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Agronomy of Grassland Systems

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Chapter 1

Overview: perspectives on grassland systems

Recent understandings from the 'new biology' and other areas of research are challenging the ways in which grassland systems have historically been 'seen'. When we say 'seen' we mean the way we think about, and use language to talk about 'grassland systems'. Most texts on agronomy or grasslands will not address these issues. Historically they have taken the perspective that certain 'real types' of grassland systems exist that can be described and classified and that these understandings can be used as a basis for intervention and change. We start from a different perspective. In recent years there has been growing acceptance of several complex, seemingly intransigent problems, often collectively referred to as environmental problems, or problems of sustainable development. Specific examples, related to grasslands, include the loss of organic matter from soils, loss of biodiversity, rangeland degradation and desertification and the contribution of grasslands to 'greenhouse effects'. The perspective of this book is that if we are to manage these complex issues, there is a need firstly to look at how we think about the issues and the ways in which historically we have chosen to manage. We recognize that many of the issues arise because of our own historical practices, and that more of the same practices will not necessarily be a good thing.

The concept of perspective is important. We recognize from daily life that none of us have the same history, that we all have different and unique experiences, and as a consequence we all have our own perspective on things and events. Historically, gender perspectives have often been ignored in the 'construction' of grassland systems; fortunately new approaches are available (Chapter 9; CIAT, 1991). Of course, because we live in families and particular cultures we share similar perspectives about many things. These cultural perspectives often determine how we see and interpret our experiences and lead us to have particular understandings and to name things in particular ways. It is thus common to talk about a transport system or a grassland system as if everyone would agree, following more detailed attention, on what these were. This is clearly not the case.

Human beings live with the strong wish to explain. When we, as humans, generate explanations of phenomena we often refer to these as theories. Different theories, however, carry with them different perspectives or viewpoints. For example, the theory of plant succession, accredited to Clements (1916), has led many ecologists, agronomists, and land managers and administrators to see grasslands in a particular way. This has led to particular research questions, definitions of what are 'good' and 'bad' grasslands and 'good' and 'bad' management, which in turn often led to particular forms of regulation. In recent years a different theory, the state and transition model for grassland dynamics (see Chapter 2), has emerged as an alternative means to explain phenomena in some types of grasslands. This has happened because the other theory did not seem to explain what people were experiencing – it was no longer useful. Unfortunately we often learn about theories as a universal truth – the 'right way' – and as a consequence there have been many examples of applying management prescriptions that match the theory but not the context. Examples are given below.

Theories thus bring certain things into focus, but leave other perspectives blurred or unconsidered. Another way of saying this is to consider any theory as an example of a social technology, and like any technology when it is used certain aspects are revealed and other aspects concealed. This is quite a challenging notion, but because we see it as important to how future grassland agronomists might conduct themselves, we devote some attention to it. A topical example is how, in recent concern with genetic engineering, we have come to think of life as being made up of sets of genes organized in particular ways.

Brian Goodwin (1994) draws our attention to how the whole organism seems to have disappeared from sight from this perspective. As a consequence the special emergent properties (Table 1.1) of whole organisms are concealed from consideration. Social technologies which derive from our theories and models of understanding are just as powerful in realizing different grassland systems as are 'harder' technologies such as tillage, fire and new plants. In fact we would go further and say from our perspective that grassland systems arise as result of our ways of thinking – grassland systems do not exist in themselves but as a relational unity between social factors and what we call our natural or biophysical environment (Russell & Ison, 1993). This is exemplified in Fig. 1.1 which pictures grassland systems as arising from the relationships between humans with differing histories and perspectives and what we call a 'grassland space'.

1.1 The social construction of grassland systems

In 1932 the physicist Max Planck said: 'Science cannot solve the ultimate mystery of nature . . . because, in the last analysis, we ourselves are part of nature, and

Table 1.1 *Generalized system concepts employed in systems thinking*

Concept	Definition
Boundary	The borders of the system determined by the observer(s) that define where control action can be taken: a particular area of responsibility to achieve system purposes
Communication	(i) First-order feedback may be regarded as a form of communication, but should not be confused with human communications, which has a biological basis (ii) Second-order occurs in languages amongst human beings and gives rise to new properties in the communicating partners who each have different histories
Connectivity	Logical dependence between elements (including sub-systems) within a system
Decision-taking	Information collected according to measure of performance is used to modify the interactions within the system
Emergent properties	Properties that are revealed at a particular level of organization and which are not possessed by constituent sub-systems. Thus these properties emerge from an assembly of sub-systems
Feedback	A form of inter-connection, present in a wide range of systems. Feedback may be negative (compensatory or balancing) or positive (exaggerating or reinforcing)
Hierarchy	The location of a particular system within the continuum of biological organization (Fig.1.4). This means that any system is at the same time a sub-system of some wider system and is itself a wider system to its sub-systems
Measure of performance	Information collected according to measures of performance is used to modify the interactions within the system
Monitoring and control	Information collected and decisions taken are monitored and controlled and action is taken through some avenue of management
Purpose	Objective, goal or mission; the 'raison d'etre' that in terms of the model is to achieve the particular transformation that has been defined
Resources	Elements that are available within the system boundary
Transformation	Changes, modelled as an interconnected set of activities, which convert an input that may leave the system (a 'product') or become an input to another transformation

Source: Adapted from Wilson (1984).

therefore part of the mystery we are trying to solve'. This captures the notion that we wish to convey – grassland systems emerge from the diverse relationships we have with 'nature'. We wish to explore how technology shapes our relationship with nature and the responsibility we, as human beings, hold with regard to this relationship. More specifically we are concerned with how a future generation of grassland agronomists might participate in the design of grassland systems that are sustainable and ethically justifiable. The perspective we as authors take is that there is value in: (i) thinking of grassland systems as social constructs (Fig. 1.2) and (ii) using systems concepts (Table 1.1) to think about, describe, and inform action in the design of future grasslands. These perspectives guide our thinking and the organization of this book.

