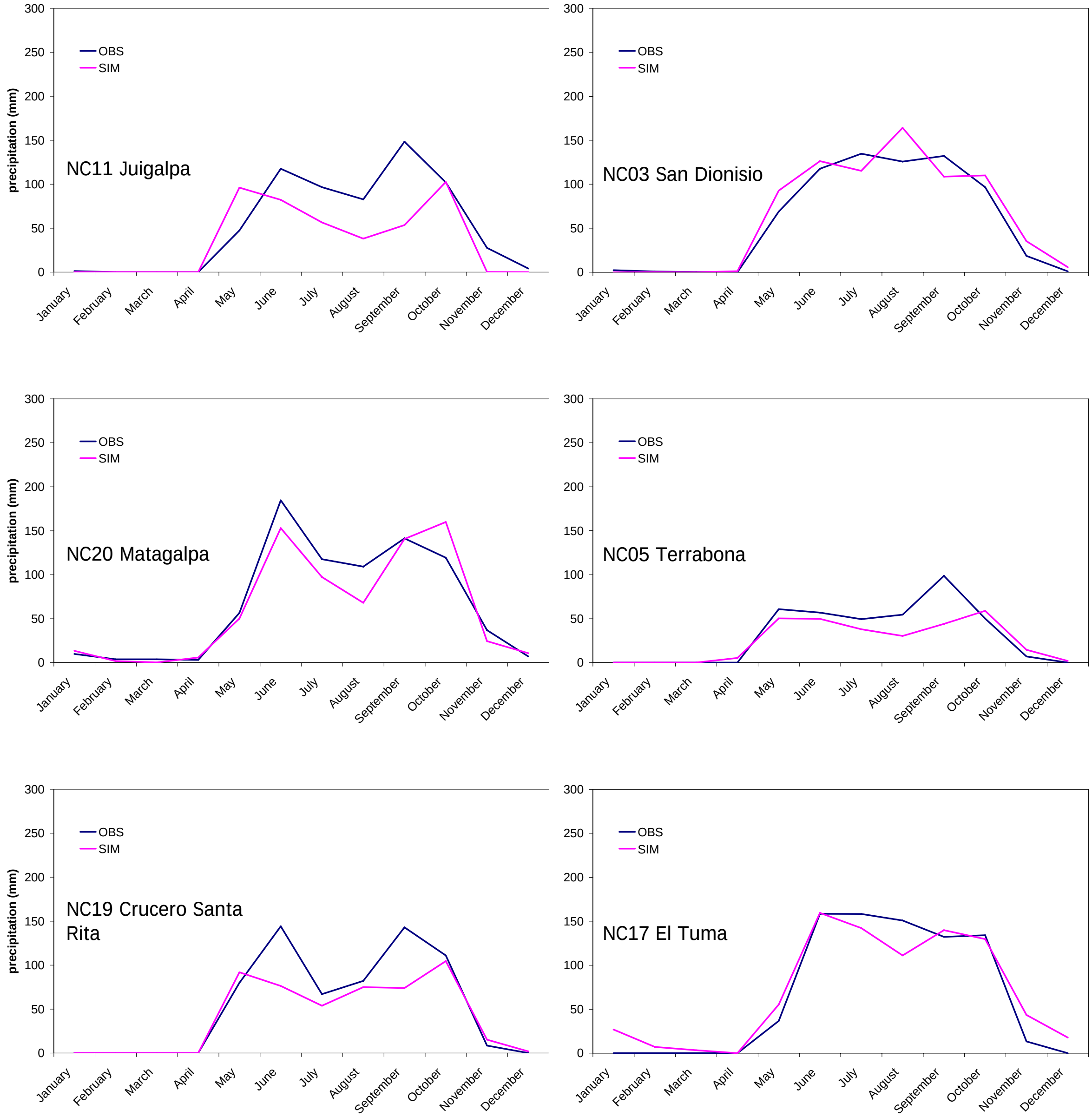


Figure 6-9 Average monthly precipitation in the lowest quartile for observed and simulated data sets (continued).

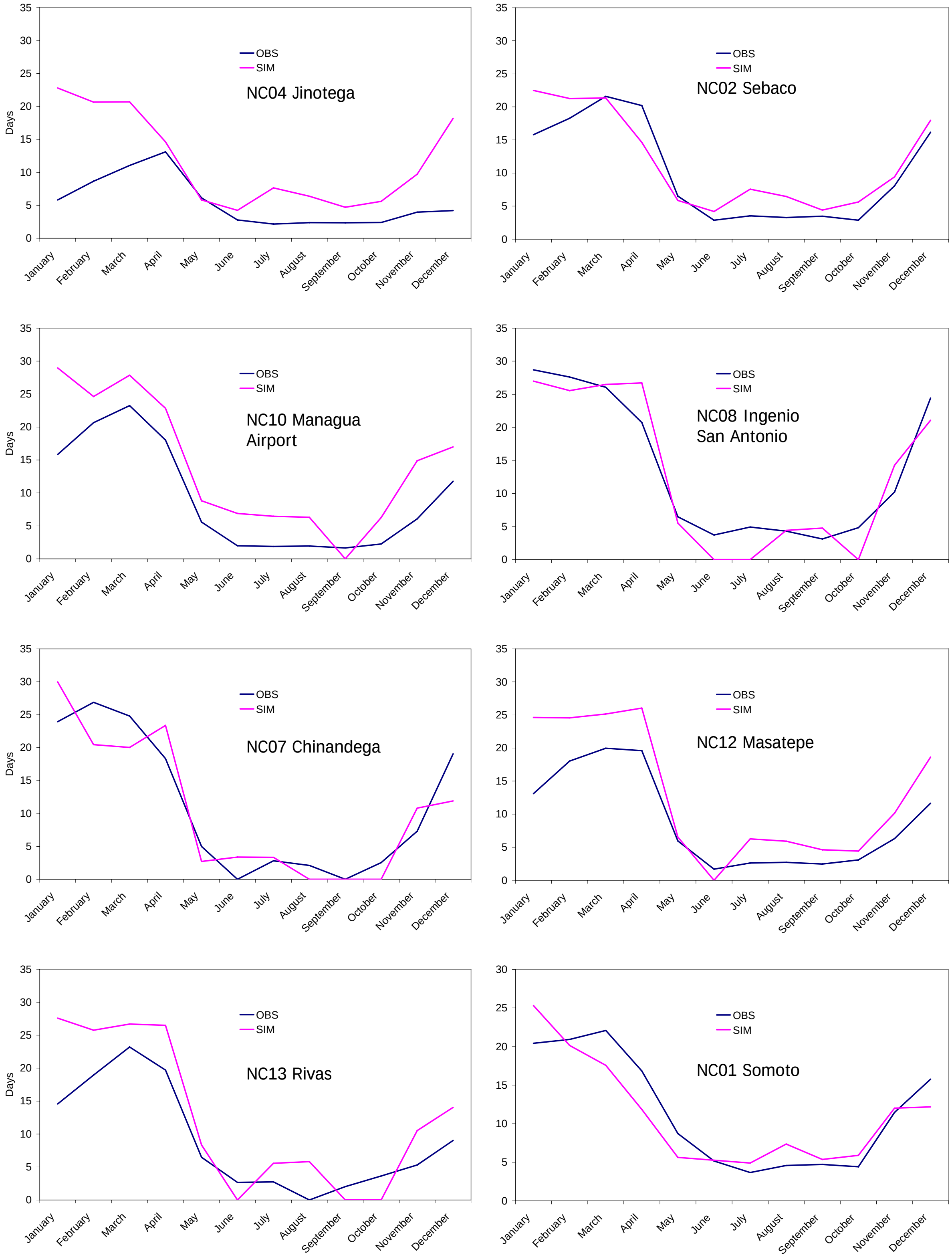


Figure 6-10 Average monthly length of dry spell length for the observed and simulated data sets.

Figure 6-11 Average monthly length of dry spell length for the observed and simulated data sets. (continued).

7. Practical issues of distributing insurance

The success of a financial instrument for small holders is dependent upon the mechanisms put in place to ensure that the product is made accessible. One obvious channel of distribution is via MFOs that already have access to small-holder scale farmers, and additionally such an instrument complements the portfolio of products MFOs already offer. Nonetheless there are many limitations that limit MFOs from effectively managing and distributing weather-insurance products. Prudent links with experienced insurers and reinsures are essential components. The following paragraphs summarize some of experiences to date with micro-insurance and rural micro-credit.

7.1. Brief literature review on experiences to date

7.1.1. The need for weather insurance

Although it is always possible to justify insurance on the basis of risk and vulnerability, this does not automatically translate into a demand for an insurance product (Brown, 2001). Nonetheless, drawing from the documented experiences of existing micro-insurance schemes and also studies regarding the demand for insurance, in general poor people do demand formal risk-management strategies and are prepared to pay for premiums to get them (Cohen and Sebstad, 2003; Morduch, 1995). Life micro-insurance is already widely adopted by the poor; at least 27 organizations globally offer life insurance to poor people (Brown and Churchill, 1999). Moreover, most cases life micro-insurance has been profitable (Zupi, 2001).

