research article

climate and development

Rainfall index insurance to help smallholder farmers manage drought risk

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The struggle to find sustainable formal insurance for droughts in developing countries captures the attention of many in the development community for good reason. Droughts disrupt the development process, and the impacts of drought are exacerbated by an unwillingness on the part of the poor to invest combined with a lack of access to credit. This paper first examines the problems associated with traditional approaches to formal drought insurance and goes on to examine the potential of index insurance that is event-driven. A combined weather-generation and crop simulation modelling approach is used to estimate site-specific risks. The method is demonstrated in a case study for dry bean production in Honduras.

Keywords: Central America; drought insurance; dry beans; Honduras; risk; poverty

1. Introduction

This paper begins by examining the role of crop insurance in assisting agricultural investment, indicating the potentials, opportunities and pitfalls. Although traditional approaches to crop insurance have been lacking, new approaches involving index insurance linked to weather events and yield shortfalls are being tested around the world. To date, these new approaches have largely neglected the potential of site-specific crop growth models that can be linked to specific weather-based insurance, which is the major focus of this paper. Crop growth simulation models are linked to a weather generation process to estimate risks of dry bean production for different locations in Honduras. The method is demonstrated by linking site- and soil-specific plant growth with drought insurance that is risk rated to cover drought risks for dry beans.

Climatic risk is a major problem for poor farmers in the tropics. The fear of damaging climatic events hinders investment that would otherwise drive development. Climatic risk therefore presents an important obstacle to changes that might otherwise enable people to climb out of poverty. Equally importantly, just as individual households are beginning to escape the grip of poverty, weather shocks can and do stop that progress. The literature that describes the poverty traps that are linked to climatic risk is growing (see Dercon, 2005). Farmers adopt a range of strategies to cope with risk, including avoidance, management or risk sharing. Possibly the most widely used method of risk sharing in the developed world is formal insurance. Yet very few poor farmers in the developing world use formal insurance; they are obliged instead to rely almost entirely on less effective mechanisms of risk avoidance, or risk sharing through informal arrangements and self-insurance.

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earthscan
doi:10.3763/cdev.2010.0050 ISSN: 1756-5529 (print), 1756-5537 (online) www.earthscan.co.uk/journals/cdev

2. Background and concepts

2.1. Crop insurance for poor smallholders

Farmers face crop losses because of drought, floods, frosts, fire, pests, theft and other hazards. Of these, the most prevalent are weather risks, which affect hundreds of millions of poor farmers each year. Nearly 80 per cent of farmers interviewed in Ethiopia cited harvest failure caused by drought, flooding or frost as the event that caused them most concern (Dercon, 2002). Pandey et al. (2001) showed that drought caused huge drops in income for rice farmers in the state of Orissa, India. In a review of chronic rural poverty, Bird et al. (2002) identified exposure to risk as a major, modifiable reason for chronic poverty, and noted that there was widespread evidence that risk is correlated with poverty. Dercon (2005) demonstrates a strong link between shocks and poverty. Increasingly, studies are finding that the poor in developing countries are a transitory group that moves in and out of poverty on a regular basis. Shocks from a wide range of risk-related events stop progress and send households who are making progress back to the ranks of poverty. These poverty traps justify some type of public intervention using both equity and efficiency criteria. Dercon (2005, p. 2) concludes that 'social protection may well be good for growth'.

Many poor farmers self-insure informally (Webb and Reardon, 1992; Morduch, 1999) (Table 1), which spreads the risk internally but is an inefficient use of capital (Hazell et al., 2000) and rarely takes account of the actual risks involved. Moreover, weather hazards make poor farmers fearful of taking risks that might otherwise allow them to escape from poverty, leading to chronic under-investment, which in turn holds back farming systems from development (Webb and Reardon, 1992; Rosenzweig and Binswanger, 1993).

In contrast, formal insurance has been used for centuries to manage catastrophic risks by sharing the risk far beyond the immediate community where the event is sustained, which results in more sustainable and affordable insurance. A well-designed insurance scheme protects the general capital and enhances the opportunity to move to enterprises with higher mean incomes. Insurance is a tried-and-tested means of encouraging reasonable risk taking while discouraging excessive risk. It is progressive, in that insurers can increase the range of hazards they cover as knowledge accumulates about likelihood of events. Insurance is an effective method for communicating knowledge about risk through prices that reflect the best available knowledge about risk, which can lead to better management practices.

TABLE 1 Self-insurance measures and their impact on development (Skees, 2003; Dercon, 2002)

Self-insurance measure	How the measure acts as a barrier to development
Diversification	Diversification is often recommended; however, it is not beneficial if it involves diversifying away from the most productive practices.
Accumulation of financial reserves and stocks on farm	Financial reserves are not re-invested but are stored as a preventative measure.
Reliance on off-farm income generation	This is effective for independent risks, but less so for correlated risks when there is high competition and low wages.
Selling assets (e.g. cattle)	Selling of assets when everyone is trying to sell lowers prices and it may involve a net loss.
Avoidance of investment (e.g. fertilizing)	The fear of losing an entire crop because of unfavourable weather holds back farmers from costly but more productive investments (such as fertilizing).