Historically texts about grasslands have tended to be based on the classification of types of grasslands – a typology or taxonomy (see Table 1.2) – based on common features such as species, rainfall, soils and other edaphic features. Such classifications have included particular types of human activity, but have rarely taken the perspective that grassland systems are social constructs, tending to refer to them as 'natural systems' or modified 'agro-ecosystems' (see Fisher, 1993). From our perspective we would wish to situate these earlier ways of seeing 'grassland systems' in a different context. We do not wish to lose that which was valuable from the earlier ways of thinking but see the need for new ways of thinking and acting to deal with the complex issues that underpin grassland sustainability.

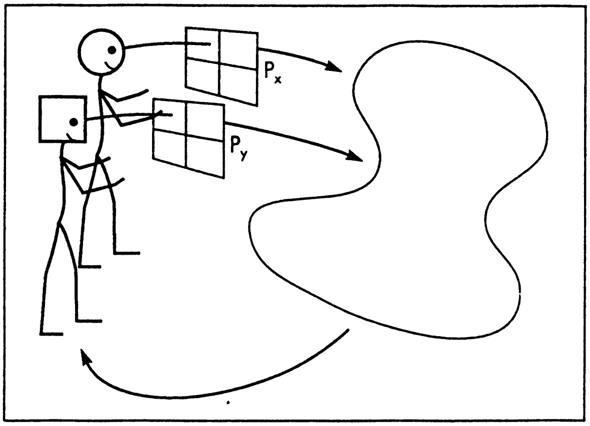


Fig. 1.1 *Grassland systems are social constructs unique to individuals or groups at particular times and in particular places. People with theories and with different experiences have different perspectives (P_x, P_y). Grassland systems emerge from the dynamic relationship between people in relationship with a grassland 'space', in which soils, water plants, etc. are recognized. Placing a boundary around this system, we are able to recognize different 'grassland systems'.*

A 'construct' is the particular viewpoint or perspective of 'reality' unique to an individual and specific to time and place (Bannister & Fransella, 1971). A constructivist perspective is one in which the observer is part of the system rather than independent of, or external to, it. In Fig. 1.2 we depict the diversity of existing socially constructed grassland systems and how these change over time with the changing perspectives of those who are 'stakeholders' in the system. To see 'grassland systems' as social constructs is to take seriously research on the biology of our own cognition. The word cognition means literally 'together to know'. Thus a group of experts with different experiences and training, when distinguishing a particular grassland system, may see quite different things (Fig. 1.3). This can lead to difficulties, particularly if individuals are not aware of it, when they try to work together in teams or groups, and when any collective must decide on a course of action when there is no clear right way to proceed. Russell (1986) points out important elements of a constructivist perspective when he states: 'My real world is different than your real world and this must always be so. The common ground, which is the basis of our ability to communicate with one another, comes about through the common processes of perceiving and conceptualizing. The processes may be the same but the end products are never the same. What we share is communication of the worlds we experience, we do not share a common experiential world.'

From this perspective any individual only has access to what we call a grassland system through communication in its many and diverse forms – communication is a process that relates us to each other and to our environment and enables us to distinguish and recognize different grassland systems. It would be necessary, for example, for the different experts depicted in Fig. 1.3 to engage in some form of communication if they were to decide on how the grassland system might be best described, changed or 'improved'. If they did not, decisions about change would be likely to be based on a very narrow perspective and for many of the complex issues or problems to be dealt with in grassland systems this would be likely to prove unsustainable.

If students of grassland agronomy recognize that they must iterate between different perspectives and levels of biological and social organization (Fig. 1.4), and that together with farmers, researchers or pastoralists, they must make decisions within a system that is socially constructed and often so complex that there may be no single, universal best solution, then it is likely that each professional will more fully understand and appreciate the other. From this recognition it also follows that prescriptive advice from a textbook is likely to have very limited applicability. In this book we try to avoid prescriptions: we are concerned with concepts and principles.

1.2 Grassland issues or problems

Future grassland agronomists will be engaged in the formulation and resolution of grassland 'problems'. This is the same as being involved in the design or 'construction' of grassland systems (Chapter 9). When we use these terms we are not referring to them in the sense commonly associated with building or architecture, but in terms of social processes. To do this it will be necessary for grassland agronomists to be aware of: (i) the problem formulation process; (ii) the need to work with others who may have different perspectives; (iii) particular ways of thinking about grassland problems; (iv) the historical understandings we have about grassland systems and (v) the language and concepts that are used to talk about them and to guide action.