Risk aversion is linked to wealth, which means that as poor people prosper they will therefore demand more insurance (Jalan and Ravallion, 1999; Barrett *et al*., 2001; Barrett and Brown, 2002). Looking at the demand question from another perspective, insurance for the poor should be viewed in the light of the alternative of the risk-avoidance strategies that they use. By minimizing investment, the poor minimize loss, but because they have made only minimal investment, their profit under favorable circumstances is also minimal (Barrett *et al.*, 2001). On the other hand, if they can insure their investment, they are covered against loss under unfavorable conditions, but the investment allows them to take full advantage of favorable circumstances when they occur. Of course, the profit in good years must be discounted by the cost of the premiums for all years.

Proposals for micro-insurance are often met with the assertion that poor people are already surviving on meager incomes, and for this reason they are unlikely to want to spend part of their much-needed cash on insurance. Ahuja and Jütting (2004) concluded that the problems with micro-health insurance in India are not related to the ability of poor people to afford the products. Rather the problem is that the administration system prevents poor people from accessing insurance. They go further saying that governments need not subsidize micro-insurance, but simply make it easier for poor people to access it. Ahuja and Jütting (2004) also note that in even in, the poorest countries of sub-Saharan Africa,, poor people were willing to pay up to 5% of their monthly income for health insurance, illustrating a demand for specific insurance products.

Zupi (2001) also notes that women interviewed in Nepal were willing to pay up to 5% of the cost of livestock each year to insure the animals. As a comment, unless the animal has a working lifespan of more than 20 years, this would not be viable. Although the poorest of the poor may not be able to afford insurance, this is not the case for those living on or just above the poverty line (Zeller and Sharma, 1998). Those living on the poverty line may not be the poorest; however they are vulnerable in that a shock could send them down the poverty spiral. For this reason, insurance is beneficial to them.

Although micro-credit schemes have been shown to address the needs of poor people (for example the classical case of the Grameen Bank in Bangladesh), it is now recognized that micro-insurance is a much needed support for micro-credit. Micro-credit in general helps a household to increase its income and build up assets, but it also increases the exposure to risk. For example, credit may be used to purchase crop inputs but subsequently a catastrophic weather event leads to crop failure so that the farmer is unable to repay the loan (Barrett and Brown, 2002). In particular, demand for credit is minimal amongst farmers because they are reluctant to undertake the added risk of defaulting on loans (Misra, 1994). Therefore a risk-management tool, such as insurance has been suggested as a mechanism to expand and strengthen credit coverage and loan recovery (Zupi, 2001). Indeed, Mishra (1994) found that the introduction of crop insurance lessened loan defaults and led to increased loan amounts.

A number of studies have determined the potential demand for weather-insurance products. Sakurai and Reardon (1997) investigated the demand for hypothetical drought insurance in Burkina Faso (not necessarily weather-based insurance) using a computer model. They concluded that because self-insurance is not adequate to reduce vulnerability, there would be a high demand for an alternative risk-coping mechanism, such as insurance. They found that the demand for insurance varied according to agro-climatic zones and that the wealthier farmers preferred self-insurance and hence had a lower demand for insurance against drought. Although Sakurai and Reardon (1997) concluded that a demand exists, they questioned whether rainfall insurance would be appropriate given that it involves substantial basis risk so that insured people may not receive indemnity payments every time the risk event occurs.

In areas where the basis risk is lower, the demand for rainfall insurance will be higher (McCarthy, 2003). This highlights the importance of addressing the issue of basis risk and reducing it to an absolute minimum. It was also noted that the expectation of public food aid would decrease demand for insurance.

The World Bank (2001) compared the demand for different types of insurance contracts across Nicaragua. Not surprisingly, there were regional differences in the types of products in demand. Regions growing crops sensitive to soil water deficits (vegetables) preferred fully proportional contracts (in which payments are directly proportional to the deficit in water) that incur high premiums. In contrast, those growing tolerant crops, but where an extreme weather event may cause crop failure preferred all-or-nothing contracts. In these latter contracts, the indemnity is paid less frequently, which is compensated by lower premiums.

In Morocco, farmers in regions with highly variable rainfall preferred contracts that paid out more often, and are therefore more costly (McCarthy, 2003). The opposite was true in areas of low variability. Moreover, fully proportional contracts may promote less corruption (Skees *et al*., 2001) because in an all or nothing contract, there is more incentive for the insured (or groups of them) to tamper with the data if the trigger is close.

Although the studies above point to a general demand for weather insurance, small producers are thought to be unlikely to be interested in purchasing insurance, at least not directly (World Bank, 2001). A key challenge is to entice small-scale, low-income farmers to commit available cash to an insurance premium, when they could use it for more productive purposes in the short term (Morduch, 2001). Lack of information and available cash in the developing world translates into little demand for formal insurance (Goes and Skees, 2003). A solution is to sell insurance through rural credit institutions or producer associations, which can aggregate the demand from many small producers (World Bank, 2001).

7.1.2. Experiences with micro insurance programs

Insurers are wary of agricultural clients because they have a high rate of loan defaults. Catastrophic weather events that can wipe out all sources of income are the main risk involved in lending to rural people (CGAP, 2004). However, it is the poor people who depend on agriculture for their income that need effective tools to cope with weather risks. In rural Ethiopia, 78% of households have been affected by harvest failure caused by drought, flooding and frost, emphasizing the need for weather insurance in rural areas (Dercon, 2003).

Evidence from developed countries, for example Canada, where there are established channels of communication and interaction with farmers, shows that weather insurance can function successfully. However, reaching the farmers at a micro level is more challenging. Weather-based insurance has advantages over traditional crop insurance and it also offers a significant contribution towards reducing poverty. For maximum impact on poverty reduction the issues of appropriate distribution have to be addressed. Marketing and distribution have to be thought out meticulously so that the scheme attracts a high demand, yet is also efficient to keep costs at a minimum.

The distribution means of any micro-insurance scheme is very closely tied to the impact on poverty alleviation, since it is clear that if the insurance does not reach those most in need it, it is ineffective (Skees *et al.*, 2001). Purchasing weather insurance by groups or co-operatives is one option. Collective schemes may be a way of addressing idiosyncratic risks that are not explicitly dealt with by weather insurance (Skees *et al.*, 2001). In addition to providing insurance that is linked to credit, and that therefore can increase access to credit for poor farmers, it will contribute to development (Skees *et al.*, 2001). Increasing access to credit will likely also stimulate the pace of development within poor farming communities.

While it is mainly the agricultural community that will be interested in weather insurance, it also has the potential to contribute to the need to increase financial services in rural areas (CGAP, 2004). Micro-credit is mainly concentrated in urban areas (Cohen and

Sebstad, 2003 and Mathie, 2001) and even when micro-finance services are found in rural areas, due to the implicit risks involved in agriculture, only a small proportion of farmers have access to this credit. This is to say that micro-credit in rural areas goes to rural activities other than farming (Figure 7-0).

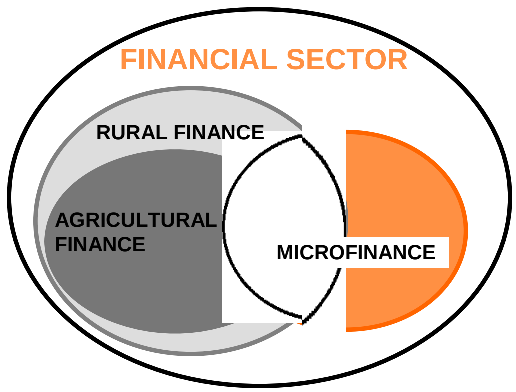


Figure 7-1 As it stands, micro-finance is mainly offered in non-rural areas. Of the rural areas where micro-finance is offered only a small proportion goes to agricultural activities. (Source CGAP, 2004).

Poor farmers face two barriers; not only do they have to face highly uncertain risks with a lot to lose, but they are caught in a vicious circle that due to their high risks they have limited access to credit. Weather insurance opens up the possibilities to credit by allowing MFOs to offer weather insurance to guarantee their loans, even for those farmers who are currently regarded as ineligible for credit because they lack irrigation.. Credit-linked crop insurance increases the flow of crop credit to insured farmers (Mishra, 1994). An additional advantage is that, although it is difficult for MFOs to enforce more profitable technologies and land management practices (Pantoja, 2002), with insurance, premiums can be adjusted to encourage sound practices indirectly.