Paradoxically, it is the people in the developing world who are most seriously affected by risk that are poorly served by insurance (Wenner and Arias, 2003). One assumption is that there is no weather insurance in developing countries because poor farmers have little surplus cash to buy it. Ahuja and Jutting (2004) concluded, however, that even the poor will buy insurance if it is incorporated into established micro-financial services.

Moreover, there will be a high demand for formal insurance where self-insurance is inadequate to reduce vulnerability (Sakurai and Reardon, 1997). The wide use of high-cost informal credit by the poor suggests that they may be willing to pay for effective insurance.

Multiple-peril or all-risk crop-insurance schemes (Table 2) were invariably government owned or heavily subsidized. Because they cover widely correlated risks, which private insurers consider imprudent to cover, they often fail when premiums do not cover indemnity payments (Miranda and Glauber, 1997; Skees et al., 1999). Their history is so poor that many governments and private companies decline to invest.

In almost all cases, formal crop insurance failed not because of the principle but because of technical and administrative problems.

Insurers cannot write policies unless they can estimate the likelihood of the insured event with reasonable accuracy. Farmers know more about the likelihood of crop failure on their farm than the insurer, however. This information asymmetry can be overcome if there are reliable and accurate historical data. Unfortunately these data are lacking in many poor countries, which is a major reason for insurance not being available. Lack of data is also a major obstacle to overcoming adverse selection (insuring high-risk farmers) and moral hazard (farmers behaving unwisely).

TABLE 2 Examples of crop insurance schemes

Location	Comments	Source
USA	Crop hail insurance has been offered for over 100 years. Private sector insurance provides single-peril insurance profitably. The government provides multiple-peril insurance; however, the scheme suffers from high loss ratios and increased premium subsidies have been used to mask poor actuarial performance.	Wenner and Arias (2003)
Brazil	A heavily subsidized government insurance scheme existed for most crops. All uncontrollable risks were covered and premium rates were equal across zones and crops, which led to manipulation of the scheme. The programme has had a high loss ratio and only high-risk farmers have benefited.	Rezende Lopes and Leite da Silva Dias (1986)
India	State-owned companies offer area index insurance but it has been unsuccessful and has a claims ratio that averages 500 per cent. Failure is attributed to the fact that premiums and claims were not equitably distributed across crops and states.	Hess (2003), Manojkumar et al. (2003)
Morocco	A heavily subsidized insurance scheme existed; however, participation rates were low and indemnity payments slow to reach policyholders. In 1999/2000 indemnity payments outstripped premiums and reinsurance resources were consumed.	Skees et al. (2001), Wenner and Arias (2003)
Uruguay	Agricultural insurance in Uruguay was available at a limited scale and was under state monopoly. The limited uptake is mainly due to the unofficial policy of automatic disaster relief.	Wenner and Arias (2003)
Mexico	In 2001 Mexico was the first developing country to experiment with weather indices. Weather markets were used to reinsure part of the multiple crop government insurance programmes. Weather index insurance for individual farmers is a voluntary programme. Although more cost-effective, coverage is lower than with the former insurance. Groups of farmers working through the FONDOs offer some promise for using weather index insurance in Mexico to basically start a mutual insurance system.	Hess (2003), Stoppa and Hess (2003), Wenner and Arias (2003)

Corruption (Wenner and Arias, 2003) and political bias are often problems. High administration costs to oversee contracts make individual contracts for smallholder farmers expensive and impracticable. Moreover, without reinsurance, multiple-peril and geographically concentrated schemes are vulnerable to collapse (Miranda and Glauber, 1997). The reinsurance market offers little support. Overall, existing insurance has been unable to support poor farmers, who are also deprived of access to finance and information technologies.

2.2. Weather insurance to cover crop loss

Although farmers want to insure against crop loss, insurers increasingly find it safer to insure against weather events. There are standard procedures to collect weather data so that it is simple to calculate the probabilities of an event that would trigger an insurance payout. Weather insurance took off in the 1990s in the North American energy sector (Turvey, 2001). Subsequently, agricultural economists have explored the potential for weather insurance to manage agricultural risks. The principles of weather insurance are summarized in Box 1 and explained in detail in Hazell et al. (2000), Skees (2000), Varangis (2001), Skees et al. (2001) and Bryla et al. (2003). Although many challenges remain, weather insurance has the potential to address many of the problems faced by formal insurance.

Weather-based insurance reduces the problem of information asymmetry because the probability of a particular weather event at a specific site is estimated from independent data, to which both the insured and the insurer have equal access. Similarly, adverse selection is no longer an issue because premiums are based on site-specific probabilities. Moral hazard becomes irrelevant because the trigger for indemnity is independent of the decisions of individual farmers. Administration costs are reduced because the trigger for indemnity payments is a defined weather event, which removes the cost of inspection to assess yield loss. Cost can be further reduced by using standard unit contracts (Skees et al., 2004).

BOX 1 Principles of weather insurance

The insurer offers protection against a defined weather event, normally a hazard such as drought, frost or excess rainfall. Since much more is known about the weather than about its consequences, the frequency of these events provides the basis for insurance instruments, which farmers can buy. The premium relates to the probability of the event and the size of indemnity according to the general formula (Brown and Churchill, 1999):

$$Premium = f(Indemnity.\,Probability\ of\ occurrence)$$

While the relationship between premium and indemnity must be determined solely on the basis of probabilities of events, certain parts of a scheme can be adjusted to suit both parties. For example, the trigger for, and the size of, the indemnity payment can be adjusted through the strike event to suit the preferences of individual customers. A farmer who believes he can manage all but the most serious events may choose a contract with low premium that pays indemnities only against the most exacting trigger. Conversely, a farmer who is in a more vulnerable situation may prefer a contract that pays smaller indemnities more frequently, or against larger premiums.