From our perspective grassland 'problems' are not something that exist independently of the processes by which they are named and recognized – we call this problem formulation, recognizing that it is a social process and that problems do not exist 'out there' just

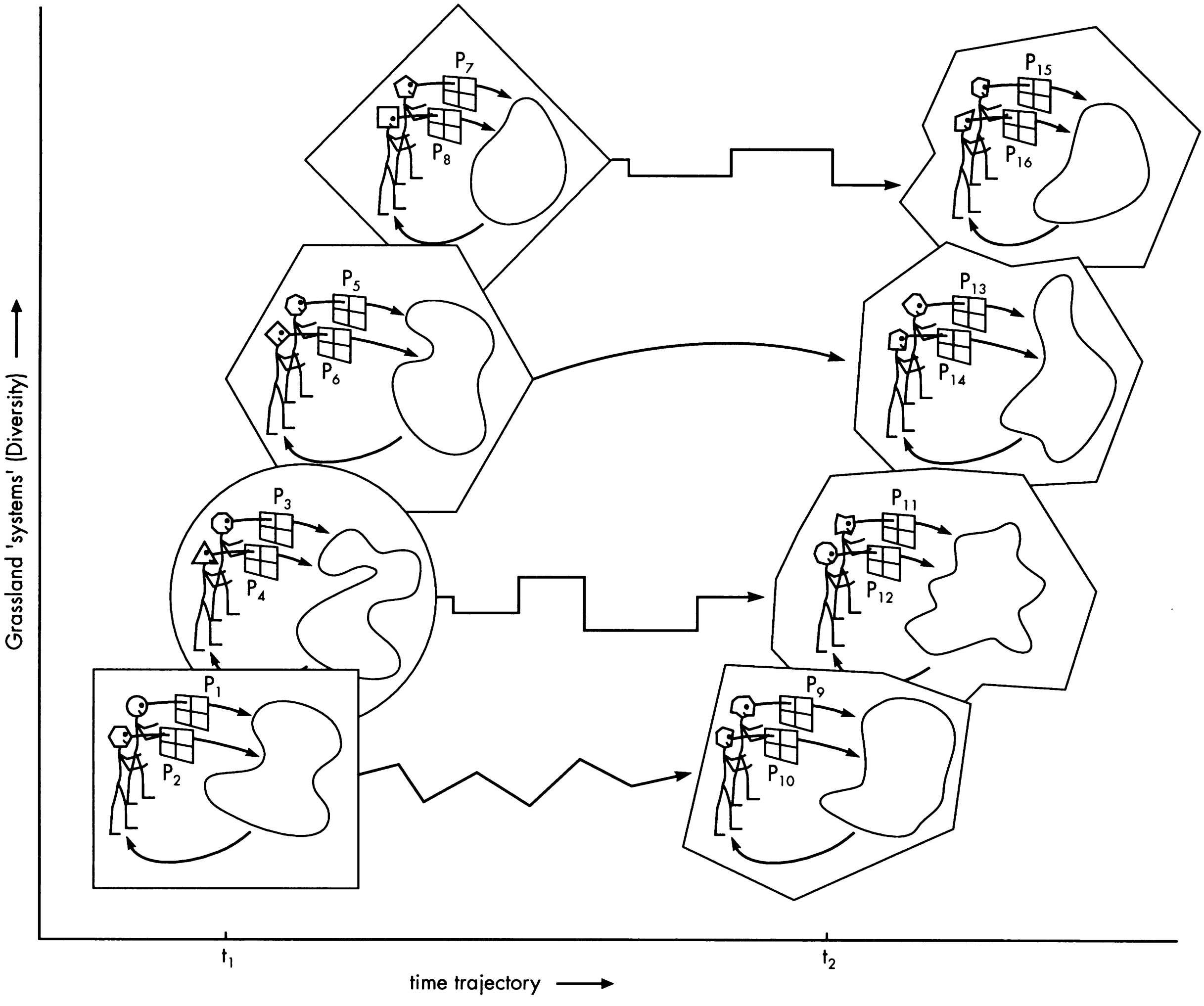


Fig. 1.2 *Grassland systems differ both spatially and temporally as a result of the different relationships between people with different perspectives (*P_1–P_8*) and a grassland 'space'. This gives rise to change and diversity and new perspectives (*P_9–P_{16}*).*

Table 1.2 *Some typical 'grassland systems' in Africa and Latin America based on typologies of classification*

