Chapter 3
A Systems Approach to Climate Risk in Rainfed Farming Systems

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Abstract Climate is a major source of risk in rainfed farming systems. Systems thinking from natural sciences is used to define and explore concepts of weather, climate and climate change before discussion of how climate data can be used in simulation models of agricultural production systems. We then use systems engineering to consider the nature of climate risk and the use of seasonal climate forecasts in managing risk in rainfed cropping decisions in case studies from Australia and the Philippines. Finally, we consider some of the human factors in managing climate risk using soft systems methodology.

Keywords Climate risk • Weather • Climate variability • Climate change • Vulnerability • Resilience • Systems approaches

3.1 Introduction – Climate Risk and Systems Thinking

Rainfed farming is risky. Perhaps the simplest notion of risk is the frustration many rainfed farmers have with planning and budgeting, leading to the complaint that the only accurate item on a budget is the date. Charles Stern listed some of the risks facing farmers in southern USA in the late 1870s: *Returns are subject to several*

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contingencies, such as follows. Your corn may not be planted early enough. The hogs may destroy one-fourth of it, the rains an eighth, and the thieves an eighth; and the drought a large portion of the remaining one half. Your cotton may not come up well, and you may not get a good stand to begin with. It may rain too little, and it may rain too much; and it may be overrun by the grass. Or the rust may take it, the army worm, and the grasshoppers may commence their ravages: or other worms may strip the stalk of its foliage, and then an early frost may nip it in the bud. But if none of these things occur, you are quite likely to get good crops; and then if none of it is stolen, and your gin house does not burn down, you may be fairly recompensed for your labour. But if any of these things happen, your profits of course will be less. (Charles Sterns 1872 cited in McGuire and Higgs 1977).

Risk is more than the notion that things can go wrong; rather it refers to outcomes (both good and bad) for any decision. Giddens (2002) maintains that the idea of risk came to the English language through Spanish or Portuguese where it referred to sailing into unchartered waters, with the chance of great gain weighed against the chance of loss. Along with risk came the value of information, not as provided by soothsayers or prophecies of the future, but as risk assessments and forecasts. Success and failure in rainfed farming has much to do with taking both the risks and the opportunities presented by climate.

This chapter addresses ways that a systems approach can be used to think about managing climate risk in rainfed farming systems. The risks from climate range from extreme weather events such as a heatwave or a frost, to year-to-year climate variability manifest in the timing and amount of rainfall in the growing season, decadal climate cycles and climate change. For understanding and managing climate risk in rainfed farming systems, systems concepts outlined in Chap. 1, such as defining the goal of a farm enterprise, looking for interactions and feedbacks within the farming system and between the farm and natural systems, are useful. When considering the notions of climate variability and climate change systems concepts such as stability, sustainability, flexibility, adaptability and resilience can be powerful tools.

Perhaps the most common use of climate information in relation to farming systems is in classifying them according to their average annual pattern of rainfall and temperature, for example Mediterranean or subtropical farming systems (Tow 1991, Chap. 2 this volume). The long-term climate characteristics of a region are key determinants of strategic choices such as the appropriate enterprise mix to pursue (ratio of livestock to cropping), which crops to grow (summer- or winter-growing crops and long duration or short-duration ones) and the optimum sowing times. Such climatic information can be derived from geographical and long-term meteorological data. Access to good historical meteorological data is essential for modelling and quantitative risk assessment. Extrapolating data from weather stations that are unrepresentative for the particular farm introduces new sources of risk. As discussed in more detail later in this chapter, climate change means that care needs to be taken when decisions are based on any historical data set.

Agroclimatic information is tied to experiences, and this may vary from generation to generation. For example, farmers may be enticed to use crops or practices

suited to the rainfall and temperatures they have experienced over, say, a decade of benign climate. If such a climate is experienced during a farmer's formative years, it may be regarded as 'normal', but this experience can mislead perceptions of 'normal' rainfall. Thus, although farmers may be aware of rainfall variation from one generational period to the next, they may still regard the climate of their own period as normal in their approach to climatic risk. In a social history account of development on the southern high plains of America, Opie (1993) argued that one of the difficulties for the frontier farmer was separating the useful information (signal) from the misleading information (noise) – the long history of the arid region being the signal and the temporarily good seasons, the noise. Mabutt (1981) reviewed the movement of cropping into the northern lands of South Australia in the last quarter of the nineteenth century (past the Goyder line[1]) and into the Mallee lands of South Australia and Victoria during the first half of the twentieth century. He argued that the Australian situation was analogous to North America whereby initial optimism was boosted by a run of better seasons which the new settlers perceived as normal. McKeon et al. (2004) traced the history of degradation in Australian rangelands and showed that degradation was episodic and followed the pattern of a run of good seasons when stocking rates increased followed by a severe drought and collapse in carrying capacity. With long-term climate change, a general principle is that ecosystems are likely to move higher in altitude and poleward; ecological studies suggest that this is what has happened in past warming events. The boundaries of agroclimatic zones will therefore shift in a changing climate (Cline 2007; Howden et al. 2007) and this will present a series of risks and opportunities.

In addition to variability on a decadal scale and climate change on a multi-decadal scale, year-to-year variability influences which crop can be grown as well as tactical decisions such as sowing dates and fertiliser rates. Decision making is difficult as farmers must allocate scarce resources each season on the basis of their expectation of the coming season; hence the interest in assessing and managing climate risk and using tools such as seasonal climate forecasts and simulation models. Later in the chapter we will discuss an example of how seasonal climate forecasts and simulation models have been used in rainfed farming in case studies from Australia and the Philippines.

In writing this chapter, we are assuming that the reader has access to the many texts describing and comparing climates of different rainfed farming systems. More recent texts describe the drivers of climate variability such as the El Niño[2]–Southern Oscillation (ENSO) phenomenon. There has also been an exponential increase in works on the science of climate change and its projected impacts on rainfed farming systems. In recent years, there has been a change from a shortage of good information on the effects of climate on agriculture to an information overload. Systems thinking can provide a framework to deal with this overload.

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[1] See Glossary.

[2] See Glossary for explanation.

Rainfed farmers dealing with climate risk are unlikely to use terms such as 'system thinking' yet, in many ways, farmers are practitioners of systems thinking. Conway (1985) maintained that farmers, of necessity, adopted a multi-disciplinary, holistic approach to their work and argued that those working with farmers also needed to adopt a systems approach to be relevant. Systems thinking may be an important way for the disciplines of climate applications and agricultural science to make their information relevant to farmers and their production systems, in a variable and changing climate.

3.1.1   What Is Meant by Systems Thinking in Agriculture?

The case for a systems approach or bringing the 'science of wholeness' to management problems in agriculture has been frequently stated (Dent and Blackie 1975; Spedding 1979; Squires 1991; Bawden and Packham 1991; Ison 1998 and in Chap. 1 of this book). Not only has the systems approach been deemed appropriate for general problems of agricultural production, it has been specifically applied to managing climate risk. For example, Parry and Carter (1988) argued that the climate impact studies, which dominated the literature until the mid-1970s, treated agriculture as passively exposed to climate. They called for a systems approach which emphasised the need of agriculture to interact with, and adapt to, a variable climate. Similarly, Hammer and Nicholls (1996) maintained that a systems approach was essential to ensure that available climate information was appropriate for management decisions. Much of the recent discussion on the response of agricultural systems to climate change (their resilience, vulnerability and productivity and the need to develop adaptive learning capacity in farmers) has roots in systems thinking (e.g. Walker and Salt 2006; Howden et al. 2007; Nelson et al. 2008).