Weather index insurance does not remove correlated risk, but over the long term catastrophic risk sharing is viable (Jaffee and Russell, 1997) because spatially distributed historical records allow risks to be spread across uncorrelated areas, which is more attractive to reinsurers. Finally, existing organizations, such as microfinance institutions (MFIs), can provide new options for access to the rural poor. There are mutual benefits in offering insurance through an MFI, since high climatic risk is an obstacle to offering credit to farmers (Hess, 2003; Skees, 2003). Farming cooperatives (Black et al., 1999) or disaster relief organizations (Goes and Skees, 2003) are other possibilities.

The quantitative nature of the relationship between weather and crop yield must be established for it to provide the basis for insurance (Skees et al., 2004). This presents two problems in developing countries. First, historical weather data are essential to estimate the frequency of given weather events. Second, the quantitative relationship between weather and crop yield must be established. Both long-term historical weather data and long-term measurements of crop yields are scarce in most developing countries. Both these issues are addressed in the method described in this paper.

Temporal and spatial basis risks are also problems. Temporal basis risk is addressed below. Spatial basis risk becomes a problem for the farmer, not the insurer, because the insurer estimates risk for a given site and the indemnity is assessed at that same site. It can be reduced by offering a greater spatial density of site-specific insurance instruments.

Secure measurement is an essential requirement, which requires that the data collector has the confidence of both the insurer and the insured. This is now addressed by reliable, tamper-proof weather stations that deliver their data wirelessly to a central data centre.

2.3. Rainfall index insurance

For some years methods of rainfall index insurance have been applied to the problem of crop insurance in developing countries (World Bank, 2005). These methods are cheap and reasonably accurate, and operate by identifying rainfall patterns that are associated with yield loss, and representing these patterns as an index, with frequency estimated from weather data. The normal method of deriving the index divides the growing season into ten-day periods (dekads). Each dekad is assigned a weight to represent the sensitivity of crop yield to rainfall deficit during that period. Weighted values of rainfall deficit for each dekad are summed over the growing season to derive a single index that represents the integrated weighted rainfall deficit. This method has been trialled in India, Ethiopia, Malawi and elsewhere (see Hellmuth et al., 2009 for a review). It offers considerable cost advantages over conventional methods yet avoids the problem of moral hazard.

There are some concerns about the precision with which the index method represents yield loss, given the quality of the data that are normally available in developing countries. Firstly, long-run data sets on which to estimate the frequency of rainfall events are scarce or non-existent. Estimating the frequency of (say) a 1 in 8-year event on the basis of a rainfall record of 30 years or less seems to us a dangerous approximation.

Secondly, there is the problem of relating variations in rainfall to variations of crop yield. The inference that yield loss occurs as a result of a given pattern of rainfall deficit is a key part of the rainfall index method. Methods for estimating dekad weights vary from statistical regressions where both crop and rainfall data sets exist, data ‘taken from the literature’, to consultations with farmer groups to agree on appropriate weights. Yet if long-run data sets for rainfall are rare in developing countries, long-run data sets for crop yield are even rarer. The inference that a given rainfall pattern – that is, frequency estimated from short-run data – will result in yield loss seems at best highly approximate.

A third difficulty is the uncertainty caused by spatial variation. Variations of climate away from those represented by data from a weather station, possibly located near a regional capital, further reduce the precision with which the index represents what will happen in farmers’ fields. The limited reach of data, especially in varied topography, introduces further uncertainty in estimates of drought frequency and of their impact on crop yield.

Finally, the conventional method of estimating the rainfall index uses no agronomic insight to help explain temporal or spatial variations in crop performance. Although such knowledge is not essential to the insurance process, it is normal that domain knowledge is used to help understand the environment in which insurance operates. In this case, it could be used to explore the impact of management options that may influence risk, such as the use of drought-resistant crop varieties, appropriate fertilizer management or variations in site selection.

None of the above uncertainties prevent the insurer offering a product, since the primary concern of the insurer is that the premium and payout structures are drawn from the same populations. This ensures that payout does not exceed the premium. However the basis risk (i.e. the uncertainty between the loss estimated by the insurer for a given location and that likely to occur at another location) is borne by the farmer.

2.4. The need to develop an insurance product

The discussion above should make it clear that one needs site-specific weather insurance to offer the most effective risk-sharing scheme. There is compelling evidence that insurance against weather risks is needed, but a major obstacle to the development of sound index-insurance products is the basis risk inherent in non-specific schemes. Although there have recently been a number of investigations into index crop insurance, these have largely been based on statistical evaluation (see e.g. Osgood et al., 2007). We contend that these have largely ignored the important aspects of crop agronomy and therefore have limited usefulness for the end user, the farmer. In this paper we demonstrate an alternative approach to provide a site-specific and soil-specific method of estimating drought risk. We apply the method to developing a hypothetical insurance instrument for bean farmers in Honduras.