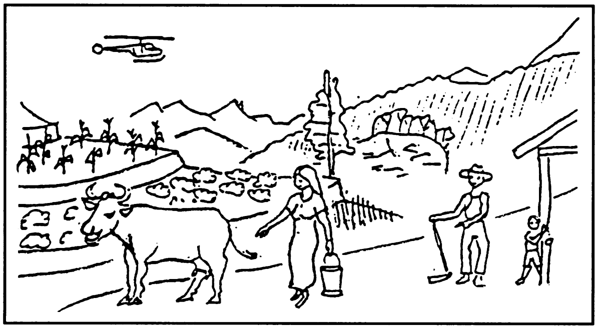
Grassland system	Major crops	Major animals	Main regions	Feed source
Africa				
Pastoral herding (animals very important)	Vegetables (compound)[ab]	Cattle, goats sheep	Savanna (Southern Guinea)	Natural rangelands, tree forage
	Millet, vegetables	Cattle goats, sheep	Savanna (Northern Guinea and Sahel)	Natural rangelands, tree forage
Mixed farming (farm size variable, animals important)	Rice/yams/ plantains	Two or more species (widely variable)	Humid tropics	Fallow, straw, brans, vines
	Rice/vegetables, yams, cocoyams	Some cattle	Transition forest/ savanna	Fallow, vines, straw
	Sorghum/millet, groundnuts, cotton, tobacco, maize, cowpeas, vegetables	Cattle, goats, sheep, poultry, horses, donkeys, camels	Savanna (Guinea and Sahel)	Stover, vines, fallow
Latin America				
Perennial mixtures (large farms) (livestock relatively unimportant)	Coconuts, coffee, cacao, plantains, bananas, oil palm, sugarcane, rubber	Cattle, swine	All[c]	Natural pastures, by-products, cull material
Commercial livestock				
Extensive large to very large (livestock dominant)	None are important	Cattle (beef)	C, V, Br, Bo, G, CA[c]	Natural grasslands
Intensive Medium to large, livestock dominant	Improved pasture, some gains	Cattle (dairy), swine, poultry	All[c]	Natural and improved pasture, feed grains, by-products
Mixed cropping, small size in settled areas; medium size in frontier areas; subsistence or cash economy (livestock relatively important)	Rice, maize, sorghum, beans, wheat, cacao, plantains, coffee, tobacco	Cattle, poultry, goats, sheep, donkeys, horses, mules, swine	All[c]	Natural pastures, crop residues, cut feed

[a] Enclosed areas around household or village.

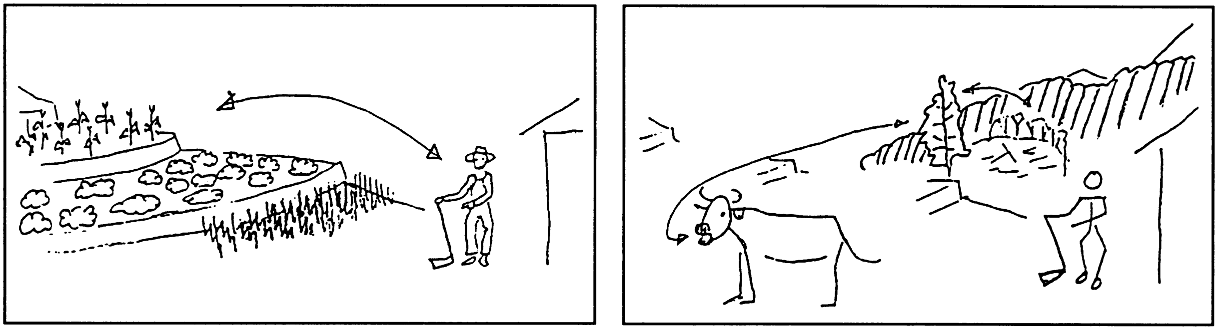
[b] Present or absent, depending on the area.

[c] All, all countries; Bo, Bolivia; Br, Brazil; C, Colombia; CA, Central America; CI, Caribbean Islands; E, Ecuador; G, Guyana; P, Peru; V, Venezuela.

Source: McDowell & Hildebrand (1980).

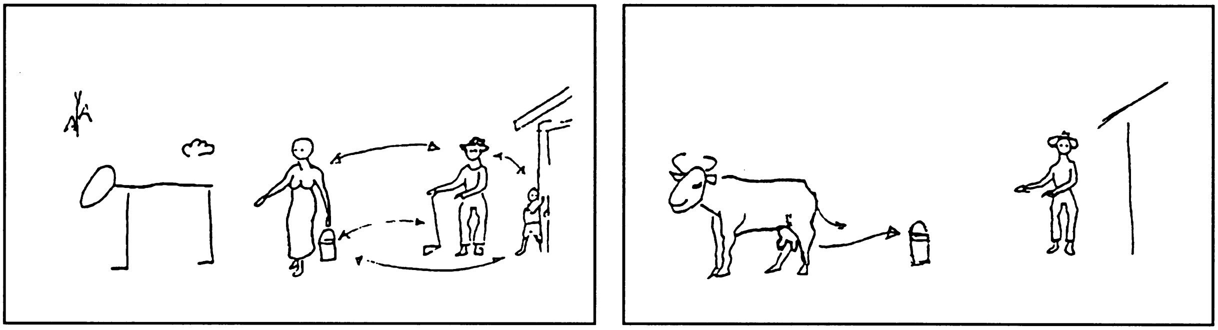


'Grassland system'