For the purposes of this chapter, three different traditions of systems thinking will be used:

1. *The natural science*, which provide many of the key concepts and examples of systems thinking; this is evident in agroecosystem analysis (Conway 1985) and in many aspects of climate science. Concepts covered in Chap. 1 such as emergent properties, boundaries and feedback are relevant to climate science and to the application of climate science to farming systems. Resilience is the ability of a system to absorb disturbance and still retain its basic structure and function (Walker and Salt 2006) and this is similar to the notion of stability used by Conway (1985). These ideas are used to think through the impact of climate on rainfed farming systems.

2. *Systems engineering and applications such as Operations Research* – which have more to do with manufacturing than natural systems – have provided most of the tools for assessing and managing risk in rainfed farming systems. Concepts such as system optimisation, efficiency and productivity underpin these tools. Techniques such as influence diagrams that can be used to map the key risks and key decision points are powerful for moving beyond describing the impact of

climate on farming systems to managing the impact. An important way of moving from impact of climate on farming to management of climate risk is to identify leverage points where decisions can make a difference – this might simply be time of sowing or choice of crop. Systems analysis is valuable in identifying trade-offs; for example, a high input crop may give higher returns but this comes with higher risk. The case studies in Sects. 4 and 5 of this chapter give examples of systems analysis.

3. *Soft systems*[3] *methodology* recognises the complexity of human involvement in farming systems. These methods have much that is relevant to managing risk as it explicitly allows for different people's perspectives on the issue of characterising and managing risk. These methodologies recognise that people's worldview will colour their sense of priorities. Whereas systems engineering may try problem mapping, soft systems methodologies are more likely to refer to issue mapping to build up a rich picture which can be improved rather than isolate and solve a problem.

A brief summary is provided in Table 3.1. The differences between Hard and Soft Systems in the context of land use planning in India is discussed in Nidumolu et al. (2006). They found that land use planning tended to have a much greater emphasis on biophysical data and hard systems approaches whereas soft systems provided a greater understanding of why farmers used land in different ways. Rather than enter into arguments about which systems framework is the best for studying the management of climate risk, the different views within different frameworks in a complex multifaceted area can each be regarded as useful.

Table 3.1   Characteristics of three traditions of systems thinking used in this chapter[4]

Applying concepts from ecology of natural systems	
Purpose	Understand and predict the impact of climate and variations in climate on farming as a biophysical system.
Concepts	System boundaries, emergent properties, feedback, stability and resilience
Tools	Climate models, agricultural production simulation models
Applying concepts from systems engineering	
Purpose	Identify decision points in rainfed farming systems that can be used to manage climate risk
Concepts	Systems optimisation, trade-offs between decisions , productivity, efficiency
Tools	Problem mapping, simulation modelling, influence diagrams, decision analysis
Applying concepts from soft systems methodology	
Purpose	Explore different people's perspectives on climate risk-
Concepts	System purpose, worldview, social and ecological resilience
Tools	Surveys, semi-structured interviews, issue mapping

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[3] See Glossary for definitions of Hard and Soft Systems methodology.

[4] See glossary for any unfamiliar terms.

3.2   Using Systems Approaches from Natural Sciences to Understand Weather, Climate Risk and Farming Systems

3.2.1   Climate at Different Scales

System thinking has been likened to an enzyme converting indigestible complexity into something more easily understood (Wilson 1988). Climate is complex – partly because there are so many interactions between the atmosphere, land and the oceans. Furthermore, there are both fast-moving variables in the atmosphere and slow-moving variables such as soil moisture and sea surface temperature. Concepts of boundaries, hierarchies, emergent properties, feedback, and interaction between sub-systems are important in modelling and understanding climate. These concepts are also useful in the task of disentangling concepts of weather, year-to-year climate variability and climate change and their associated risks. Not only are there different decisions made on a time scale of weather, seasonal climate and decadal climate change, there are important differences in the sort of information available from climate science at these scales.

Figure 3.1 shows atmospheric phenomena ranging from a small-scale short-duration local event to global, long-term ones. We experience climate through local weather events. While the strongest evidence of a changing climate lies in the steady increases in global temperature, the most dramatic impact is through weather events such as cyclones and heat-waves and seasonal events such as droughts. Thus in Fig. 3.1, local weather events are in the bottom left-hand corner, yet the strongest
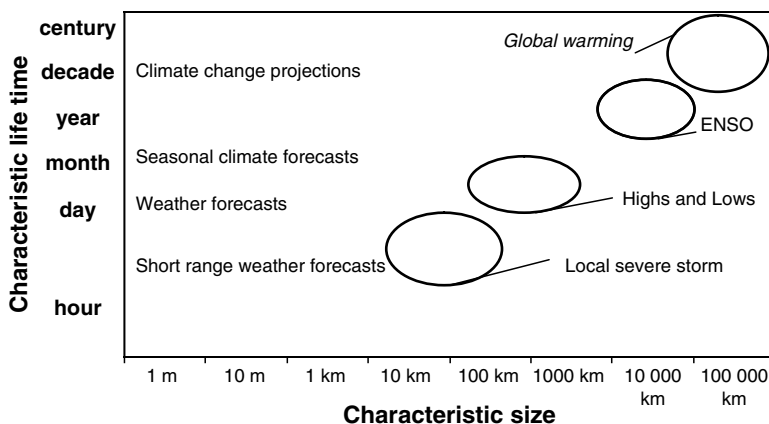

Fig. 3.1 Time and space scale of atmospheric phenomena (modified from WMO graphic). Both axes are logarithmic, a local severe storm may be forecast and have an impact in a radius of 10–100 km, whereas high-pressure systems that cross Australia are 2,000–3,000 km across. The impact of ENSO is at a continent scale and, as the name suggests, global warming affects the planet

evidence for changing climate is from global aggregated data (top right-hand corner). The different boundaries in terms of time and space are associated with different impacts; a single weather event such as a frost or heat-wave is likely to have an impact only on a region; droughts, especially El Niño-related droughts, often have an impact at a national and international level; climate change is global and will have different impacts on different farming systems around the world, and will also influence the non-farming sectors such as energy and transport. The nature and complexity of the risks change at the different levels; a local weather event such as an untimely frost contributes to production risk, widespread drought can influence production and price risk and global climate change will contribute to production, price and input cost risk. Many rainfed farmers find that their most profitable years are when production risk somewhere else has created reduced output and led to increased prices.