3. Method

For a given site and soil, the method estimates the frequency of drought events that are associated with crop yield loss and the premium that would be required to indemnify it, given the frequency of the event. The basis of this relationship is explained in Box 1.

The method has four steps:

1. Establish a transparent insurance process that relates indemnifiable events, indemnity payments and premiums.
2. Generate weather data for specific sites, and determine frequencies of events.
3. Relate weather events to their likely impact on crop yield with the crop simulation model DSSAT (Decision Support System for Agrotechnology Transfer).
4. Relate likely yield loss to readily determined weather indices.

3.1. Site selection

We chose Honduras as the site for this site-specific exploratory study. Honduras is often hit by droughts that have a serious impact on dry bean crops, which is an important source of food and income for poor farmers. For example, a drought in 2001 reduced the country's dry bean harvest by 16,000 tonnes, one-third of the expected yield (CEPAL, 2003). Insurance premiums were estimated for six locations chosen to represent the main bean-growing areas of Honduras (Figure 1 and Table 3).

3.2. The four steps of the method

Step 1: Establishing an insurance process

In the proposed insurance process the insurer agrees to indemnify policyholders in the event of drought. A drought insurance premium is established for a particular location on the basis of the average indemnity payment that is expected at that location. This is estimated on the basis of the frequency of the drought events. In any given year, payment is triggered by a drought event, or 'strike'. Drought is deemed to occur when the rainfall falls below a predetermined 'strike' level. Rainfall is expressed as an index that is weighted to account for the temporally variable effects on crop yield. The size of indemnity payment is scaled according to the severity of drought, up to a maximum limit determined by the insurer. The strike and maximum indemnity may be adjusted by the insurer to improve the viability or attractiveness of the insurance scheme.

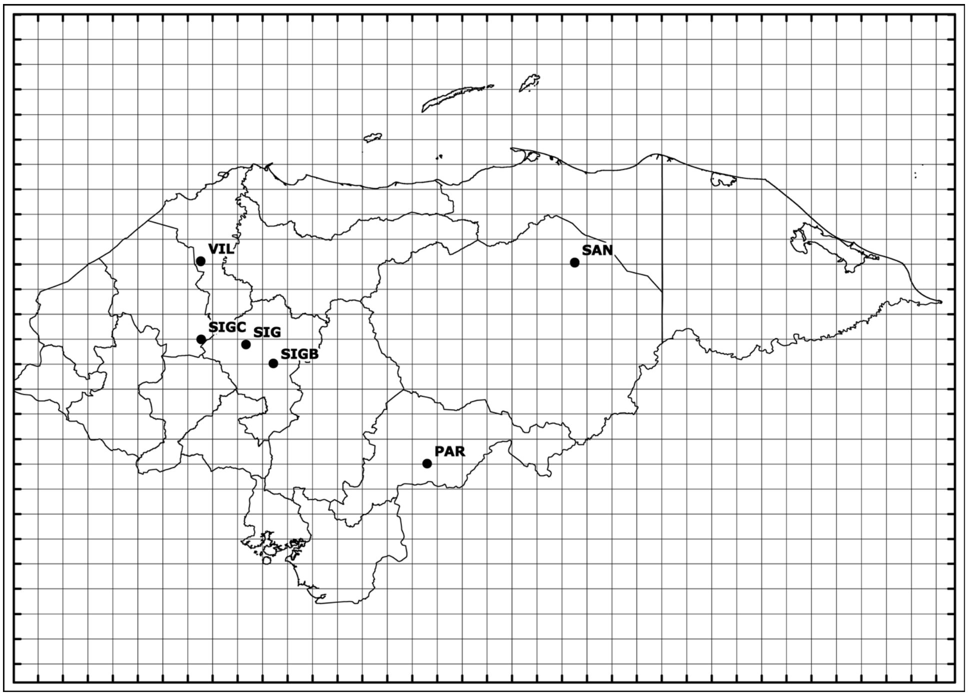

FIGURE 1 Location of trial sites in Honduras shown in relation to the grid used for climate interpolation by MarkSim. PAR is El Paraiso, SAN is San Esteban, SIG is Siguatepeque, SIGB and SIGC are two unnamed (in MarkSim) populated places in the vicinity of Siguatepeque and VIL is Villanueva

Step 2: Generating site-specific weather data

An insurable event is normally defined on the basis of historical data, which do not exist for Honduras (or many other areas in the developing world) at the spatial resolution required. We therefore generated pseudo-historical data using the MarkSim weather generator, designed specifically for tropical weather systems (Jones et al., 2002).

MarkSim uses a third-order Markov model to generate daily rainfall and temperature data for any point in the tropics. It has a geographical surface of 10 arc minutes resolution (approximately 17 km in the Central American region)

TABLE 3 Location and characteristics of six sites in the bean-growing area of Honduras input to MarkSim to generate 99 years' climate data

Site	Code	Latitude (ºN)	Longitude (ºW)	Altitude (masl)	Annual rainfall MarkSim surface (mm)	Mean temperature MarkSim surface (°C)	Mean temp range MarkSim surface (°C)
El Paraiso	PAR	13.921	86.568	790	1,020	23.5	10.9
San Esteban	SAN	15.263	85.582	760	2,220	22.9	8.1
Siguatepeque	SIG	14.716	87.778	850	1,910	22.1	9.7
SiguatepequeC	SIGC	14.750	88.077	610	1,850	23.3	9.9
SiguatepequeB	SIGB	14.589	87.595	1,070	1,240	21.6	10.3
Villanueva	VIL	15.271	88.080	760	1,140	20.6	9.0

The random number seed was 1234 in each case.

based on over 9,200 sets of weather data (Jones and Thornton, 1993, 1999, 2000; Jones et al., 2002). We generated 99-year series of weather data for each of the six selected sites (Table 4).