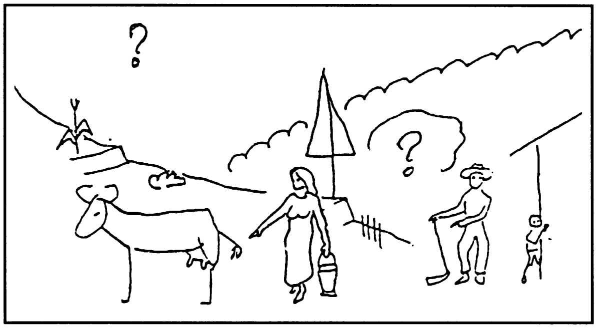
Agronomist

Ecologist



Sociologist

Animal scientist



Interdisciplinary team

Fig. 1.3 *Perspectives of a grassland system taken by disciplinary experts differ from that taken by an effective interdisciplinary team. (Source: adapted from U. Scheuermeier, unpub.)*

waiting to be identified. Some problems may be formulated in a way that is quite specific, e.g. the poor growth response of plants to a non-optimal condition such as increasing aluminium toxicity in the soil solution. Such problems are amenable to analysis using hypotheses that are testable. The analysis should lead to a definite solution or, at least, to a 'best' or an optimal solution to that specific problem. At the other extreme, in terms of levels of complexity, are problems that arise because of the uncertain interrelationships that are a part of farming systems: there is generally no single, static 'best' solution to problems of interrelationships in a dynamic system involving environment, plants, animals, technology (types of ploughs, etc.), economics and the social values and goals of the farmer. It is therefore important to distinguish between problems for which there is an agreed solution and those for which there is no clear 'right' answer. Many grassland 'problems' are of the second type, and for this reason we often refer to them as issues, rather than problems.

The way in which we formulate issues shapes the sort of answers we get; this is because of the ways in which we choose to think about issues. Thinking about issues in only one way leads us into traps from which it is often difficult to escape (Open University, 1991). Botswanan and Australian examples demonstrate this notion of 'traps'. In Botswana, Louise Fortmann's (1989) case study of 50 years of rangeland use showed how official policy consistently defined the major problem of the pastoral regions as overstocking leading to certain ecological disaster. The problem was clear, as was the technical solution (destocking). Local experience, however, defined the problem as too little

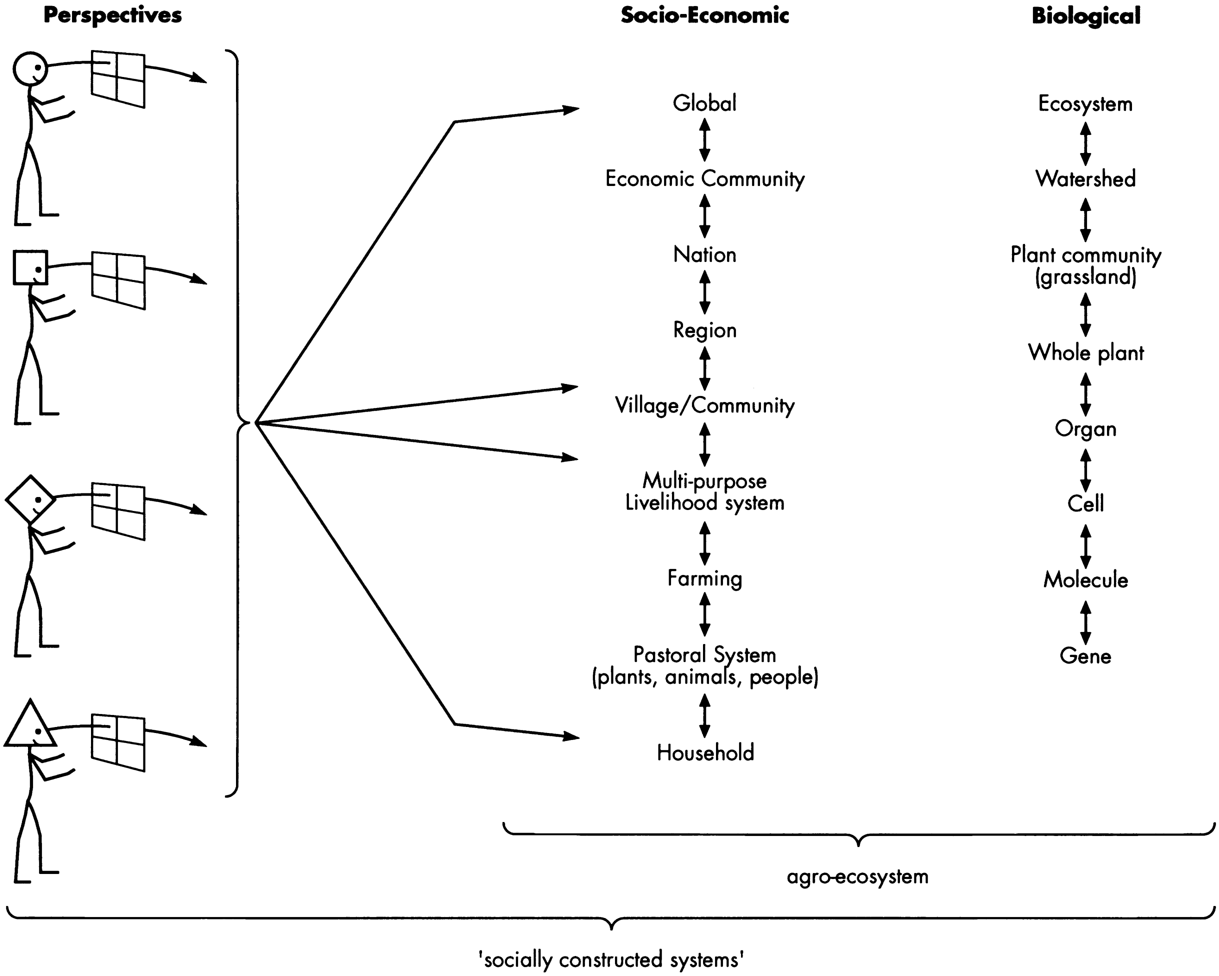


Fig. 1.4 *Hierarchy of levels of system organization. The complexity of such a schema is increased when we recognize the many perspectives we as observers bring and that this operates at each 'level' of organization.*