3.2.2 Concepts of Weather, Climate and Climate Change

Weather is a 'snap shot' of the atmosphere at a particular time. If climate is what is generally most likely to occur (i.e. what you expect); weather is what you get. Weather is understood to be determined by the timing of individual synoptic events such as a cold front or high-pressure systems and can last between a few hours and a week. The conventional time for climate is 30 years (often the period 1960–1990) which may be too short for analysis of drought, especially if using the fifth percentile or 1 in 20 event to define drought. In much of Australia, the 30 years from1960 to 1990 received rainfall above the long-term median and hence can be misleading for risk management if taken as the 'normal' climate.

Climate change is any long-term significant change in the 'average weather' that a given region experiences. It involves changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years. These changes can be caused by dynamic processes on Earth, external forces including variations in solar intensity and, more recently, by human activities. We will return to a systems understanding of the causes of climate change shortly, but first it is important to recognise that climate has always varied on all time scales and hence is a source of uncertainty and risk for decision making on different time scales. Surveys with rainfed farmers in both Australia (Hayman et al. 2007) and the Philippines (Predo et al. 2008) indicate confusion between weather, climate and climate change. The distinction is important to understand the information available from climate science and the decisions made in farming systems.

While climate is often expressed as the average or most common conditions, this can lead to the mistaken concept that climate is constant year by year and decade by decade; thus it is important for descriptions of climate to include extremes and frequencies of events such as droughts, heatwaves or frosts. Maunder (1989) asserted that the climate archive was rarely used for planning and risk assessment until the 1950s because, although treating climate as constant was at odds with

experience, it was convenient for planning. The Sahel drought of the 1970s is widely recognised as having a major impact on global opinion about climate variability and possible climate change. The discussion of expanding deserts (desertification) opened up the distinction between cyclical drought and a longer-term process of creeping aridity or desiccation, described by Hare (1987) as *"a prolonged, gradually intensifying nightmare from 1968 to 1984",* only to be relieved with good rains in 1985 and 1986. Unfortunately recent conditions in the Sahel are dry, again implying an effect of climate change (Dai et al. 2004a).

UNESCO (1977) defined bioclimatic zones based on the aridity index P/ETP, where P=precipitation and ETP=evapotranspiration. The hyperarid zone (P/ETP≤0.03) is desert with ephemerals and shrubs in river beds; the arid zone (0.03< P/ETP <0.20) has sparse perennial and annual vegetation utilised by grazing systems; the semi-arid zone (0.20< P/ETP <0.5) is a region where rainfed farming is widely practiced but plants suffer water stress during some part of the growing season. The sub-humid zone (0.5< P/ETP <0.75) is more favourable for rainfed farming. The Food and Agriculture Organization of the United Nations (FAO 1978) categorises climate on the length of the growing period (days when the mean temperature is warmer than 5° and precipitation exceeds half the potential evapotranspiration). Less than 59 days is considered arid, 60–119 days semi-arid, 180–269 as sub-humid and more than 270 as humid (Fischer et al. 2002).

Such zonation schemes are useful tools to define boundaries and understand rainfed farming systems but, when a key parameter is rainfall, long-term mean monthly data hide important parameters such as variability from year to year in the timing and amount of rainfall. Thus locations with similar predictions of plant growth based on long-term mean data can have very different probabilities of good pasture growth and cropping success.

3.2.3   Weather and Climate Forecasting

The difference in time scale between weather and climate is also important in understanding the process of developing a forecast. Weather forecasts are mostly based on numerical models; these are initiated from the current state of the atmosphere and used to predict future states of the atmosphere, including the timing and amount of rainfall for up to 10 days ahead. Rainfed farmers have little difficulty using these categorical weather forecasts for up to 4 or 5 days in advance.

In contrast, seasonal climate forecasts typically give the chance (probability) of the next 3–6 months being wetter or drier (or hotter or cooler) than the long-term average. Rather than being based on prediction from the inherently chaotic dynamics of the atmosphere, they tend to be based on patterns of the sea surface temperature (SST) or associated atmospheric characteristics. There is good scientific evidence that changes in the patterns of sea-surface temperatures have an impact on the behaviour of the atmosphere for months ahead and over widespread regions. Nicholls and Wong (1990) showed that regions of the world that are influenced by

El Niño–Southern Oscillation[5] (ENSO) tend to have greater interannual variability than other regions at the same latitude and annual rainfall, but have a greater capacity to predict interannual variability in seasonal rainfall. Many decision makers would like categorical long-range weather forecasts that would tell them the day that the rainy season will start or rainfall on a given day, rather than seasonal climate forecasts; this is not possible. Using seasonal climate forecasts is better than guessing but well short of perfect knowledge. Using seasonal climate forecasts increases the chances of making a good decision—even though it may turn out not to be the most lucky one.

3.2.4   Climate Change

Climate change projections are different again from seasonal climate forecasts in that they have the added complexity of assumptions about future emissions of green-house gasses. About half of the uncertainty in forecasts of temperature by the end of this century is due to uncertainty about emissions; the other half is due to scientific uncertainty represented by alternative models of global climate processes.

Climate can be studied as a complex system. The Intergovernmental Panel on Climate Change (IPCC) suggests five sub-systems: the atmosphere, the hydro-sphere (water in oceans, rivers and underground), the cryosphere (snow, ice and frozen ground including permafrost), the land surface (lithosphere) and biosphere. There are three sources of change for this climate system:

1. The climate system will change and evolve over time due to interactions between component parts; for example, El Niño events are naturally occur-ring shifts in energy in the tropical Pacific Ocean that have impacts on most continents (Ropelewaski and Halpert 1987). A run of decades with a higher frequency of El Niño events can have far reaching impacts on the climate system. It is important to recognise decadal variability – for example, the major impact of a decade of low rainfall on American rainfed farming systems creating the 1930s 'dust bowl'.
2. Natural external influences such as solar variations due to the orbital tilt of the earth, sunspot activity or volcanic eruptions – well understood to cause climate change. As the world warms due to the orbital tilt, the oceans release carbon dioxide which provides a positive feedback on the warming process.
3. Human-induced changes due to increased greenhouse gases, land use change and aerosols. The argument of climate science is that recent warming cannot be explained by internal forcing or by natural forcing, and that most of the recent warming is due to greenhouse gasses released by human activity.

'Global warming' is defined as the gradual increase in global average surface temperature as one of the consequences of increased greenhouse gases. The term

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[5] See Glossary.

'climate change' is more commonly used than global warming because of the many changes to other climatic parameters such as rainfall, wind and evaporation.

The importance of greenhouse gas emissions from agriculture (carbon dioxide, methane and nitrous oxide) has highlighted that, not only does climate influence farming, farming practices also influence climate. Agricultural science now has had to look increasingly beyond artificially tight boundaries around production systems and consider off-site impacts on the surrounding environment of land and water (Chap. 13). The emerging challenge is to consider off-site impacts of farming on the atmosphere through the release of greenhouse gasses. These interactions become further complicated when considering the role of agriculture as a means of sequestering carbon in the soil, in crop residues, in pastures and through agroforestry. Even further complexity is added as agriculture is considered as a source of biofuels. The role of agriculture in production for biofuels has raised the need for lifecycle analysis[6] of the energy involved in making the fertiliser to grow the crops that are used for biofuel production. Further, it has highlighted the interactions between the area of land cropped and international agricultural commodity prices. When asked about risks and opportunities from climate change, some rainfed farmers and analysts see the greatest risks and opportunities coming from national and international policies to reduce greenhouse gasses. This is apparent when agriculture is considered both as a source of greenhouse gases and also a sink for carbon in soils and plants and a supplier of biofuels (Keating and Carberry 2008; Keogh 2008).