Step 3: Establishing an activity-specific relationship between rainfall and yield

Although payment is triggered solely by the weather event, this event has to be defined in a way that reasonably represents the likely degree of yield loss. Accordingly, we transformed the weather data into weighted indices using the BEANGRO simulation model from the DSSAT suite of crop models (Tsuji et al., 1994; Boote et al., 1998).

BEANGRO operates on a daily time step and represents crop growth, taking account of rainfall, temperature, solar radiation, soil characteristics and all the various components of crop management. The soil is represented as a one-dimensional profile, horizontally homogeneous but consisting of a number of vertical soil layers (Jones et al., 2003). We used 12 generic soils from the DSSAT database, representing four texture classes and three profile depths. For simplicity, we only report data from the main contrast in texture between the sand and the silty clay soils.

We used the sowing date for each year at each site as the first day between 1 April and 31 July in which the ratio of actual evapotranspiration to potential evapotranspiration, calculated after Linacre (1977), exceeded 0.7 for 5 consecutive days. Soil water was initialized at 20 per cent of available soil water for each layer in the profile at the start of simulation on 1 January. An example of the sitecode.bnx file (the fileX in DSSAT nomenclature) is included in the Appendix to this paper. All six sites used the same fileX structure apart from the weather station code (WSTA on line 20 of the fileX), the sowing date and harvest date (PDATE on line 48 and HDATE on line 52). Because our interest in this study was the effect of drought, we did not simulate the nitrogen, phosphorus, rhizobium symbiosis, residues from the preceding crop or pest damage components of BEANGRO. Harvest was set at 90 days after sowing, which is some 20 days after physiological maturity. We used the dry bean cultivar Rabia de gato +, whose genetic coefficients are included in the DSSAT database and which is widely adopted in Central America. The information in Table 4 and in the Appendix is sufficient to allow any reader to recreate the data using MarkSim and BEANGRO.

Grain yield of the crop is more sensitive to water deficits during specific phenological stages than at others. For at least the three high-rainfall sites (SAN, SIG and SIGC), examination of the MarkSim data showed that drought during growth was unlikely in all but a few years. Because we wished to investigate the sensitivity of yield to drought at different phenological stages, we estimated this sensitivity by imposing droughts in 10-day periods (dekads) at random during the growing season and assessing the yield reduction compared with the control simulation (see below). The crop-weather system also interacts

TABLE 4 Variable data for each site input to DSSAT BEANGRO in the sitecode.BNX file. The SIGA9901.bnx file is in the Appendix

Site	Code	WSTA	Mean sowing date	Earliest sowing date	Latest sowing date	Range of sowing (days)
El Paraiso	PAR	PARA	1 June	8 May	21 July	74
San Esteban	SAN	SANE	29 April	3 April	23 June	81
Siguatepeque	SIG	SIGA	11 May	17 April	15 June	59
SiguatepequeC	SIGC	SIGC	16 May	3 April	5 July	93
SiguatepequeB	SIGB	SIGB	11 May	5 April	30 July	116
Villanueva	VIL	VILL	7 June	3 April	30 July	118

with soil texture, through the varying ability of soils to store and release rainwater. This is reflected in soil-specific rainfall-weighting schemes and contracts (hence premiums) that reflect the different levels of risk posed by different soils.

Step 4: Relating weather indices to yield loss

We estimated the sensitivity of dry bean yield to rainfall deficits at different times during the growing season by modifying the generated weather data to impose dekads with no rainfall. We made nine copies of the generated weather data for each site and used a Monte Carlo method to allocate the rainless dekads over the 90 days' duration of the simulated crop. We repeated this for each of the 99 years' weather data for each site. We compared the yields of the droughted runs with those without drought to estimate the relative impact ('weights') of drought at different growth stages. These weights are equivalent to the crop sensitivity coefficients (CSCs) of Doorenbos and Pruitt (1975). The difference is that instead of generic CSCs derived from the literature and hence of uncertain utility for specific sites and varieties, the weights derived here are specific to site and variety. Table 5 indicates the influence of crop stage and soil type on the sensitivity of the crop, expressed as weights. Crops were most sensitive to drought during flowering or early grain fill (days 30–50). Sandy soils were more sensitive to short-term drought because of their low water-holding capacity.