land. The local solution was also very different: renting, or using land previously let to a European mining company. The local experience was that the local range could and did carry an increased cattle population and that besides localized problems, the dire official predictions did not eventuate. While there is general agreement that the quality of the environment (as indicated by the quality of the grazing, the number of trees and the extent of erosion) is deteriorating, there is clearly no agreement on causes or solutions. It is significant that the story has been told consistently from both perspectives for 50 years: this shows how different and how unconnected traditions can be (Russell & Ison, 1993).

An Australian study (Kersten, 1994) demonstrates a similar contest between researchers and pastoralists over the nature and causes of a so-called 'rangeland degradation problem' in the semi-arid pastoral zone. Similar experiences have occurred in the USA, so this is not a phenomenon peculiar to either the 'developing' or 'developed' world. These are examples of failure of the problem-formulation process. They demonstrate how easy it is to fall into traps when particular ways of thinking are consistently employed.

1.3 Systems thinking

The two most common ways of thinking in our (Western) society have been logical and causal thinking. The former is of the type: 'If all grasses are plants, and this is a grass, then it is a plant'. As the Open University team (1991) point out, this statement: 'starts with a generalisation, a premise which is assumed to be true and then deduces a conclusion about a particular case.' Three things characterise this type of thinking: (i) it is objective – the conclusion does not depend on your point of view, your opinions and values about the world; (ii) it is necessary: that is the conclusion always follows from the premise; (iii) the structure of the thinking is sequential or linear – it has the form of 'if a, then b', often called a chain of reasoning. Logical thinking is a way of linking ideas together.

Causal thinking is a way of linking events together. A grassland agronomist explaining why a cow is not growing may tell you that there is a protein deficiency in the pasture at the end of a dry season. This is of the form 'a causes b' and superficially is not unlike logical thinking; many would suggest it has the same three characteristics. However causal thinking is always an explanation by an observer of an event, and an event is dynamic, with participants. So causal thinking is really a statement about a relationship and the nature of the event (e.g. the protein deficient pasture and the cow) is dependent on the properties of the participants in the event that is distinguished by an observer. As observers we tend to put boundaries around what we are studying – thus an animal nutritionist may place a boundary around the relationship between the animal and the plant, whereas a plant nutritionist may place the boundary around the plant and its nitrogen supply. The poor nitrogen supply may be causing low protein but this in itself is a poor explanation of the overall problem if it only concentrates on one set of relationships. This is where the so-called objectivity of causal thinking breaks down, because explanations are not offered from a value-free perspective. We all have perspectives. Our perspective often determines where we place our boundaries around problems or issues. Economists refer to this as externalities.

The so-called objective forms of reasoning are not very suitable by themselves for sorting out many of the issues to do with grassland systems – they are not very helpful when it comes to preferences about breeds of animal, family values, lifestyle questions, enterprise goals nor deciding what to do about vegetation management in a whole watershed, rangeland degradation or policies to mitigate contributions by ruminants to greenhouse gas emissions. Hence there is a need for a way of thinking about systems that takes the characteristics of systems into account (Table 1.1). There are two adjectives derived from 'system': 'systemic', or thinking in wholes and 'systematic', step-by-step thinking or procedures. Checkland (1988) notes that to many people a computerized information system 'is the very paradigm of what they mean by "system"'. This is not what we mean when we talk about 'system' but it does largely account for the lack of attention to the development of the ideas of 'system' in agriculture and the lack of attention to systems-based methodologies that are not computer based.

Systems thinking is a special form of holistic thinking – dealing with wholes rather than parts. One way of thinking about this is in terms of a hierarchy of levels of biological organization and of the different 'emergent' properties that are evident in, say, the whole plant (e.g. wilting) that are not evident at the level of the cell (loss of turgor). It is also possible to bring different perspectives to bear on these different levels of organization (Fig. 1.4). Holistic thinking starts by looking at the nature and behaviour of the whole system that those participating have agreed to be worthy of study. This involves: (i) taking multiple partial views of 'reality', as exemplified by the interdisciplinary team in Fig. 1.3; (ii) placing conceptual boundaries around the whole, or system of interest and (iii) devising ways of representing systems of interest.

1.4 Representing grassland systems

We represent grassland systems in three ways: (i) in the choice of language to describe them; (ii) using diagrams and (iii) using models. We do not propose to spend much time talking about language, because the book itself is an introduction to the language commonly used to talk about grassland systems. It is, however, worth pointing out that some particular features of language can be important in shaping the perspective we use to 'construct' a grassland system. Metaphors are a good example: if we choose to see a dairy farming system as if it were a factory, then we generate certain images and ways of looking at the design of a system. If we chose to look at it as if it were an ecological system this might reveal different features and lead to different designs.