Figure 3.2 provides a framework for considering confidence and uncertainty with respect to climate change. The vertical arrows represent a high level of confidence in the evidence that global climate is changing and strong evidence that most, but not all, of this change is due to changes in greenhouse gasses in the atmosphere. It also stands to reason that changes to global climate will have an impact at
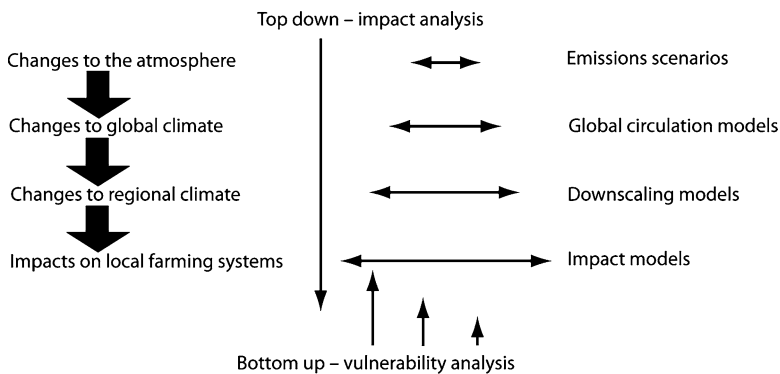

Fig. 3.2 The cascading uncertainty in climate change projections; the solid vertical arrows represent the links between the different levels and the changing length horizontal arrows represent the increasing uncertainty – adapted from Schneider (2004)

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[6] See Glossary.

regional and local levels as indicated with the vertical arrows and this will have an impact on activities that are sensitive and exposed to climate such as rainfed farming systems.

When it comes to impacts of climate change at a regional level, each horizontal arrow is wider than the level above; in other words there is cascading uncertainty. The different levels of greenhouse gasses or emission scenarios provide uncertainty which is further increased by the way alternative global circulation models translate an increase in greenhouse gasses to global warming. There are further differences in the projections of global circulation models to regional climate and then questions of how these changes in climate will influence rainfed farming. Climate science tends to use the term projection rather than the more common term prediction. This is because about half the uncertainty in what the global temperature will be in 2,100 is due to the level of greenhouse gasses in the atmosphere at that time and half is due to scientific uncertainty on the impact of a given level of greenhouse gasses on global temperature. Unlike predicting the weather for tomorrow, the climate in 2,100 depends on the level of population growth, and the greenhouse gas emissions associated with future economic growth.

As shown in Fig. 3.2, there are two complementary approaches to considering the impacts of climate change. The first is a top-down[7] approach of getting the projections and considering what impact they will have on agriculture and the second is to consider a bottom-up approach to identifying what level of changes in climate will make the farming system vulnerable to failure.

Figure 3.2 has four levels: changes to the atmosphere; changes to global climate; changes to local climate; and impacts on local farming systems. As individuals and societies we have a choice about the changes to the atmosphere; however, the next two levels in Fig. 3.2 relate to scientific uncertainty on how sensitive the climate system is to different levels of greenhouse forcing and how the global change in climate will manifest at a regional level. While we can conduct research on these questions to reduce the uncertainty, we cannot change the final outcome. However, it is possible to influence the outcome at the fourth (farm) level in Fig. 3.2. The better prepared and resourced local farming systems are, the less they are likely to suffer from climate change. Climate variability will continue and, in some situations become more extreme, over the decades as the climate changes. The best preparation by a farmer for the early stages of climate change is to understand how to manage climate variability.

A consequence of warmer mean growing-season temperatures will be a longer growing season in regions where low temperature is the limit – as in many cereal growing regions of the Northern hemisphere. In some regions of the cereal belt of Australia where hot, dry conditions end the growing season, warmer temperatures will reduce its length. Because most plants effectively measure time by temperature, modelled as degree days, increased mean temperature will lead to faster development. Because crop development is dependent on cumulative temperature, even small

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[7] See Glossary for definitions of top down and bottom up approaches.

changes in temperature add up to significant changes in wheat phenology (Sadras and Monzon 2006). Not only will crops develop faster but, since the lifecycle of insects is also temperature dependent, there are likely to be important changes in pest incidence.

Changes in extreme temperatures such as heatwaves are likely to cause major damage to crops, pastures and livestock. Although frosts are likely to decrease in the longer run, it is possible that the warmer average temperatures will shift sensitive crop stages into earlier higher frost risk times of the year.

Although less certain than changes in temperature, changes in rainfall are also likely, with an expectation of increased frequency of drought across many parts of the world (Dai et al. 2004b; IPCC 2007). Changes in evaporation are complex outcomes of changes in radiation, windspeed and temperature. If radiation and windspeed were to stay the same, potential evaporation will increase by about 4% per °C of warming.

One of the tools used to understand the interaction of climate change in farming systems is simulation modelling based on the four key environmental inputs for crop growth namely water, temperature, incident solar radiation and nutrients. Simulation modelling provides a quantitative way of accounting for how these environmental inputs interact with plant growth, development and, for crop plants, yield partitioning. The impact of climate on rainfed farming can be represented formally through detailed simulation models, such as CERES, APSIM or GRASSGRO,[8] using daily climate data. Simulation models have relied on the understanding of interactions occurring in natural systems, and are a powerful way to describe the impact of a warmer, drier world. They can also be used to understand the essential role of management in adapting to climate change and managing year-to-year variability. An example is the use of the cropping simulation model APSIM Yield Prophet (Hunt et al. 2008) where farmers can enter details from their own fields through the season and access updates of simulated yield via the internet (see Chap. 37). The application of simulation modelling to the challenge of climate variability and climate change has been within the framework of systems engineering.

3.3 Using Systems Engineering to Manage Climate Risk

Agricultural science, despite obvious links with biology, has primarily adopted the engineering treatment of systems, largely based on a machine metaphor. This is not surprising given the applied nature of agricultural science and the industrial treatment of a farm as a factory converting inputs – whether natural (radiation and water) or synthetic (fertilisers and fuel) into outputs. McCown et al. (1993) drew attention to the strong links between operational research (OR) and the systems approach familiar to most agriculturalists since the early 1960s. They pointed out that the main similarities were: (a) the problem of

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[8] See Glossary for description of various simulation models.

researching complex systems where risk is important; and (b) the method of using simulation experiments based on process models.

Case studies later in this chapter show how simulation models such as APSIM and CERES, used with historic weather data, are powerful quantitative tools to compare management options and their associated risks. These tools can also be used to explore how seasonal climate forecasts can be used in management (Meinke and Stone 2005; Meinke et al. 2003).

Seasonal climate forecasts (SCF) are potentially a powerful tool available to agricultural producers to manage production or other risk. SCFs offer skilful, but uncertain, information on future climate conditions, expressed as probabilities for periods of generally 3–6 months duration. We use the term 'skilful' to mean that the forecasts provide a better indication of a coming season than simply relying on the all-year, long-term climate record.