TABLE 5 Influence of soil type and timing of rainfall deficits on yield

Days after planting	Crop stage	Sensitivity of yield to rainfall deficit expressed as a weight	
		Clay soils	Sandy soils
Day 1–10	Planting/seedling	0.1	0
Day 11–20	Seedling/flowering	0.2	0
Day 21–30	Flowering	0.2	0.2
Day 31–40	Flowering/grain fill	0.2	0.4
Day 41–50	Grain fill	0.2	0.3
Day 51–60	Grain fill/maturity	0.1	0.1
Day 61–70	Maturity	0	0
Day 71–80	Maturity	0	0
Day 81–90	Maturity	0	0

4. Results

4.1. Basic insurance scheme

Figure 2 shows the results of simulation from the Siguatepeque site (SIG). The lower than average yields (bar down) correspond partially to the lower than average weighted precipitation (dots). When the weighted precipitation index drops below the rainfall strike, payment is made at a level proportional to the discrepancy, up to a maximum payout (in this case the maximum payment is USD100 for a maximum deviation value of zero-weighted rainfall). The premium is related to the average payout. It is estimated at USD1.44/ha for the strike of 60 per cent negative deviation from the average rainfall. This example used a shallow sandy soil for simulation and

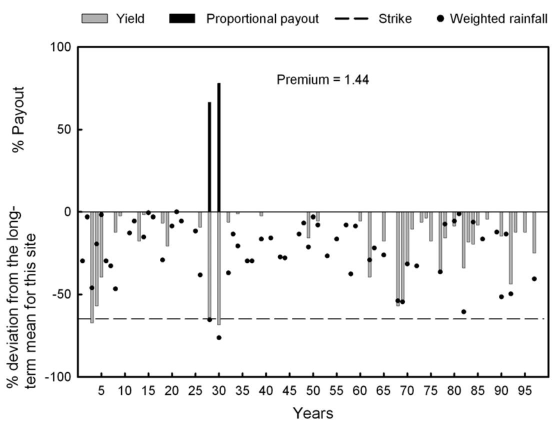

FIGURE 2 Design of insurance for a shallow sand soil at site SIG (Note: only lower than average yields and weighted rainfall are shown.)

consequently the strike is probably conservative, since weighted rainfall deficit triggered payment only twice, or once in 50 years. After consultation with users, the strike would probably be adjusted to allow more frequent claims, against which premiums would increase.

4.2. Site-specific variation of drought risk

For the same soil type, the premiums for six sites within Honduras indicate a more than tenfold variation in risk (Figure 3). For a strike of less than 65 per cent of the average rainfall, premiums varied between a low of USD1.44/ha at SIG to a high of USD16.12/ha at SAN. An average scheme would charge a pure premium of approximately USD7.50/ha. But an ‘average’ scheme makes no sense, since there is no ‘average’ site on which to assess risk and determine payouts in the six sites selected in this study. This fact emphasizes the need for site specificity in the instruments offered. In the unlikely event that an insurer were to offer an average cover, the low-risk farmers at SIG would be subsidizing the high-risk farmers at SAN. The outcome is obvious: the SIG farmers would not buy an overpriced product, even though they would receive payouts when they may not have suffered losses. The SAN farmers would pay less than they should for the risk that they face, but the payouts would not fairly compensate for their losses. The only viable solution is that all parties recognize the site-specificity of the risk, and tailor instruments for each site. The question of how much basis risk a farmer will accept will become obvious in the market. Farmers will only buy insurance if it covers the risk that they face and if the premium reflects that risk. If there is a mismatch in either component, the scheme will fail.

4.3. Soil-specific effects

The impact of rainfall deficits is strongly influenced by the water-holding capacity of the soil. In all cases, weighting the rainfall improved the correlation between rainfall variation and simulated yield, suggesting that the modelling process improves the representation of variation of drought effects likely to be experienced on soils of different textures and profile depths. In the case of sandy soils, correlations remained at only 35 per cent even after weighting, illustrating the risk of basing insurance premiums on rainfall alone. The indexing method effectively ‘normalizes’ rainfall on the basis of simulated influence. Although this improves the relationship between rainfall and likely yield variation, it also re-scales variation in ways that may call for subsequent adjustment of triggers. Accordingly, strikes may be varied to modify the insurance scheme for soils expected to be of low or high risk. Rainfall indices for clay soils, which have a high available water capacity (AWC), tend to be conservative. Although the correlation between weighted rainfall and simulated yield is good ($\sim$60 per cent), many yield-reducing events miss the trigger because weighting overdampens the influence of drought. In such cases, it would be appropriate to modify the strike to increase the frequency of payment and increase the premium. Silty loams appeared insensitive to short-term rainfall deficits. Indices for growing season rainfall correlated poorly with simulated yield, suggesting that soil water is most important for soils with very high AWC. But in the end, it will be up to the farmer to choose an insurance that meets his requirements. If his farm has high-risk soils, he can choose to buy an instrument that covers high risks, but it will be costly. Alternatively, he may choose a cheaper instrument that offers less cover. On the other hand, if he has low-risk soils, he is unlikely to buy a high-cost high-risk instrument.

5. Discussion

This study demonstrates the potential application of weather generation and crop simulation models to design site-specific and soil-specific drought insurance. The results show that trigger events, indemnities and premiums in weather