Agent-partner models are widely advocated for successful micro-insurance schemes (Zupi, 2001, Brown, 2001). If weather insurance is to reach the poor, it has to do in a micro form. This consists of an agent with strong links to customers who are responsible for the marketing and delivery of the insurance product and a partner whose role is the design of the insurance product and provide the capital input. The detailed considerations of agent-partner models have been discussed earlier (See Section 1.3.7, page 2)

Regulatory environments can also act as an obstacle for the distribution of micro-insurance. In many countries there are regulatory impediments that prevent MFOs or NGOs from selling insurance products. One way around this is for MFOs to team up with the formal insurance sector as described in the partner-agent model. The biggest challenge faced in an agent-partner model is that there are few insurers willing to involve themselves in micro-insurance (Brown and Churchill, 1999). Micro-insurance organizations need to copy existing successful schemes to be successful. Pilot schemes proposed by Diaz Nieto *et al*. (2006*a*) are therefore much needed to illustrate to insurers that such schemes can be viable.

7.2. Proposed distribution mechanism for Nicaragua

A generalized schema for a proposed mechanism for the distribution of micro insurance to drybean growers in Nicaragua is presented in Figure 7–0. The roles of the different actors are discussed below.

7.2.1. Role of micro finance organizations

Micro finance organizations (MFOs) are best positioned to implement a marketing and distribution network rapidly, since they already have the contacts with the small-holder farmers and in most cases they are already actively involved in marketing and in

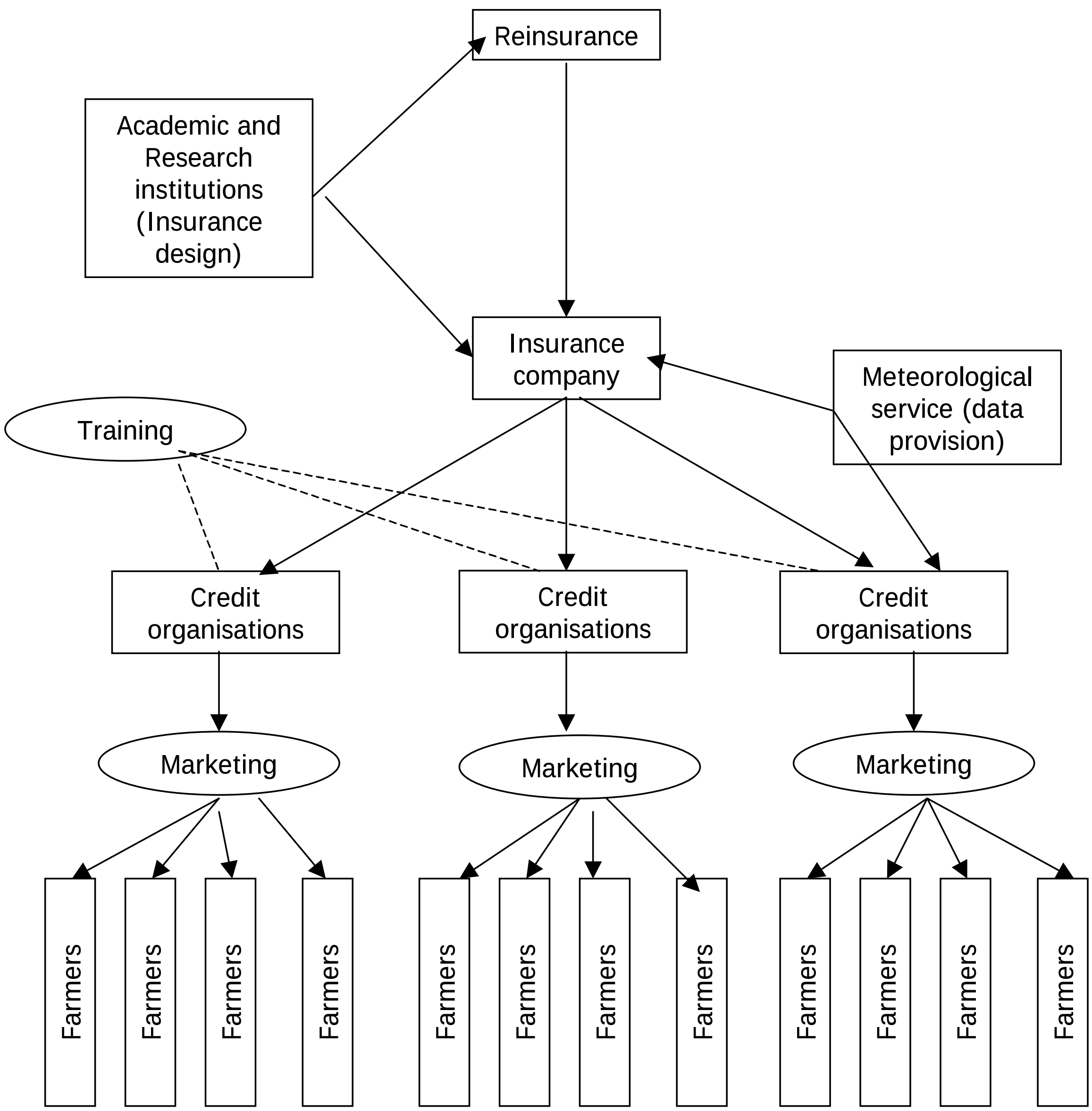


Figure 7–2 Schematic for the proposed distribution of weather insurance to drybean farmers in Nicaragua.

programs to communicate with clients.

Ideas for the distribution of micro-weather insurance were discussed at interviews with MFOs in northern Nicaragua in 2005. Regulatory restrictions were commonly cited as an obstacle. In Nicaragua MFOs are not even able to offer a savings services to customers because the Micro Finance law has not yet been passed by the government. Only institutions that qualify as a bank, and are therefore subject to supervisory regulations can offer a wide selection of financial products. However, when the partner-agent model was discussed, most of the MFOs commented that this would be a satisfactory and favourable manner of getting micro-weather insurance products to their customers.

The MFOs do not believe that acting as sales agents for weather insurance would incur many additional costs. They already carry out regular farm inspections and their sales agents promote their credit schemes in the field, so that promoting weather insurance could easily be incorporated into their daily operations. CARITAS-Estelí (2005) added that the sales agent usually travels to the communities by motorcycle so that marketing costs are therefore minimal. CARITAS-Estelí (2005) further suggested that insurance companies' commissions could prove to be a valuable additional incentive to their field agents. FIDER-Estelí (2005)considers their relative advantage not only to be access to small-holder producers, but also that they have the producers' best interests in mind, compared to the likely orientation of large companies, which are only loosely linked to the rural community.

The MFOs viewed a weather-indexed insurance product as being beneficial to their own organizations. Offering weather insurance as part of a portfolio of micro-finance products would help with loan recovery and reduce risk. Some of MFOs also considered the possibility weather insurance could act as a guarantee for credit.

The MFO's major concern was the financial viability of such an insurance scheme. Drybean producers are typically very small scale and also their holdings are physically widely dispersed. It is likely therefore that the coverage will be low in terms of insured hectares (and hence low cash flow from premiums) coupled with high transaction costs.

Catholic Relief Services, which works in partnership with MFOs, is very interested to support development of this type of tool. It was thought that CRS could play a coordinating role; for example in coordinating training for MFO partners or acting as a central agent for access and distribution of relevant information.

7.2.2. Role of insurance companies

Although the proposed weather insurance is primarily aimed at small-holder producers, and it therefore seems logical to use MFOs as contact points, the role of the insurer is critical. National insurance companies are fully aware of the regulatory requirements and how to comply with these. They are also better positioned to calculate premium prices using their skills in actuarial practice. It is unlikely that any national insurance company will have a wide network of branches in rural areas, and this would be a significant hindrance on the success of a weather insurance scheme designed for small holders. It is therefore critical to forge effective partnerships.

7.2.3. Re-insurance

Re-insurance is essential to ensure the continuity and viability of any insurance scheme. Furthermore it is nearly always a regulatory requirement that insurance schemes are backed up by re-insurance. The role of re-insurance companies is to provide coverage to local and national insurers. In the case of weather insurance it is of particular importance to have re-insurance coverage since weather risks are highly covariant and therefore these risks have to be spread out around the world. This is only possible through re-insurance.

Re-insurance is critical for the success of weather insurance schemes, and yet at the moment are their biggest challenge. There are two main reasons for this. Firstly re-insurance companies are unlikely to be interested in dealing with small-scale transactions, which implies pooling at a national scale. The second and more important challenge is that these companies have very strict climate-data requirements. To obtain re-insurance, the data used by the local insurer to calculate premium prices has to be acceptable to the re-insurer. At this stage it is unknown how re-insurers would react to the scheme proposed here. Initial responses have been encouraging.

7.2.4. Role of meteorological data providers

One of the advantages of a weather insurance scheme is that, in theory, payments can be made as soon as the adverse weather event is recorded or the trigger is reached. In practice however, for this to be the case, collection and distribution of reliable weather data must be timely. It is generally accepted that the weather data should be managed by an independent source (someone other than the insurer or the insured) to minimize the possibility of corruption. The role of the independent weather data provider is therefore critical. The data that are used to determine whether the payments threshold is met or not should be quality checked and quality guaranteed. Agreements need to be drawn up with weather data providers that carefully lay out responsibilities for maintenance of weather stations, guarantee the data quality and also responsibilities for the timely collection and distribution of the data. As discussed earlier in this report, one further point is contingency planning for occasions when weather stations are tampered with or break down.