Diagrams have the advantage of showing interconnections in ways that words alone can not. The development of diagramming skills is a useful adjunct to creative problem solving – an important ingredient is iteration – repeating the process – until you are satisfied with the outcome. Figure 1.5 is a diagram showing the interconnections between biological components of a grassland system. In our diagram the biological components of grassland or pastoral systems are the environment, plants and animals. These are closely interrelated in a cyclical fashion. We emphasize the quantitative interrelationships within the biological cycle and the feedback nature of the cycle. This contrasts with the perspective of the traditional agronomist, who usually thinks of the cycle as a simple catena: environment – growth of grass – animal production – product removal. Diagrams such as that shown in Fig. 1.5 can be made specific by emphasizing particular developmental aspects, environmental variables or loops feeding back material or information. An example of this specificity is provided by a grassland comprised of a mixture of the tropical annual legume Townsville stylo (*Stylosanthes humilis*) and annual grasses in the Australian wet-and-dry tropics. Here, in a climate in which rainfall during the wet season dominates the productivity and composition of the grassland, the agronomist pays particular attention to estimating how the composition and productivity are affected by water through rainfall, infiltration, run-off, soil moisture, soil drying and drought (Fig. 1.6).

It is useful to note, in passing, that the amount of control which the farmer is able to exercise over the

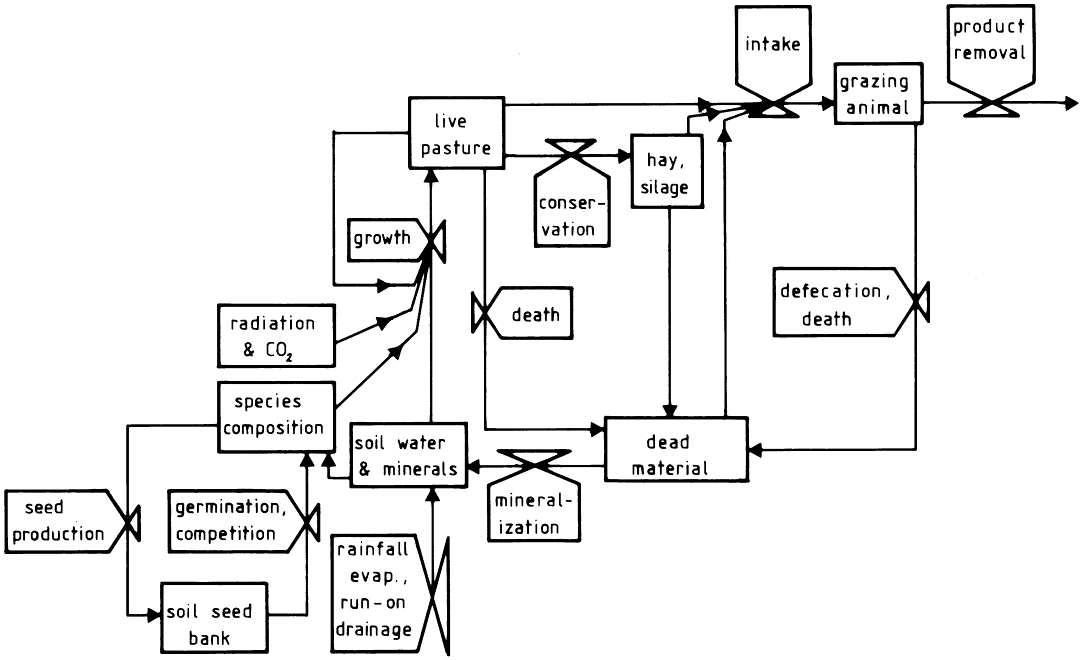


Fig. 1.5 *The main biological components in the function and management of grassland systems. A grassland system is dynamic: various pools or state variables (□) are linked by flows of material, e.g. seed, leaf (arrows) and governed by rate variables (⊠).*

components in the grassland system ranges from virtually nil to total (Table 1.3).

1.4.1 *Modelling*

Modelling is a means of understanding and reducing complexity. The word 'model' and the act of 'modelling' have many meanings. Here we use a very broad interpretation of Wilson's (1984): 'a model is the implicit interpretation and representation of one's understanding of a situation, or merely of one's ideas about the situation constructed for some purpose. It can be expressed in mathematics, symbols or words, but is essentially a description of entities and the relationships between them. It may be prescriptive or illustrative, but above all it must be useful.' At the end of each chapter we demonstrate how the use of models can enhance analysis and decision-making using the material that has been discussed. Here we wish to give an overview of the approaches to modelling.