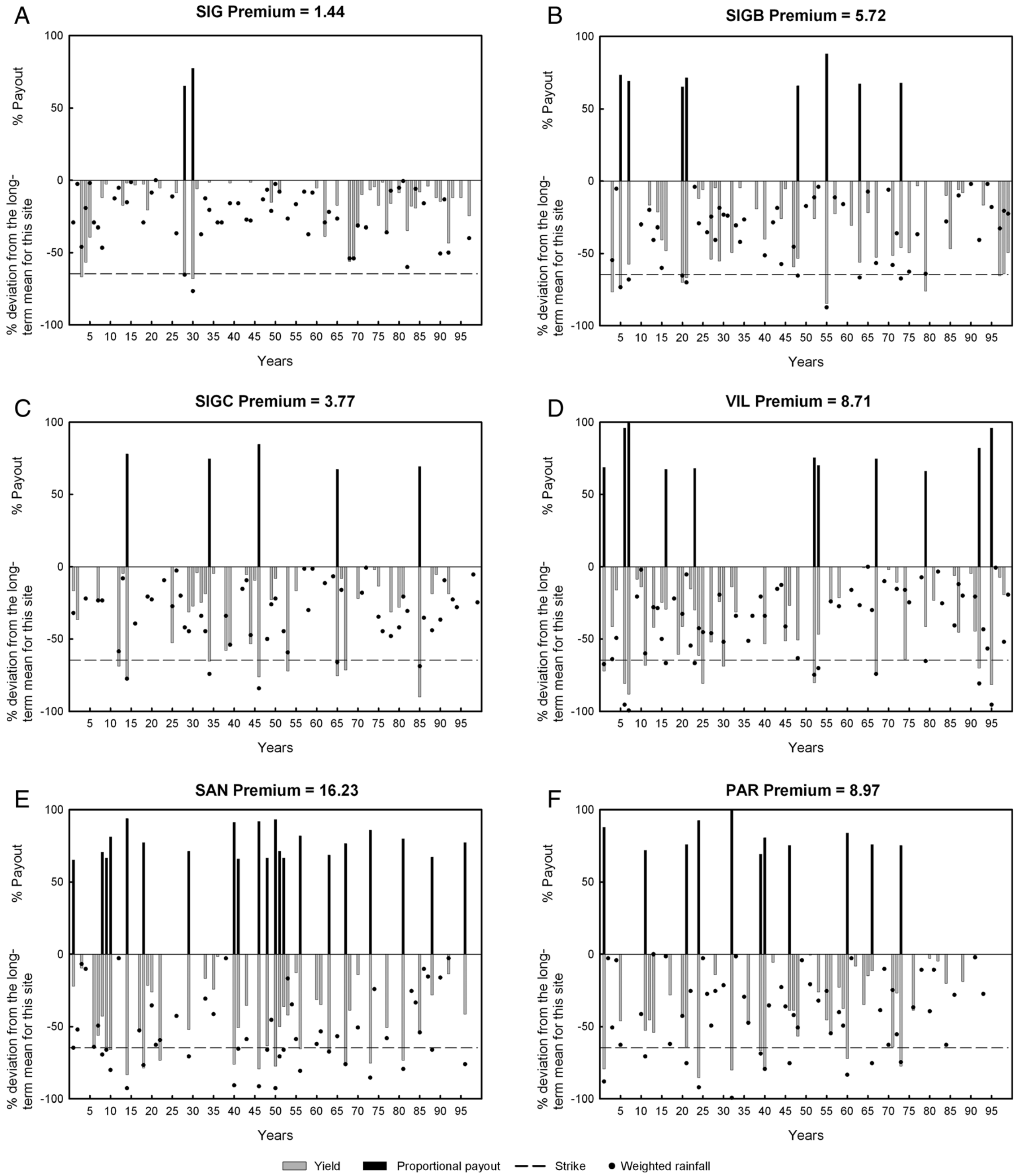

FIGURE 3 Payments and premiums for six sites within the bean-growing area of Honduras. The codes, which precede the Premium in the title of each subfigure, are those of the sites detailed in Table 3

index-insurance schemes can be based on the frequency of drought and its effects on yield. The method is particularly relevant to those less-developed countries that do not have adequate historical data on which to base conventional crop insurance. The method is applicable for any site in the tropics and for any crop for which DSSAT has been validated.

High levels of basis risk are a major source of uncertainty in weather-based insurance. Here we demonstrate that spatial variation can introduce substantial basis risk even within the relatively short distances across the bean-growing areas of Honduras. Sample premiums varied at least tenfold between the six sites that we chose. Insurance schemes that do not include this variation in their estimates expose the insured to unnecessary basis risk. This can seriously prejudice the success of the scheme, in that if farmers do not perceive that the scheme is relevant to them, they will not buy the insurance. We identified additional basis risk due to the interaction between climate and soil, in particular due to the influence of soil texture and depth on the soils' water-holding capacity. The approach that we describe here addresses both these issues.

Researchers have used DSSAT for over 20 years (e.g. Alexandrov and Hoogenboom, 2000; O'Neal et al., 2002; Jones and Thornton, 2003; Terrasson et al., 2009). Although some workers have written that DSSAT is 'too site specific' to use in formulating indices for crop weather insurance (e.g. 'DSSAT results are calibrated to a very specific and idiosyncratic situation', Osgood et al., 2007), we contend that, far from a weakness, this is its great strength. With DSSAT we can reduce spatial basis risk, in a transparent and logically consistent manner, to the minimum that the circumstances demand, which is impossible in the statistical approaches advocated by others. Osgood et al. (2007, p. 31) provide a comparison between DSSAT and historical yields of peanuts and maize in Mali, showing very low correlations. They give no details of how they set up the simulations, so we can make no judgement as to how valid the comparisons might be. In our experience, the results they report are so bad that we wonder whether the simulations were set up correctly. Certainly DSSAT can give bad results if the models are not set up with some basic understanding of crop agronomy.