7.2.5. Role of academic and research institutions

Technical design of weather insurance schemes should incorporate sound science. The design of weather insurance may therefore be contracted out to academic and research institutions.

7.2.6. Role of government

The case for government involvement has been much disputed. On the one hand it is argued that any insurance scheme should be self-sufficient by not needing subsidies. On the other hand, it is also argued that small-holder, resource-poor farmers need subsidized premiums otherwise they simply cannot access these risk-management tools. Although many government schemes have failed, Skees *et al.* (2001) believe that solely private schemes are likely to fail without some government intervention.

National governments could assume the role of setting benchmark standards for private insurance companies. Moreover, the information, data and infrastructure that serve government purposes can also be used for commercial insurance. The government could act as the central agent for obtaining re-insurance on a national scale. Involvement of the state can reduce moral hazard by making it clear that there will be no *ad hoc* intervention. Economists suggest that government intervention should only occur in the most severe and catastrophic events, leaving the less catastrophic risks to be dealt with by private companies (Skees *et al.*, 2001).

7.2.7. Providing insurance with supplies

In addition to providing insurance with micro-credit, there is also the possibility of providing micro insurance via agricultural suppliers. This proposal met with a mixed reaction amongst MFO partners in Nicaragua. Clearly the proposal needs more thought.

8

8. Consultation with farmers

8.1. How much rain do farmers think they need

We carried out an exercise with Nicaraguan farmers to identify how much rain they thought they needed to grow a crop of drybeans compare these with our estimates in section 4.3. This exercise also gave us an indication of what farmers might or might not like about the technical structure of the proposed insurance. It also started farmers thinking about rainfall and crop yield so that we could subsequently present the insurance product and gather feedback.

Although the results varied considerably, farmers had a good idea of the rain that they needed to grow a good crop (Figure 8-0), which was congruent with the main findings of section 4.3. Most of them knew that sufficient rainfall during flowering was critical. When we compare the farmers' results to those of the simulation, we see that they believe they need more rainfall during the first 20 days after sowing than the simulations suggest, 10 to 30 mm depending on the soil texture and slope.

8.2. Farmer feedback on weather insurance

At the second session of the farmers' workshops, we introduced the topic of weather insurance and asked the farmers for feedback and comments. We started by asking

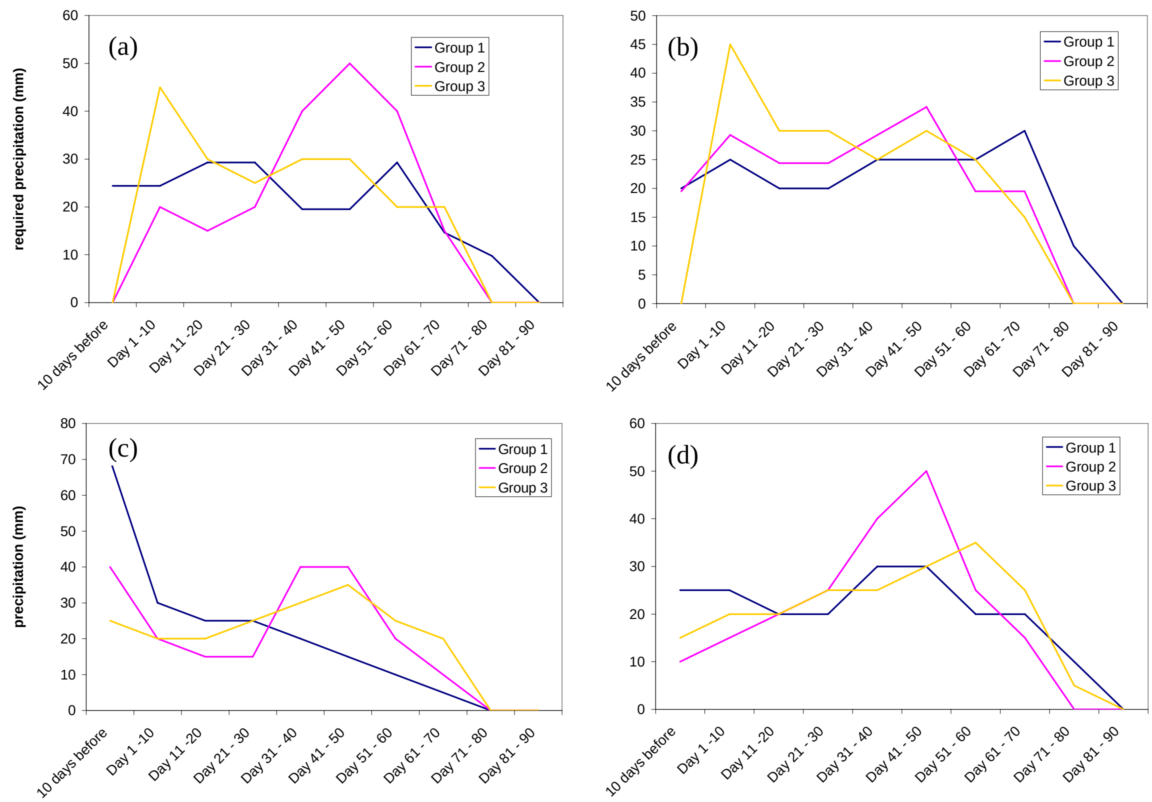


Figure 8-1 Rainfall requirements for bean development according to farmer groups. Note the different scales on the ordinate. (a) Matagalpa, (b) Sébaco, (c) Jinotega, (d) Estalí.

farmers what they knew about insurance. A few of them said that they had a general understanding, but on the whole they said that they did not know how insurance works and have never had any experience with it. Insurance will therefore be a new instrument to most poor farmers, and emphasizes the need for communicating with the potential clients. This will require providing information as well as marketing in an ongoing program as farmers gain experience with insurance products.

After introducing the topic, we asked farmers to vote their preferences among the different types of contract and coverage. Mostly they voted for those contracts that gave the higher levels of coverage even though these contracts cost more. Responses to individual questionnaires confirmed this. In more humid areas, however, farmers wanted contracts that paid out higher amounts in more extreme droughts.

Farmers also preferred contracts that paid in proportion to the severity of drought. This site-specific voting shows that contracts should be tailored to farmers' needs by region. Although interesting, the exercise does not reflect the farmers' ability or even their willingness actually to buy insurance cover. This aspect needs further study.

Farmers were also asked how they would prefer to be offered weather insurance. The options were:

- Purchase insurance with input supplies (seed, fertilizer),
- Insurance incorporated into credit or
- Insurance as a standard stand-alone contract.

The farmers' preferences varied by region. In Estelí most farmers preferred to buy weather insurance combined with credit while in both Jinotega and Sebaco this was the least popular option. A Matagalpa farmer expressed the concern that if insurance is sold only with credit, how would he able to get coverage if he was either not eligible for credit or did not chose to take it? This illustrates the importance of offering multiple choices in weather insurance to ensure wider coverage.

Following the voting exercises we asked farmers for their queries and comments about the weather-insurance product. Farmers were very enthusiastic. The most frequent question was whether this product would also be available for excess rainfall. Farmers in all the workshops asked if the product was available to buy now, where they could buy it, or when would it be available.

Farmers understood the concept that premium prices would depend on their location. Time and again farmers asked us after the workshop how much premiums would cost for their specific area. In the Estelí workshop farmers quickly understood the concept of the index and asked very specific questions about its structure. For example, one farmer asked if rainfall deficits at flowering would pay a higher indemnity payment, since this was the most critical period during the crop's growth. The correct response to this is that the different levels of minimum water requirement implicitly contain a weighting factor that takes this point into account.

Farmers at Estelí also questioned the way the index assigned very little rainfall to the first twenty day period. They said that if there is no rainfall in the first two weeks after sowing, the bean crop will die, but they would not get a payout if it rained for the remainder of the contract period, which would be useless since the crop was already dead. This point is well taken, and in fact Figure 4.3 shows that the minimum water requirement is from 10 to 30 mm in the second dekad, depending on soil texture and slope. In Jinotega, four producers asked for a copy of the materials so that they could tell the rest of their community about weather insurance.

Farmers provided valuable feedback on administrative and operational aspects of such a scheme. When asked to comment on the weather stations that would determine payouts, farmers at Estelí mentioned that as a minimum requirement they wanted a weather station in each community. When asked who should be in charge of the stations and the rainfall data, there were several suggestions such as community leaders, independent organizations, the state meteorological department INETER with emphasis on trained and reliable personnel.