Because climate will always contain uncertainty, SCFs are best interpreted as shifts of the climatological probability distribution (Hansen 2002). These new probability distributions are potentially valuable if they enable the decision-maker to allocate resources better between poor years and good years.

One of the tools of operations research is decision analysis, which identifies the outcome (profit), the decision nodes (e.g. fertiliser rates) and the chance nodes (e.g. the seasonal rainfall). A probabilistic forecast of seasonal rainfall, or of wheat yields under different fertiliser rates, is likely to lead to better decisions and higher profits over the long term. A seasonal forecast might be in the form of '70% chance of above-median rainfall'. Care should be taken not just select a single year when the forecast was followed and a good outcome occurred. For example, if extra fertiliser is applied when above-median rainfall is forecast, this will lead to gains in 70% of the years (but no change or losses in 30% of the years). Most studies of the economic value of seasonal climate forecasts have been cast within the framework of Expected Utility Theory[9] and assume a Bayesian[10] revision of probabilities of particular climatic states (Marshall et al. 1996). The value of the climate forecast is the change in expected utility resulting from the more informed decision. In the following sections, this basic framework has been applied to decisions of crop choice of wheat or sorghum on the Liverpool Plains in eastern Australia and of corn or grazed fallow in the central Philippines.

3.4   Example from Liverpool Plains in NSW

Situated in northern NSW in the southern edge of the northern cropping belt (see Fig. 3.3), the Liverpool Plains are amongst the most productive farming regions in Australia. This is largely due to the combination of fertile, high water-holding

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[9] See Glossary for explanation.

[10] Bayes' theorem relates the conditional and marginal probabilities of two random events. It is often used to compute posterior probabilities, given observations.
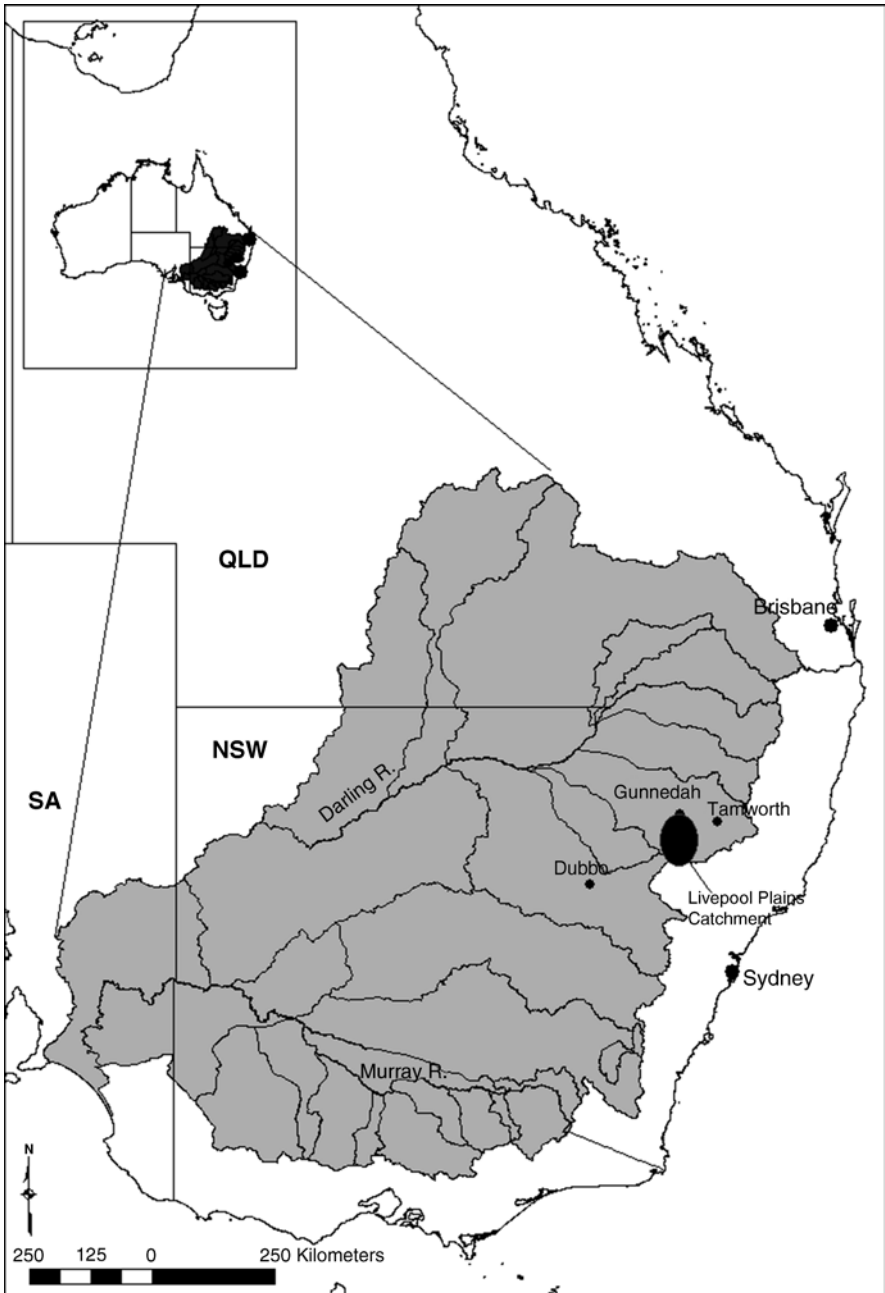
Fig. 3.3 Liverpool Plains Catchment – part of the Murray Darling Basin (*shaded*). Generated from data originally from Geosciences Australia

Table 3.2 Mean monthly rainfall (mm), pan evaporation (mm) and maximum and minimum temperature (°C) for Gunnedah, NSW (Source: Rainman-Clewett 2003)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain	72	66	48	38	43	44	43	42	40	55	60	68
Evap	279	221	189	135	90	66	78	96	117	164	234	298
T^{max}	32	32	30	26	21	17	17	18	22	25	28	32
T^{min}	19	19	16	12	8	5	4	5	8	12	14	17

capacity soils and a climate that allows both winter and summer cropping. The mean annual rainfall is relatively high (580–680 mm). However, rainfall is variable with an average of 60% occurring during summer, and mean evaporation rates exceed mean rainfall in every month of the year (Table 3.2). Reliable cropping depends on storing water over a fallow for use by the subsequent crop.

The Liverpool Plains provide an interesting case study for managing climate risk in rainfed farming systems because of the contrast between (1) conservative but inefficient risk management through long periods of fallow and (2) an approach that responds to the variable climate and sows a crop whenever soil moisture reserves are judged by the farmer to be adequate. This is known as opportunity cropping, or sometimes as response cropping or flexi-cropping.