Osgood et al. (2007) claim the DSSAT models 'require a great deal of data'. We have shown above that the data needs are not particularly onerous: latitude and longitude, which any hand-held GPS device will give or which can be obtained from an internet geographical image; some indication of sowing window and crop duration, which only requires a chat with some of the farmers; and soil texture (the squeezed handful of soil method will do) are sufficient. We believe that it is illogical to ignore the rich insights that the DSSAT models bring and that, in conjunction with MarkSim, they can provide the biological and meteorological basis for insurance instruments for poor smallholder farmers anywhere in the tropics.

Although this exploratory study has illustrated how the use of simulation models may be able to address some of the problems outlined in the introductory review, challenges remain. For example:

- For an insurance product based on simulated data, the issue of verification is of great importance, and further verification is needed of the accuracy of MarkSim to simulate frequency probabilities.
- At present we cannot assign confidence levels to estimates derived from simulated data.
- To prevent adverse selection because of asymmetric knowledge, it is common to sell weather index insurance only until two weeks before the crop cycle begins. This could be a major limitation for those (many?) farmers who do not have cash immediately before the cropping season starts. These farmers may prefer to purchase insurance in mid season, which would require an appropriate method to update premiums based on events to date in the growing season.

The effect of the El Niño-Southern Oscillation (ENSO) can be strong in Central America, which can create serious intertemporal problems of adverse selection, since everyone knows when there is an ENSO event. Weather risk in the region undoubtedly needs to be conditioned based upon the ENSO signal, which would increase premiums in ENSO years, but which would be offset in non-ENSO years. In this context, it is worth noting that MarkSim does not attempt to identify the ENSO phenomenon, although it does include its effect in the temporal variation it represents.

The proposed method does not include farmer preferences for design of the insurance contract, trigger selection, premium cost, indemnity payments and distribution. We need to ascertain what these are and incorporate them into the final product. Another paper in this series will address this issue.

The way in which insurance instruments are distributed to farmers will directly influence the impact that the scheme has on poverty alleviation. Any scheme will need to design a method for offering and distributing the insurance so that it has the greatest impact on poverty alleviation. Furthermore, it should be organized in such a way that it will promote rural development and adoption of progressive farm management.

Acknowledgements

We thank Arjan Gijsman, Steve Beebe, Douglas White, Delmar Peña and José Ignacio Sanz, who made important contributions to the study. We also acknowledge partial funding from the German Federal Ministry for Economic Cooperation and Development (BMZ).

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Appendix

The SIGA9901.bnx file (see below). Note that this is for one year's run only (year 99) with sowing (determined independently as described in Step 3 of Section 3.2) on julian day 113 and harvest on julian day 203. The simulation starts and the initial conditions are set on julian day 001. The 2-character line number is for identification only and is not part of the .bnx file. The file structure and the meanings of the codes are in volume 2 of the DSSAT v3 manual (Tsuji et al., 1994).

```
01*EXP.DETAILS: SANA9901BN SIG DEEP SILTY CLAY RABIA DE GATO
02
03*GENERAL
04@PEOPLE
05Jacqueline Díaz Nieto
06@ADDRESS
07CIAT
08@SITE
09Siguatepeque Honduras
10
11*TREATMENTS                        -------------FACTOR LEVELS------------
12@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
13 1 1 1 0 Sim1                       1  1  0  1  1  0  0  0  0  0  0  1  1
14
15*CULTIVARS
16@C CR INGENO CNAME
17 1 BN IB0007 Rabia de Gato+
18
19*FIELDS
20@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX   SLDP  ID_SOIL    FLNAME
21 1 SIGACLAY SIGA9901   -99   -99 DR001    60     6   -99 -99     -99  IB00000001 -99
22@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS
23 1         -87.778          14.716       850             -99.0 -99.0 -99.0 -99.0
24
25*INITIAL CONDITIONS
26@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
27 1    MZ 99001     1   -99  1.00  1.00 -99.0  1000  1.00  1.50    40    15 -99
28@C  ICBL  SH2O  SNH4  SNO3
29 1     5 0.324   0.1   1.3
30 1    15 0.324   0.1   1.3
31 1    30 0.324   0.1   1.3
32 1    45 0.324   0.1   1.3
33 1    60 0.324   0.1   1.3
34 1    90 0.324   0.1   1.3
35 1   120 0.321   0.1   1.3
36 1   150 0.322   0.1   1.3
37 1   180 0.322   0.1   1.3
38 1   210 0.322   0.1   1.3
39
40*PLANTING DETAILS
41@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL
42 1 99113   -99  17.0  15.0     S     R    50   -99   4.0   -99   -99 -99.0 -99.0 -99.0
43
44*HARVEST DETAILS
45@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
46 1 99203   -99   -99   -99 100.0   0.0
47
48*SIMULATION CONTROLS
49@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
50 1 GE              1     1     S 99001  1234 DEFAULT SIMULATION CONTROL
51@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
52 1 OP              Y     N     N     N     N     N     N     N
53@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
54 1 ME              G     M     E     R     S     C     R     1     P
55@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
56 1 MA              R     N     N     N     R
57@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT  LONG CHOUT OPOUT
58 1 OU              N     Y     Y     1     Y     Y     Y     Y     Y     Y     Y     N     N
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