Concerns were expressed about the sort of company that would manage this type of scheme. An Estelí farmer worried that if there was a widespread drought so that the insurance company had to pay indemnities to many farmers, it would go bankrupt and not be able to pay. We explained that there would be legal requirements about statutory reserves to protect clients and how reinsurance secures primary insurers but the farmers were not convinced. When we told them about the possibility that the MFOs (i.e. FIDER and CARITAS) would possibly be involved farmers were happier with the idea, saying that they trusted these organizations more than some outside and unknown organization.

In summary the producers showed a lot of interest in the product. To conclude, below is a quote from a producer at Matagalpa:

"Esto lo que quiere decir es que me estoy asegurando para que? – para tener un futuro mejor. Aquí lo más importante es prevenir que si viene la sequía estoy asegurado – para mantener mi familia"

(What does it mean to be insured? It means to have a better future. The most important thing here is to be prepared if a drought comes along, so that I can support my family).

9. Next steps

Pilot run

The general consensus among both farmers and MFOs is the need for a pilot run in which the MFOs were very keen to be involved. A pilot run would increase community awareness of weather insurance and would also contribute towards communication with the public that is needed to support such a scheme.

Gain acceptance of proposed methodology in the re-insurance industry

It is essential to work very closely with the re-insurance industry in any methodology development in this area, since it is the re-insurance industry that will ultimately approve it or not. Without acceptance by re-insurers, insurance schemes at the local level cannot take off, since re-insurance is not only critical to ensure long-term viability, but in almost all cases it is a legal requirement.

Viability study

Before becoming involved, an insurance company needs to know that it is financially viable to offer weather insurance to small-holder producers. Since small-holder producers by definition imply high transaction costs. Moreover, the amount of insurance coverage is small, so there is likely to be a fine line between making a profit making and incurring a loss. Market studies are therefore needed to determine the number of farmers that would opt to purchase insurance.

Further technical development

In section 4.3.1 we highlighted several areas for further technical development (soil texture and water availability, effect of cultivar, effects of temperature due to altitude, accuracy of the MarkSim weather surface and how to specify sowing date in the insurance contract in a simple and transparent way). These points should be developed so that the final product is technically unassailable. Farmer workshops also highlighted some important points (rainfall in the first 20 days after sowing), which also need consideration. In addition to refinement of the drought index, research should also be started into the design of insurance against excess rainfall, a feature requested by many farmers.

10. References

Abarca, H.S., Araya, V.R, Chaves, F.C.A. and Rivera, G.J.C. (1988). Efecto del déficit hídrico en varias etapas de desarrollo del fríjol común (*Phaseolus vulgaris* L. cv. Huetar). Boletín Técnico Estación Experimental Fabio Baudrit. **21**(2):1-8. (Quoted by Ríos and Quirós, 2002.)

Ahuja, R. and Jütting, J. (2004) Are the poor too poor to demand health insurance. Indian Council for Research on International Economic Relations, Working Paper No. 118. 27pp.

Baltodano, M.E. (ed.) (2001). *Línea Base del Sitio de Referencia, San Dionisio, Nicaragua*. Publicación No 9. CIAT- Proyecto Comunidades y Cuencas, Nicaragua. Centro Internacional de Agricultura Tropical (CIAT), Managua, Nicaragua. 38pp.

Barrett, C.B. and Brown, D.R. (2002). Agriculture and rural development: lessons for Christian groups combating persistent poverty. Working Paper 2002-45, Department of Applied Economics and Management, Cornell University, Ithaca, New York. Available at: http://aem.cornell.edu/research/researchpdf/wp0245.pdf. 17pp. Accessed 26 March, 2006.

Barrett, C. B., Reardon, T. and Webb, P. (2001). Non-farm income diversification and household livelihood strategies in rural Africa: Concepts, dynamics and policy implications. Working paper. Available at: http://www.inequality.com/publications/working_papers/Barrett-Reardon-Webb_IntroFinal.pdf. 31pp. Accessed 26 March, 2006.

Brown, W (2001). Micro-insurance: The risks, perils and opportunities. Small Enterprise Development **12**(1):11-24.

Brown, W. and Churchill, C. (1999). Providing Insurance to Low-Income Households Part I: A Primer on Insurance Principles and Products. USAID - Microenterprise Best Practices (MBP) Project. 91pp.

Brown, W., Green, C. and Lindquist, G. (2000). Cautionary note for MFIs and donors considering developing microinsurance products. Development Alternatives Inc., USAID's Microenterprise Best Practices Project, Bethesda, MD. Available at: http://www.usaidmicro.org/pdfs/mbp/a_cautionary_note_for_microfinance_institutions.pdf. 42pp. Accessed 27 March, 2006.

Bryla, E., Dana, J., Hess, U. and Varangis, P. (2003). Innovative approaches for improving access to agricultural lending: The use of price and weather risk management instruments. Paving the Way Forward for Rural Finance: An International Conference on Best Practices, 2-4 June, 2003, Washington DC. Available at: http://www.basis.wisc.edu/live/rfc/cs_03a.pdf. 18pp. Accessed 27 March, 2006.

CARITAS-Estelí. (2005) Meeting to discuss micro weather insurance, Estelí, Nicaragua. Personal communication.

CGAP (2004). Consultative Group to Assist the Poor. Available at: http://www.cgap.org/direct/docs/presentations/Rural_Poor.ppt. Powerpoint presentation of 23 slides including notes. Accessed 26 March, 2006.

Cohen, M. and Sebstad, J. (2003). Reducing vulnerability: The demand for microinsurance. Available at: http://www.microfinanceopportunities.org/docs/Reducing_%20Vulnerability_the_Demand_for_Microinsurance_CohenSebstadmarch2003.pdf. 73pp. Accessed 26 March, 2006.

Davidson, B.R. 1965. The Northern Myth: A Study of the Physical and Economic Limits to Agricultural and Pastoral Development in Tropical Australia. Melbourne University Press, Carlton, Victoria. 283pp.

Dercon, S. (2001). Income risk, coping strategies and safety nets. The Centre for the Study of African Economies Working Paper, CSAE WPS/2003-01. Oxford University. Available at: http://www.wiwiss.fu-berlin.de/w3/w3collie/SocPolWS03/DerconSurvey.pdf. 37pp. Accessed 27 March, 2006.

Dercon, S. (2003). Risk and poverty: a selective review (Or: Can social protection reduce poverty?). Mimeo, Department of Economics, Oxford University.

Díaz Nieto, J., Cook, S., Jones, P. and Skees, J. (2006*a*). Developing a method of site-specific drought insurance for bean farmers in Honduras. Research Journal on Microfinance and Development (in press)

Díaz Nieto, J., Cook, S.E., Lundy, M. and Fisher, M.J. (2006*b*). Weather indices for designing micro-insurance products for poor small-holder farmers in the tropics: Design considerations for

applying computer-based simulations. Journal of Computers and Electronics in Agriculture (in press).
FIDER-Estelí (2005). Meeting to discuss micro weather insurance, Estelí, Nicaragua. Personal communication.
FIDER-Jinotega (2005). Meeting to discuss micro weather insurance, Jinotega, Nicaragua. Personal communication.
Goes, A. and Skees, R.J. (2003). Financing natural disaster risk using charity contributions and *ex ante* index insurance. The annual meetings of the American Agricultural Economics Association, Montreal, Canada, July, 27-30. 15pp.
Hazell, P.; Larson, D.; Mac-Isaac, D. and Zupi, M. (2000). Weather insurance project study: Ethiopia feasibility assessment. World Bank/Fondazione Salernitana Sichelgaita/IFPRI. Available at: http://alphaweb.economia.uniroma2.it/sichelgaita/forum/session2/subsession22/subsession221/hazel.pdf. 46pp. Accessed 27 March, 2006.
Hess, U. (2003*a*). Innovative financial services for rural India: Monsoon-indexed lending and insurance for small holders. Agriculture and Rural Development Working Paper 9. World Bank, Washington, DC.
Hess, U. (2003*b*). Comments on paper "Risk management challenges in rural financial markets: blending risk management innovations with rural finance" by J. Skees. Paving the Way Forward for Rural Finance: An International Conference on Best Practices, 2-4 June, 2003, Washington DC. Available at: http://www.basis.wisc.edu/live/rfc/theme_risk_r3.pdf. 5pp. Accessed 27 March, 2006.
Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology **25**:1965-1978.
Jaffee, D.M. and Russell, T. (1997). Catastrophe insurance, capital markets and uninsurable risks. Journal of Risk and Insurance **64**(2):205-230.
Jalan, J. and Ravallion, M. (1999). Are the poor less well-insured? Evidence on vulnerability to income risk in rural China. Journal of Development Economics **58**:61-81.
Jaramillo, P.M. (1989). El cultivo del fríol. Federación Nacional de Cafeteros, Colombia. 36pp. (Quoted by Ríos and Quirós, 2002.)
Johnson, N.L. and Klass, J. (2003). The impact of crop improvement of rural poverty: An analysis of bean varieties resistant to bean golden mosaic virus in Honduras. In: Mathur, S., Pachico, D.H. and Jones, A.L. (eds.). *Agricultural Research and Poverty Reduction: Some Issues and Evidence.* Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia. (CIAT Publication No. 335). p.241-258.
Jones, J.W., Hoogenboom, G., Porter, C.H., Boote, K.J., Batchelor, W.D., Hunt, L.A., Wilkens, P.W., Singh, U., Gijsman, A.J. and Ritchie, J.T. (2003). The DSSAT cropping system model. European Journal of Agronomy **18**:235-265.
Jones, P.G. and Thornton, P.K. (1999) Fitting a third-order Markov rainfall model to interpolated climate surfaces. Agricultural and Forest Meteorology (Netherlands) **97**:213-231.
Jones, P.G.; Thornton, P.K. (2000). MarkSim: Software to generate daily weather data for Latin America and Africa. Agronomy Journal **92**:445-453.
Jones, P.G.; Thornton, P.K.; Díaz, W.; Wilkens, P.W.; Jones, A.L. (2002). MarkSim: a computer tool that generates simulated weather data for crop modeling and risk Assessment: Version 1. Centro Internacional de Agricultura Tropical, Cali, Colombia. 87pp.
Magaña,V., Amador, J.A., and Medina, S. (1999). The midsummer drought over Mexico and Central America. American Meteorology Society **12**:1577-1588.
MAGFOR (2001). *Atlas Rural de Nicaragua.* Ministerio Agropecuario y Forestal, Managua, Nicaragua.
Manojkumar, K., Sreekumar, B. and Ajitkumar, G. S. (2003). Crop insurance scheme: A case study of banana farmers in Wayanad district. Kerala Research Programme on Local Level Development, Centre for Development Studies, Thiruvananthapuram. Discussion Paper No. 34. Available at: http://krpcds.org/publication/downloads/54.pdf. 56pp. Accessed 26 March, 2006.
Mather, D.L., Bernsten, R., Rosas, J.C., Viana Ruano, A. and Escoto, D. (2003). The economic impact of bean disease resistance research in Honduras. Agricultural Economics **29**:343-352.
Mathie, A.. (2001). Including the excluded: Lessons learned from the poverty targeting strategies used by micro-finance providers. Occassional Paper. Available at