Long fallow–wheat–sorghum rotations have been widely practiced in the region since the 1970s. In this system, wheat is harvested in early December and the land is left fallow over the coming summer *and* winter months. Sorghum is then planted in the following November and harvested in March. The land is then left fallow for the winter and the following summer before wheat is planted in June. This means that one crop of wheat and one of sorghum is grown over a 3-year period. Long-fallow rotations are simple to implement, provide good disease and weed control and minimise cropping risk by ensuring crops are generally sown on a nearly full profile of water. While building up adequate soil water reserves under fallow may take up to 12 months in a dry year, 1 or 2 wet months under fallow can be adequate to fill the soil profile. Long-fallow systems can waste potentially profitable cropping opportunities, and are thought to be contributing to excessive deep drainage and possible salinity through rising water tables because of the limited time in which crops are actively growing.

In contrast to long-fallow systems, the practice of opportunity cropping involves sowing a summer or winter crop whenever stored soil moisture levels are considered to be adequate. Studies of opportunity cropping suggest that tighter cropping sequences lead to higher profit and reduce erosion and deep drainage[11]; but they are more risky because there is greater chance of crop failure when crops are planted on less than a full soil moisture profile. Growers have developed various sowing rules for opportunity cropping based on availability of some minimum level of soil moisture. This minimal soil moisture level will vary with location, crop prices,

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[11] Deep drainage is important in this case as it may raise watertables and introduce salt into the root zone.

production costs and technologies, expectations of growing season rainfall and the grower's attitude toward risk. A common opportunity cropping system is based on a 70 W/90 S rule (sow with 70 cm of wet soil for wheat and 90 cm for sorghum) (Scott et al. 2004). Sowing rules of either 50 W/70 S or 70 W/90 S appear to provide a good compromise between reducing deep drainage from full profiles and having enough soil moisture to ensure profitability (Ringrose-Voase et al. 2003). The depth of wet soil is measured with a metal rod pushed into the ground; as a guide for these clay soils every 10 cm of wet soil equals 18 mm of stored soil water.

Under opportunity cropping, crop yields and financial return are influenced both by the level of stored soil moisture at planting and by in-crop rainfalls. An accurate forecast of growing season rainfall, as well as information on the level of soil moisture, could help growers decide whether a crop should be grown now or delayed to the next opportunity (either a rainfall event or changed forecast). Figure 3.4 shows wheat yields simulated by the cropping systems model APSIM under a range of phases of the Southern Oscillation Index (SOI)[12] that allow a forecast of seasonal rainfall to be made at the end of May. Simulated wheat yields using long-term climate data show that in the years when the SOI is rising (higher in May than April) simulated wheat yields have been higher; and when it is negative in April and May, yields have been lower.
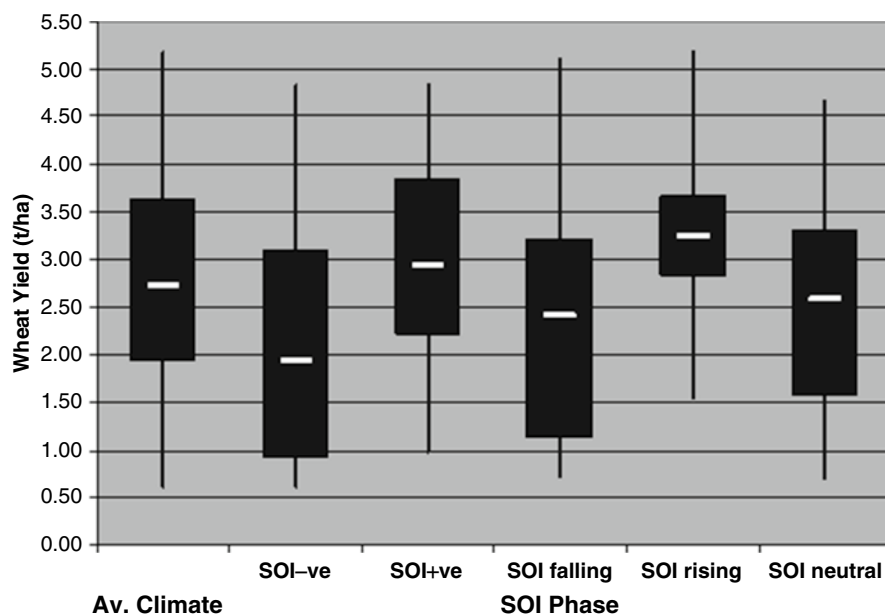

Fig. 3.4 APSIM simulated wheat yields for June sowing based on five SOI phases at the end of May. The box plots cover the 20th and 80th percentile, white line is median and the vertical lines show the 5th and 95th percentile. The box plot represents the distribution of simulated wheat yields under average climate and the years when SOI was in different phases at the end of May

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[12] See Glossary for explanation.

The simulated wheat yields in Fig. 3.4 are all based on 100 mm of water in the soil at sowing. When there is less water in the soil, the yield difference between phases of the SOI is greater and when there is more water in the soil, the effect is dampened.

Because climate forecasts are imperfect, there are years when decisions taken in light of a forecast make the grower worse off rather than better off. Provided the forecast has some relevance and possesses some skill, over a long period of time, the benefits of following the forecast should exceed the costs. However, if a failure occurs in the first year that a farmer uses SCF, it may take a long time to recover the benefits calculated in a 100-year simulation, and the farmer may lose confidence in the forecast method (Robinson and Butler 2002). The forecast needs to indicate a significantly different probability distribution to the probability distribution based on all years. In other words, a farmer using the forecast has a different view of the risk profile of the coming season than a farmer who is just using the long-term climate record. Figure 3.4 shows that this is the case for wheat when the SOI is rising. In other words, for the 100 year record, not all of the 16 years when the SOI was rising had higher yields, but a greater portion were high yielding, as reflected in the distribution. However, under some circumstances of the relative prices of wheat and sorghum, it may be optimal to plant wheat, even without the forecast. In this case although the forecasts offers confirmation, it is difficult to put an economic value on the forecast because a farmer who used the forecast would take the same action as other farmers who did not have access to the forecast.

The greatest value of the forecast was that it moderated some of the risk of opportunity cropping. Opportunity cropping is a responsive form of rainfed farming that relies on responding to the status of the paddock in the form of disease, weeds and soil moisture, to the market signals for different crops and to the atmospheric signals for the SOI. A systems approach highlights that all of these, as well as other whole farm considerations, need to be thought through before making a decision.

3.5   Example of Corn Decision Making from the Philippines

In the Philippines, corn is the most important rainfed crop, second only to rice. About 30% of Filipino farmers grow corn as the primary crop and 20% of the population relies on corn as the staple food, especially in the central and southern islands of the archipelago. The main climatic limit to successful crop growth is rainfall, as air and soil temperature are always warm enough for germination and growth.