http://www.stfx.ca/institutes/coady/about_publications_occasional_including.html. Unpaginated html file. Accessed 26 March, 2006.

McCarthy, N. (2003). Demand for rainfall-index based insurance: a case study from Morocco. Available at: http://www.ifpri.org/divs/eptd/dp/papers/eptdp106.pdf. 39pp. Accessed 26 March,2006.

Miranda, M.J. and Glauber, J.W. (1997). Systematic risk, reinsurance, and the failure of crop insurance markets. American Journal of Agricultural Economics **79**:206-215.

Miranda, M.J. and Vedenov, D.M. (2001). Innovations in agricultural and natural disaster insurance. American Journal of Agricultural Economics **83**:650-655.

Mishra, P.K. (1994). Crop insurance and crop credit: Impact of the comprehensive crop insurance scheme on cooperative credit in Gujarat. Journal of International Development **6**(5):529-568.

Morduch, J. (1995). Income smoothing and consumption smoothing. Journal of Economic Perspectives **9**(3):103-114.

Morduch, J. (1999). Between the state and the market: Can informal insurance patch the safety net? The World Bank Research Observer **14**(2):187-207.

Morduch, J. (2001). Rainfall insurance and vulnerability: Economic principles and cuationary notes. Available at: http://www.nyu.edu/projects/morduch/documents/rainfall%20insurance.pdf. 7pp. Accessed 16 March, 2006.

Mosley, P. and Krishnamurthy, R. (1995). Can crop insurance work? The case of India. Journal of Development Studies **31**(3):428-450.

Pantoja, E. (2002). Microfinance and disaster risk management: Experiences and lessons learned. Available at: http://www.proventionconsortium.org/files/microfinance_drm.pdf. 93pp. Accessed 26 March, 2006.

Quintana, J.O. and Caceres, V.H. (1983). Suelos y fertilización del fríjol *Phaseolus vulgaris* L. en las zonas de producción de Nicaragua. In: Tapia and Garcia (eds.) *Manual de Producción de Fríjol Común*. Ministerio de Desarrollo Agropecuario y Reforma Agraria, Managua, Nicaragua. p.126-139.

Ríos, M.J. and Quirós, J.E. (2002). *El Frijol (*Phaseolus vulgaris *L.): Cultivo, Beneficio y Variedades.* Federación Nacional de Cultivadores de Cereales y Leguminosas (FENALCE), Medellín, Colombia. 193pp.

Rosenzweig, M.R. and Binswanger, H.P. (1993). Wealth, weather risk and the composition and profitability of agricultural investments. The Economic Journal **103**:56-78.

Sakurai, T. and Reardon, T. (1997). Potential demand for drought insurance in Burkina Faso and its determinants. American Journal of Agricultural Economics **79**:1193-1207.

Skees, J., Hazell, P. and Miranda, M. (1999). New approaches to crop yield insurance in developing countries.. Environment and Production Technology Division, IFPRI, Discussion Paper No. 55. Available at: http://www.ifpri.org/divs/eptd/dp/papers/eptdp55.pdf. 40pp. Accessed 27 March, 2006.

Skees, J. (2003). Risk management challenges in rural financial markets: Blending risk management innovations with rural finance. Paving the Way Forward for Rural Finance: An International Conference on Best Practices, 2-4 June, 2003, Washington DC. Lead Theme Paper. Available at: http://www.basis.wisc.edu/rfc/documents/theme_risk.pdf. 36pp. Accessed 27 March, 2006.

Skees, J., Gober, S., Varangis, P., Lester, R. and Kalavakonda,V. (2001). Developing rainfall based index insurance in Morocco. Policy Research Working Paper 2577. World Bank, Washington DC. Available at: http://wdsbeta.worldbank.org/external/default/WDSContentServer/IW3P/IB/2001/04/27/000094946_01041305561587/Rendered/PDF/multi0page.pdf. 37pp. Accessed 27 March, 2006.

Stoker, R. (1974). Effect of dwarf beans of water stress at different phases of growth New Zealand. Journal of Experimental Agriculture. **2**(1):13-15. (Quoted by Ríos and Quirós, 2002.)

Stoppa, A. and Hess, U. (2003). Design and use of weather derivatives in agricultural policies: The case of rainfall index insurance in Morocco. International Conference: Agricultural Policy Reform and the WTO: Where Are We Heading? Capri (Italy), June 23-26, 2003. Available at: http://www.itf-commrisk.org/documents/rainfallmorocco.pdf. 18pp. Accessed 27 March, 2006

Tapia Barquero, H. and García Alarcón, J.W. (eds.) (1983). *Manual de Producción de Fríjol Común.* Ministerio de Desarrollo Agropecuario y Reforma Agraria, Managua, Nicaragua.

Turvey, C.G. (2001). Weather derivatives for specific event risks in agriculture. Review of Agricultural Economics **23**(2):333-351.

van Oppen, C. (2001). Insurance: A tool for sustainable development. Available at: http://microfinancegateway.org/files/2709_file_02709.doc. 19pp. Accessed 27 March, 2006.
Varangis,P., Skees, J., and Barnett,B. (2004). Weather indexes for developing countries. In: Mathur, A., Burton, I. and van Aalst, M. (eds.) *An Adaptation Mosaic: A Sample of the Emerging World Bank Work in Climate Change Adaptation.* World Bank, Washington DC. p.99-118.
Voysest, O. and Dessert, M. (1991). Bean cultivars: Classes and commercial seed types. In: Schoonhoven, A. van and Voysest, O. (eds.) *Common Beans: Research for Crop Improvement.* C.A.B. International, Wallingford, UK and Centro Internacional de Agricultura Tropical, Cali, Colombia. p.119-162.
Webb, P. and Reardon, R. (1992). Drought impact and household response in East and West Africa. Quarterly Journal of International Agriculture **31**(3):230-246.
Wenner, M. and Arias, D. (2003). Agricultural insurance in Latin America: Where are we? Paving the Way Forward for Rural Finance: An International Conference on Best Practices, 2-4 June, 2003, Washington DC. Case Study**.** Available at: http://www.basis.wisc.edu/live/rfc/cs_03b.pdf. 19pp. Accessed 27 March, 2006.
White, J.W. (1985). Conceptos básicos de fisiología del frijol. En: *Fríjol, Investigación y Producción*. CIAT, Cali, Colombia. p. 43-60 (Quoted by Ríos and Quirós, 2002)
White, J. W. and Izquierdo, J. (1989). *Fisiología del Potencial de Rendimiento y la Tolerancia al Estrés.* CIAT, Cali, Colombia and FAO, Chile. 91pp. (Quoted by Ríos and Quirós, 2002.)
White, J.W. and Izquierdo, J. (1991). Physiology of yield potential and stress tolerance In Schoonhoven, A. van; Voysest, O. (eds.) *Common beans: research for crop improvement*. Wallingford, UK, C.A.B. International; Cali, Colombia, Centro Internacional de Agricultura Tropical. p.287-382
White, J.W., Hoogenboom, G., Jones, J.W., and Boote, K.J. (1995). Evaluation of the dry bean model BEANGRO V1.01 for crop production research in a tropical environment. Experimental Agriculture **31**:241-254.
World Bank (2000). *Managing Catastrophic Risks Using Alternative Risk Financing And Insurance Pooling Mechanisms*. The World Bank, Washington DC. Available at: http://wbln0018.worldbank.org/External/lac/lac.nsf/c3473659f307761e852567ec0054ee1b/42d730ec3090933a852568ef0057639b/$FILE/Risk+Management.pdf. 118pp. Accessed 27 March, 2006.
World Bank (2001). Innovations in managing catastrophic risks: how can they help the poor?. Available at: http://www.proventionconsortium.org/files/wharton_010801/questions_for_sessions.pdf. 6pp. Accessed 26 March, 2006.
Zeller, M. and Sharma, M. (1998). Rural finance and poverty alleviation. Available at: http://www.ifpri.org/pubs/fpr/fpr25.pdf. 32pp. Accessed 26 March, 2006
Zupi, M. (2001). The connection between micro-finance and micro-insurance in LDC: A review of literature and experiences. World Bank, Washington DC. 43pp.

11

11. Full list of reports completed for this study

1. Report 01 Literature review on experiences to date
2. Report 02 Nicaragua case study information
3. Report 03 Methodology development 1
4. Report 04 Methodology development 2
5. Report 05 Methodology development 3
6. Report 06 Producer workshop in Sébaco
7. Report 07 Producer workshop in Matagalpa
8. Report 08 Producer workshop in Jinotega
9. Report 09 Producer workshop in Estelí
10. Report 10 Methodology development 4
11. Report 11 Comparison of MarkSim and Observed data
12. Report 08. Taller de productores de Jinotega
13. Report 09. Taller de productores de Estelí

APPENDIX: Soil and simulation input values used for DSSAT simulations

Sand Flat

SCOM	-99	Colour
SALB	0.15	Albedo (fraction)
SLU1	4	Evaporation limit (mm)
SLDR	0.4	Drainage rate(fracion/day)
SLRO	73	Surface runoff (Soil conservation service number)
SLNF	1	Mineralization factor (0-1)
SLPF	1	Photosynthesis factor (0-1)
SMHB	IB001	pH in buffer determination method, code
SMPX	IB001	Phosphorus determination code
SMKE	IB001	Potassium determination method, code

Depth to base of layer	Master soil horizon (code)	Soil water at lower limit (cm^3/cm^3)	Soil water at upper limit (cm^3/cm^3)	Upper limit, saturated (cm^3/cm^3)	Root growth factor, soil only, 0.0 to 1.0	Sat. hydraulic conductivity, macropore, cm h-1	Bulk density, moist, g cm-3	Organic carbon, %	Clay (<0.002 mm), %	Silt (0.05 to 0.002 mm), %	Coarse fraction (>2 mm), %	Total nitrogen, %	pH in water	pH in buffer	Cation exchange capacity, cmol kg-1
SLB	SLMH	SLLL	SDUL	SSAT	SRGF	SSKS	SBDM	SLOC	SLCL	SLSI	SLCF	SLNI	SLHW	SLHB	SCEC
5	-99	0.025	0.096	0.345	1	-99	1.66	0.29	5	5	0	0.03	6.5	-99	-99
15	-99	0.025	0.096	0.345	1	-99	1.66	0.29	5	5	0	0.03	6.5	-99	-99
30	-99	0.023	0.097	0.345	0.638	-99	1.66	0.28	5	5	0	0.03	6.5	-99	-99
45	-99	0.023	0.097	0.345	0.472	-99	1.66	0.24	5	5	0	0.02	6.5	-99	-99

Sand Slope

SCOM	-99	Colour
SALB	0.15	Albedo (fraction)
SLU1	4	Evaporation limit (mm)
SLDR	0.4	Drainage rate(fracion/day)
SLRO	83	Surface runoff (Soil conservation service number)
SLNF	1	Mineralization factor (0-1)
SLPF	1	Photosynthesis factor (0-1)
SMHB	IB001	pH in buffer determination method, code
SMPX	IB001	Phosphorus determination code
SMKE	IB001	Potassium determination method, code

Depth to base of layer	Master soil horizon (code)	Soil water at lower limit (cm^3/cm^3)	Soil water at upper limit (cm^3/cm^3)	Upper limit, saturated (cm^3/cm^3)	Root growth factor, soil only, 0.0 to 1.0	Sat. hydraulic conductivity, macropore, cm h-1	Bulk density, moist, g cm-3	Organic carbon, %	Clay (<0.002 mm), %	Silt (0.05 to 0.002 mm), %	Coarse fraction (>2 mm), %	Total nitrogen, %	pH in water	pH in buffer	Cation exchange capacity, cmol kg-1
SLB	SLMH	SLLL	SDUL	SSAT	SRGF	SSKS	SBDM	SLOC	SLCL	SLSI	SLCF	SLNI	SLHW	SLHB	SCEC
5	-99	0.025	0.096	0.345	1	-99	1.66	0.29	5	5	0	0.03	6.5	-99	-99
15	-99	0.025	0.096	0.345	1	-99	1.66	0.29	5	5	0	0.03	6.5	-99	-99
30	-99	0.023	0.097	0.345	0.638	-99	1.66	0.28	5	5	0	0.03	6.5	-99	-99
45	-99	0.023	0.097	0.345	0.472	-99	1.66	0.24	5	5	0	0.02	6.5	-99	-99

Sand Loam Flat

SCOM	-99	**Colour**
SALB	0.13	**Albedo (fraction)**
SLU1	6	**Evaporation limit (mm)**
SLDR	0.4	**Drainage rate(fracion/day)**
SLRO	73	**Surface runoff (Soil conservation service number)**
SLNF	1	**Mineralization factor (0-1)**
SLPF	1	**Photosynthesis factor (0-1)**
SMHB	IB001	**pH in buffer determination method, code**
SMPX	IB001	**Phosphorus determination code**
SMKE	IB001	**Potassium determination method, code**

Depth to base of layer	Master soil horizon (code)	Soil water at lower limit (cm^3/cm^3)	Soil water at upper limit (cm^3/cm^3)	Upper limit, saturated (cm^3/cm^3)	Root growth factor, soil only, 0.0 to 1.0	Sat. hydraulic conductivity, macropore, cm h-1	Bulk density, moist, g cm-3	Organic carbon, %	Clay (<0.002 mm), %	Silt (0.05 to 0.002 mm), %	Coarse fraction (>2 mm), %	Total nitrogen, %	pH in water	pH in buffer	Cation exchange capacity, cmol kg-1
SLB	**SLMH**	**SLLL**	**SDUL**	**SSAT**	**SRGF**	**SSKS**	**SBDM**	**SLOC**	**SLCL**	**SLSI**	**SLCF**	**SLNI**	**SLHW**	**SLHB**	**SCEC**
5	-99	0.052	0.176	0.359	1	-99	1.61	0.7	10	30	0	0.07	6.5	-99	-99
15	-99	0.052	0.176	0.359	1	-99	1.61	0.7	10	30	0	0.07	6.5	-99	-99
30	-99	0.052	0.176	0.359	0.638	-99	1.61	0.66	10	30	0	0.07	6.5	-99	-99
45	-99	0.073	0.192	0.36	0.472	-99	1.61	0.58	10	30	0	0.06	6.5	-99	-99

Sand Loam Slope

SCOM	-99	**Colour**
SALB	0.13	**Albedo (fraction)**
SLU1	6	**Evaporation limit (mm)**
SLDR	0.4	**Drainage rate(fracion/day)**
SLRO	83	**Surface runoff (Soil conservation service number)**
SLNF	1	**Mineralization factor (0-1)**
SLPF	1	**Photosynthesis factor (0-1)**
SMHB	IB001	**pH in buffer determination method, code**
SMPX	IB001	**Phosphorus determination code**
SMKE	IB001	**Potassium determination method, code**

Depth to base of layer	Master soil horizon (code)	Soil water at lower limit (cm^3/cm^3)	Soil water at upper limit (cm^3/cm^3)	Upper limit, saturated (cm^3/cm^3)	Root growth factor, soil only, 0.0 to 1.0	Sat. hydraulic conductivity, macropore, cm h-1	Bulk density, moist, g cm-3	Organic carbon, %	Clay (<0.002 mm), %	Silt (0.05 to 0.002 mm), %	Coarse fraction (>2 mm), %	Total nitrogen, %	pH in water	pH in buffer	Cation exchange capacity, cmol kg-1
SLB	**SLMH**	**SLLL**	**SDUL**	**SSAT**	**SRGF**	**SSKS**	**SBDM**	**SLOC**	**SLCL**	**SLSI**	**SLCF**	**SLNI**	**SLHW**	**SLHB**	**SCEC**
5	-99	0.052	0.176	0.359	1	-99	1.61	0.7	10	30	0	0.07	6.5	-99	-99
15	-99	0.052	0.176	0.359	1	-99	1.61	0.7	10	30	0	0.07	6.5	-99	-99
30	-99	0.052	0.176	0.359	0.638	-99	1.61	0.66	10	30	0	0.07	6.5	-99	-99
45	-99	0.073	0.192	0.36	0.472	-99	1.61	0.58	10	30	0	0.06	6.5	-99	-99