The Philippines is greatly affected by the El Niño–Southern Oscillation with the main impact being in the months from October to March (Harger 1995; Jose 2002; Hilario et al. 2008). The 1997/1998 El Niño event dramatically reduced both rice and corn production (Albarece 2000). Seasonal climate forecasting has been shown to have a potential benefit for risk assessment and decision making in both rainfed rice production in the Philippines (Abedullah and Pandey 1998) and corn production in the northern island of Isabella (Lansigan 2003).
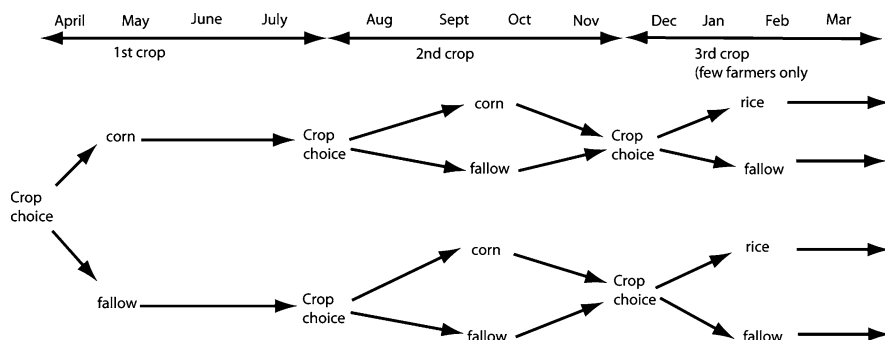
Fig. 3.5 Climatically-sensitive decision points for corn farmers in Leyte, Southern Philippines

Figure 3.5 shows the climatically-sensitive decision points for rainfed corn production in the study area of Mahaplag in the island of Leyte in the central islands of the Philippines, the Visayas. The fallow is a grazed fallow where livestock feed on volunteer pasture and weeds and is a low-risk, low-return option. The decision to fallow will mean that there is more water stored in the profile for the subsequent crop, but the main impact will be the mineralised soil nitrogen. The decision to plant corn in April or May needs to be made in March. The Philippine national meteorological service PAGASA issues 3-monthly forecasts and declares the states of El Niño and La Niña based on information from a number of international climate centres and models. In August, there is a second planting choice that will have been influenced in part by the choice in April whether to plant a crop or not, but also it will be influenced by the price of corn in August and the expectations of rainfall in the approaching season. A few farmers will consider a third crop planted in the wet season in January which could be corn or rice, but most will have a fallow and plan for corn the following April.

In the study area of Mahaplag, traditional varieties of white corn are the most commonly grown, followed by commercially available open-pollinated varieties, and then hybrid varieties. Hybrid varieties are potentially high return, but the cost of the seed and fertiliser also makes them high risk. Interviews with farmers indicate that climate risk is the primary barrier to growing hybrid varieties, especially when they have to purchase the seed and fertiliser on credit.

Figure 3.6a shows a time series from 1980 to 2007 of simulation results from CERES-Maize model within DSSAT v4[13] using local climate, soil and crop

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[13] Decision Support System for Agrotechnology Transfer Version 4.0 CERES-Maize (Crop Environment Resource Synthesis) model is a predictive, deterministic model designed to simulate corn growth, soil, water and temperature and soil nitrogen dynamics at a field scale for one growing season. The model is used for basic and applied research on the effects of climate (thermal regime, water stress) and management (fertiliser practices, irrigation) on the growth and yield of corn. It is also used to evaluate effects of nitrogen fertiliser practices on nitrogen uptake and nitrogen leaching from soil; and in global climate change research, to evaluate the potential effects of climate warming and changes in precipitation and water use efficiency due to increased atmospheric CO_2.
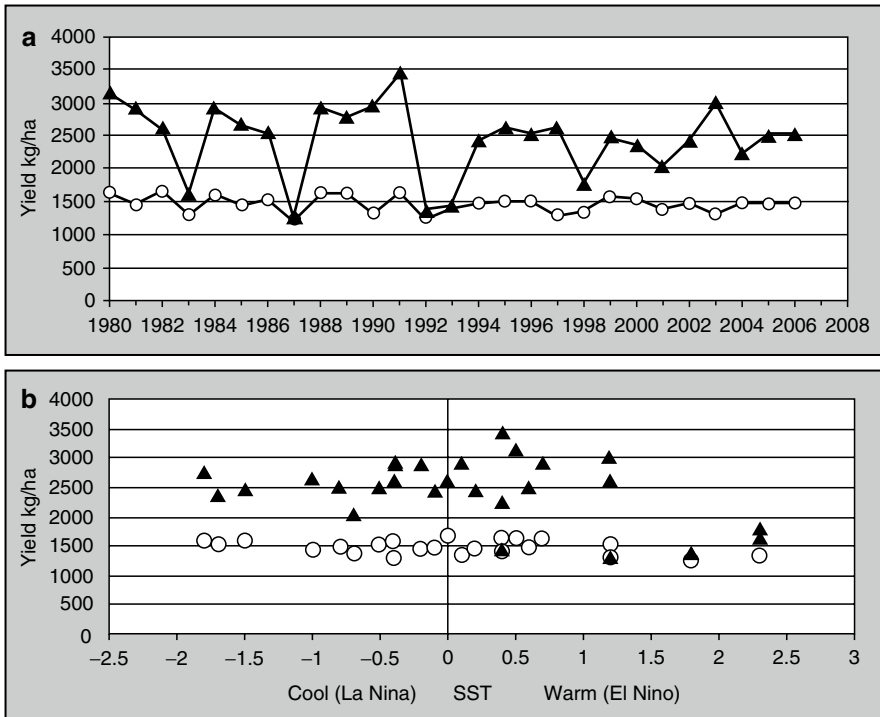
Fig. 3.6 CERES-Maize simulated corn yield showing hybrid corn with high fertiliser (*closed triangles*) and the traditional 'native' corn (*open circles*). Upper panel (**a**) shows simulated yield plotted as a time series and lower panel (**b**) shows the simulated yield plotted against an indicator of ENSO (Niño 3.4 sea surface temperature anomaly between December and February – see text for description)

development inputs. These results are for the first cropping season in Fig. 3.5. This shows that, on average, hybrid corn with the extra fertiliser is much more productive than the traditional variety. However, in some years (many but not all El Niño years) the yield of the hybrid corn is the same as the traditional variety and the high input costs lead to substantial losses. Although there is a range of definitions of El Niño years from different centres, the 1982/1983, 1986/1987, 1991/1992/1993, 1997/1998 and 2002 events show up as poor production years. 2006 was also an El Niño year but there was no dramatic impact on simulated corn production.

Figure 3.6b shows the same simulated yield data plotted against the sea surface temperature anomaly between December and February of Niño region 3.4[14] available from the Climate Prediction Centre of the National Oceanographic and Atmosphere Administration (NOAA). An anomaly that is more than 0.5° warmer

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[14] See US National weather service Climate Prediction Centre .http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/nino_regions.shtml.

can be categorised as a warm event or El Niño and more than 0.5° cooler as a La Niña event. It is important to note that the SST data are available before the decision to plant corn or to choose the variety. The primary message from Fig. 3.6b is that extreme warm events in the tropical Pacific Ocean (>1.5°C) are associated with the worst outcomes for hybrid corn. ENSO-based forecasts have the potential for picking the low-yielding seasons and this should be of value to risk-averse farmers. The challenging message from Fig. 3.6 is that there will be mild El Niño events (greater than 0.5°C or even greater than 1°C) that do not lead to low yields. These false alarms may persuade a farmer not to plant corn or not to use hybrids. An example was the 2006 El Niño event when some farmers planned for a drought, but the seasonal rainfall was average. There is also one low-yielding year where the Sea Surface Temperature was only 0.4° warmer; this could be considered a bad outcome that was missed in the forecasting. A conservative approach would be to only plant hybrid corn in La Niña years (< −0.5°C), but this will result in missing many opportunities from the neutral years (> −0.5 and < +0.5). There is likely to be a benefit from following ENSO-based forecasts but the benefit will be aggregated over a number of years; in any single year, a farmer could be worse off following the forecast than another farmer who did not have access to the forecast.