Silt Loam Flat

SCOM	-99	Colour
SALB	0.12	Albedo (fraction)
SLU1	6	Evaporation limit (mm)
SLDR	0.2	Drainage rate(fracion/day)
SLRO	81	Surface runoff (Soil conservation service number)
SLNF	1	Mineralization factor (0-1)
SLPF	1	Photosynthesis factor (0-1)
SMHB	IB001	pH in buffer determination method, code
SMPX	IB001	Phosphorus determination code
SMKE	IB001	Potassium determination method, code

Depth to base of layer	Master soil horizon (code)	Soil water at lower limit (cm^3/cm^3)	Soil water at upper limit (cm^3/cm^3)	Upper limit, saturated (cm^3/cm^3)	Root growth factor, soil only, 0.0 to 1.0	Sat. hydraulic conductivity, macropore, cm h-1	Bulk density, moist, g cm-3	Organic carbon, %	Clay (<0.002 mm), %	Silt (0.05 to 0.002 mm), %	Coarse fraction (>2 mm), %	Total nitrogen, %	pH in water	pH in buffer	Cation exchange capacity, cmol kg-1
SLB	**SLMH**	**SLLL**	**SDUL**	**SSAT**	**SRGF**	**SSKS**	**SBDM**	**SLOC**	**SLCL**	**SLSI**	**SLCF**	**SLNI**	**SLHW**	**SLHB**	**SCEC**
5	-99	0.11	0.227	0.45	1	-99	1.37	1.16	10	60	0	0.12	6.5	-99	-99
15	-99	0.11	0.227	0.45	1	-99	1.37	1.16	10	60	0	0.12	6.5	-99	-99
30	-99	0.103	0.201	0.451	0.638	-99	1.37	1.1	10	60	0	0.11	6.5	-99	-99
45	-99	0.099	0.193	0.452	0.472	-99	1.37	0.97	10	60	0	0.1	6.5	-99	-99

Silty Loam Slope

SCOM	-99	Colour
SALB	0.12	Albedo (fraction)
SLU1	6	Evaporation limit (mm)
SLDR	0.2	Drainage rate(fracion/day)
SLRO	91	Surface runoff (Soil conservation service number)
SLNF	1	Mineralization factor (0-1)
SLPF	1	Photosynthesis factor (0-1)
SMHB	IB001	pH in buffer determination method, code
SMPX	IB001	Phosphorus determination code
SMKE	IB001	Potassium determination method, code

Depth to base of layer	Master soil horizon (code)	Soil water at lower limit (cm^3/cm^3)	Soil water at upper limit (cm^3/cm^3)	Upper limit, saturated (cm^3/cm^3)	Root growth factor, soil only, 0.0 to 1.0	Sat. hydraulic conductivity, macropore, cm h-1	Bulk density, moist, g cm-3	Organic carbon, %	Clay (<0.002 mm), %	Silt (0.05 to 0.002 mm), %	Coarse fraction (>2 mm), %	Total nitrogen, %	pH in water	pH in buffer	Cation exchange capacity, cmol kg-1
SLB	**SLMH**	**SLLL**	**SDUL**	**SSAT**	**SRGF**	**SSKS**	**SBDM**	**SLOC**	**SLCL**	**SLSI**	**SLCF**	**SLNI**	**SLHW**	**SLHB**	**SCEC**
5	-99	0.11	0.227	0.45	1	-99	1.37	1.16	10	60	0	0.12	6.5	-99	-99
15	-99	0.11	0.227	0.45	1	-99	1.37	1.16	10	60	0	0.12	6.5	-99	-99
30	-99	0.103	0.201	0.451	0.638	-99	1.37	1.1	10	60	0	0.11	6.5	-99	-99
45	-99	0.099	0.193	0.452	0.472	-99	1.37	0.97	10	60	0	0.1	6.5	-99	-99

Silty Clay Flat

SCOM	-99	Colour
SALB	0.11	Albedo (fraction)
SLU1	6	Evaporation limit (mm)
SLDR	0.1	Drainage rate(fracion/day)
SLRO	84	Surface runoff (Soil conservation service number)
SLNF	1	Mineralization factor (0-1)
SLPF	1	Photosynthesis factor (0-1)
SMHB	IB001	pH in buffer determination method, code
SMPX	IB001	Phosphorus determination code
SMKE	IB001	Potassium determination method, code

Depth to base of layer SLB	Master soil horizon (code) SLMH	Soil water at lower limit (cm^3/cm^3) SLLL	Soil water at upper limit (cm^3/cm^3) SDUL	Upper limit, saturated (cm^3/cm^3) SSAT	Root growth factor, soil only, 0.0 to 1.0 SRGF	Sat. hydraulic conductivity, macropore, cm h-1 SSKS	Bulk density, moist, g cm-3 SBDM	Organic carbon, % SLOC	Clay (<0.002 mm), % SLCL	Silt (0.05 to 0.002 mm), % SLSI	Coarse fraction (>2 mm), % SLCF	Total nitrogen, % SLNI	pH in water SLHW	pH in buffer SLHB	Cation exchange capacity, cmol kg-1 SCEC
5	-99	0.228	0.385	0.463	1	-99	1.35	1.74	50	45	0	0.17	6.5	-99	-99
15	-99	0.228	0.385	0.463	1	-99	1.35	1.74	50	45	0	0.17	6.5	-99	-99
30	-99	0.228	0.385	0.459	0.638	-99	1.36	1.66	50	45	0	0.17	6.5	-99	-99
45	-99	0.249	0.406	0.461	0.472	-99	1.36	1.45	50	45	0	0.14	6.5	-99	-99

Silty Clay Slope

SCOM	-99	Colour
SALB	0.11	Albedo (fraction)
SLU1	6	Evaporation limit (mm)
SLDR	0.1	Drainage rate(fracion/day)
SLRO	94	Surface runoff (Soil conservation service number)
SLNF	1	Mineralization factor (0-1)
SLPF	1	Photosynthesis factor (0-1)
SMHB	IB001	pH in buffer determination method, code
SMPX	IB001	Phosphorus determination code
SMKE	IB001	Potassium determination method, code

Depth to base of layer SLB	Master soil horizon (code) SLMH	Soil water at lower limit (cm^3/cm^3) SLLL	Soil water at upper limit (cm^3/cm^3) SDUL	Upper limit, saturated (cm^3/cm^3) SSAT	Root growth factor, soil only, 0.0 to 1.0 SRGF	Sat. hydraulic conductivity, macropore, cm h-1 SSKS	Bulk density, moist, g cm-3 SBDM	Organic carbon, % SLOC	Clay (<0.002 mm), % SLCL	Silt (0.05 to 0.002 mm), % SLSI	Coarse fraction (>2 mm), % SLCF	Total nitrogen, % SLNI	pH in water SLHW	pH in buffer SLHB	Cation exchange capacity, cmol kg-1 SCEC
5	-99	0.228	0.385	0.463	1	-99	1.35	1.74	50	45	0	0.17	6.5	-99	-99
15	-99	0.228	0.385	0.463	1	-99	1.35	1.74	50	45	0	0.17	6.5	-99	-99
30	-99	0.228	0.385	0.459	0.638	-99	1.36	1.66	50	45	0	0.17	6.5	-99	-99
45	-99	0.249	0.406	0.461	0.472	-99	1.36	1.45	50	45	0	0.14	6.5	-99	-99

DSSAT input requirements		**Inputs for simulations**
General information	Crop	Dry bean
	Weather data	Simulated MarkSim WTG files
	Soil type	Various from DSSAT generic soil file
Initial conditions	Simulation start date	January-11
	% available water at start	10
	Nitrogen at start (kg/ha)	40
Cultivar		Rabia de Gato+ and BAT477+
Planting	Planting method	Dry seed
	Plant population at seedling, plants m^{-2}	17
	Plant population at emergence, plants m^{-2}	15
	Row spacing (cm)	30
	Planting depth (cm)	3
Planting date rules	Earliest planting date	April-11
	Latest planting date	May-11
	Lowest available soil water for planting	30
	Highest available soil water for planting	100
	Depth of soil water constraints (cm)	30
Simulation options	Limited by water	Yes
	Limited by nitrogen	No
	Limited by symbiosis	No
	Limited by phosphorus	No
	Limited by potassium	No
	Limited by chemicals	No
	Limited by diseases	No