3.6   Soft Systems

Managing climate risk in farming is a human activity. Many of the approaches used by agricultural science rely heavily on a systems approach from the natural sciences and systems engineering for what are essentially social activities. While all these approaches recognise that humans are involved, the question is how they are included in the description of the system. For example, an agroecosystem view tends to treat humans as an off-stage forcing function or, if included, human labour is an input and decision-making a control. Often the farmer is included as a single decision maker without reference to surrounding social and economic structures and culture. The soft systems movement contends that this is problematic. A summarising phrase for this system school is the title of Sir Geoffrey Vickers (1983) book, *Human Systems are Different*.

A logical outcome of the systems engineering approach is a decision support system that gives a farmer access to long-term climate records and combines this with simulation models whereby the outcomes of different management choices can be determined. A repeated finding from analyses of farmers' use of decision support systems is the disappointing level of their use, and much has been written on why this might be the case (Malcolm 2000; McCown et al. 2002; Hayman 2004). See also Chaps. 35–37. Ullman (1997), a computer programmer, reflecting on the limits of software for managers observed that a computer cannot look round edges as their dumb declarative nature cannot comprehend the small, chaotic accommodations to reality which keep human systems running. One of these chaotic accommodations to reality is intuitive, messy decision-making.

Decision-making is often treated as a step-by-step, conscious, logically defensible process, whereas management more often than not involves intuitive judgement which is continuous, rapid and perceptive. That is not to say that information from climate science and agricultural science is not useful; rather, it is only part of what is required for farm decision making.

One of the most challenging aspects of recognising the central role of people in farming systems highlights the point that the boundaries and emergent properties of the system are determined by the person defining the system. Flood and Jackson (1991) defined systems as 'situations perceived by people'; it follows that what is seen as part of a farming system (and what is excluded) depends on the perspectives of who is defining the system. The challenge of managing climate risk in a farming system will have different meanings for those considering the farm as (1) a biophysical ecosystem processing materials, (2) a business or production system generating income, or (3) a family farm integrated into the wider rural community. A banker might view a farm as a system in a different way from a partner in a family farm. Bawden and Packham (1991) argued that it is important to explicitly recognise that farming systems are mental constructs or figments of the imagination which are useful to structure debate. This implies that farming systems do not exist in the way a tractor or wheat crop exists; hence care must be taken in clearly defining the system and being aware that others may have alternative perspectives.

Just as there is human judgement in defining a farming system, there is human judgment involved in how a climate is described for a region and whether the emphasis is placed on averages or variability. This is apparent in discussion of drought policy (Botterill 2003; Hayman and Cox 2005; Wilhite 2005). After reviewing a series of definitions of drought, the Australian Drought Policy Review Task Force concluded that drought was essentially relative, reflecting a situation whereby there was a mismatch between the agriculturists' expectations of a normal climate and the climate at that time. Another definition is that a drought is when it is too dry for the usual agricultural enterprise. This raises the question of whether the usual enterprise is appropriate.

There is also a strongly human dimension in how we experience and remember weather and climate. As an historian, Sherratt (2005) observed that we cannot reliably remember climate because memory generates meaning – not statistics. He noted that our lives lurch between expectation and event, between the idea of climate and the reality of weather. Rainfed farmers and those working with them will always be talking about the weather, waiting for rain or worrying about too much rain at the wrong time. The composite of these events will make up their experienced understanding of the climate that they are working with. Farmers do measure rainfall and keep records of rainfall, yield and dollar returns and increasingly use spreadsheets and commercial software to reflect on different years. Nevertheless, most farmers will speak of the lived experience of drought, dust and floods.

Common terms in dealing with climate and farming systems such as risk and vulnerability are words used in everyday language but can mean quite different things to different people. In fields such as pollution and safety, scientists have been criticised for distinguishing between 'real risk' and 'perceived risk', because risk

only makes sense in the individual and social and economic context of the decision maker. In one sense, all risks are perceived and all risks are real (Beck 1992). Psychological studies have identified various issues that influence the perception of risk including the subject's sense of control and worldview, whether a risk is voluntary, and the distribution of costs and benefits. Hazards judged as dreadful and unknown are also judged as the most risky. Climate is an interesting case in point; we all know that climate varies and that moving to another location involves a change in climate, but the notion of global climate change has a sense of dread, especially the notion of dangerous climate change. Identifying dangerous climate change for the planet as a whole is challenging. Identifying dangerous climate change for rainfed farming systems is more difficult than for natural systems such as a rainforest or the Great Barrier Reef because there are clever humans involved who will engage in active adaptation. Clearly there is a level of climate change that will be almost impossible to adapt to, for example Cline (2007) modelled the impact of 4° rise in global temperatures and showed that if this occurs, along with ecosystem destruction and massive flooding of low lying regions, that the world will face significant food shortages. The more difficult question is the impact of 1.0–1.5° warming that is expected by 2030.

Vulnerability in the context of climate change is usually viewed as the endpoint or residual of climate change impacts minus adaptation. However, vulnerability can also be a starting point characteristic generated by multiple factors and processes (O'Brien et al. 2004). The vulnerability of Australian and Philippine farmers to climate change depends on the likely changes to climate and how close their production systems are to climatic thresholds. It also depends on their wealth, resources and access to information. Successful rainfed farming systems have characteristics that make them resilient, but they can only absorb a certain number of disturbances before there are major changes to their basic function. Much of the thinking about farming systems has involved a notion of a variable, but stationary, climate. The implicit assumption is that there is a static envelope within which climate will vary. A changing climate implies a non-stationary envelope, and this requires adaptive management at the farm, regional and policy level (Nelson et al. 2008). Milly et al. (2008) noted that accepting non-stationarity would require a major rethink for teaching, research and the practice of water management. The same is true for rainfed farming systems where there is, up to now, an expectation that within any decade there will be some dry years, but these will always be interspersed with average and wet years; this fails to recognise decadal variability where certain decades are drier or wetter or the bigger challenge of climate change.

3.7   Conclusion

By definition, rainfed farming has to deal with climate risk. Systems approaches are useful to understand the interaction between farming systems and climate systems and to harness the enormous amount of information from climate science to

minimise the risks and maximise the opportunities in rainfed farming. Understanding how climate interacts with farming systems will benefit from systems frameworks from ecology and biology; the task of managing climate risk will benefit from systems engineering but to understand how rainfed farmers manage risk will require methods from soft systems approaches.

Climate change takes us beyond classic risk management because more and more will be unknown. Accepting a non-stationary climate and a situation where uncertainty replaces risk assessments involves a shift from 'knowing' what will happen to learning from what happens and setting a range of hypotheses about what might happen and what the best response will be. This is the process of adaptive management. Systems thinking will be essential to this process.

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