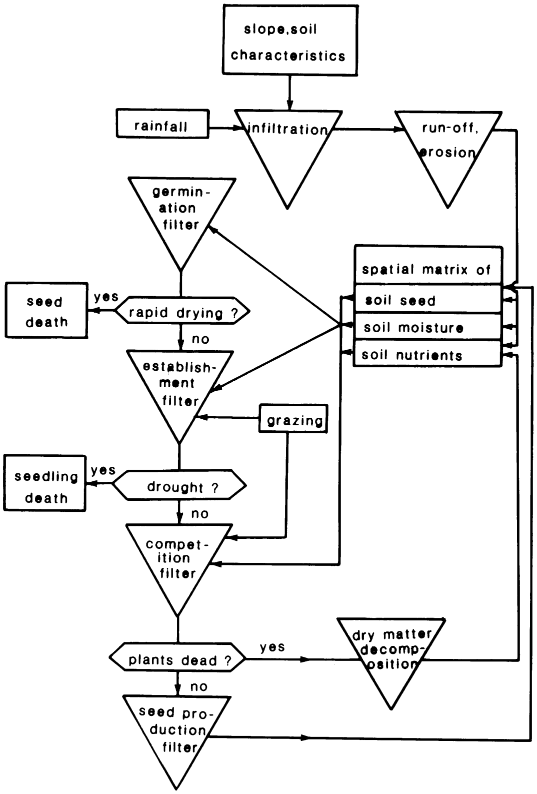


Fig. 1.6 *Environmental and plant factors that dominate grassland pattern and species cycling in a grassland comprised of Townsville stylo and annual grasses in the wet-and-dry tropics. The factors exert quantitative effects on yield and species composition; the plant factors germination, establishment, competition and seed production may be seen as a series of filters through which individual plants attempt to pass. (From Torssell, 1973.)*

Modelling is carried out for some purpose. We need to be careful not to use models for purposes other than which they were designed and to recognize that the learning that occurs in the process of developing models is qualitatively different from the use of models already developed by someone else. Purpose reflects the notion that a model is not a goal in itself but rather a part of some analysis associated with problem resolution that leads to increasing knowledge and sometimes an increasing need for quantitative results. Different forms of modelling find greater use in different problem-formulating strategies and at different levels of biological organization (Fig. 1.4). Used in this way, modelling may serve as a unifying function in the study of grassland systems if the steps outlined in Table 1.4 are followed within a relevant systemic or interdisciplinary framework (Rykiel, 1984).

Conceptual modelling

Conceptualization of what the system under study is or might be is usually a starting point (Rykiel, 1984; Wilson, 1984). Thus conceptual modelling precedes other forms, as well as being a modelling form in its own right.

Conceptual or qualitative models may be used: (i) as an aid to clarifying thinking about an area of concern; (ii) as an illustration of a concept; (iii) as an aid to defining structure and logic; and (iv) as a prerequisite to design. These uses are not mutually exclusive. We will use examples that combines aspects of (ii) and (iii), presenting some of the key concepts and interactions in plant generation.

The modelling of human activity systems, as distinct from biological or natural systems, utilizes a particular form of conceptual model. The modelling language developed by Checkland (1981) and colleagues is the use of verbs to model functions or activities. Plant domestication can be viewed as a human activity system (Chapter 2) and modelled in this way. Conceptual modelling often relies on particular types of diagrams (Fig. 1.7).

Expert systems, fuzzy thinking and chaos

Expert systems are also commonly referred to as computer-based decision support systems (DSS). They usually combine data (for example, by spreadsheets as look-up tables) and quantitative relationships with rule-based or qualitative inferences. They are thus mixes of qualitative and quantitative models and may contain either as sub-models. Their common purpose is to assist decision-making; their output is usually a set of options for action with likely benefits and perhaps risks, associated with each option (see Stuth & Lyons, 1993). Hochman *et al.* (1995) have coupled quantitative, rule-based outputs from an expert system with economic analyses to assign likely economic scenarios to each option for management of a beef-based, grassland production system.

Fuzzy thinking probably has much to offer future grassland agonomists; Zhang & Oxley (1994) found fuzzy set ordination (FSO) able to analyse and synthesize ecological information. This form of thinking relies on both quantitative and qualitative modelling. Fuzzy cognitive mapping (FCM), a particular form of fuzzy thinking, enables 'everyone to pack their own wisdom and nonsense into a math picture of some piece of the world. But once packed in, the FCM predicts outcomes and we can compare these with data to test them' (Kosko, 1994). FCM employs the power of computing to examine feedback in complex systems. It thus acts like a neural net. Kosko (1994) argues that 'fuzzy logic will change our world views in small ways and deep ways. It will bring us closer to machines and bring them closer to us. And fuzzy logic will poke holes in moral absolutes. It will help solve some problems and will muddy up others.'

Chaos is the sensitive dependence of a system to initial starting conditions. That is, very small differences in a system, say two populations, can over time lead to vastly different trajectories and outcomes. Such systems have chaotic dynamics (Hastings *et al.*, 1993). Understandings from studies of chaos and complexity will also increasingly inform grassland agronomists (e.g. Grenfell, 1992; Godfray, Cook & Hassell, 1992). As Brian Goodwin (1994) notes: 'life exists at the edge of chaos, moving from chaos into order and back again in a perpetual exploration of emergent order.' He explains further: 'For complex non-linear dynamic systems with rich networks of interacting elements, there is an attractor that lies between a region of chaotic behaviour and one that is 'frozen' in the ordered regime with little spontaneous activity. Then any such system, be it a developing organism, a brain, an insect colony, or an ecosystem will tend to settle dynamically at the edge of chaos. If it moves into the chaotic regime it will come out again of its own accord; and if it strays too far into the ordered

Table 1.3 *Level of control which farmers are able to exercise over environmental and biological variables in grassland systems*

Environmental factor	Level of control	Method of control
Grazing pressure	Good	Stocking rate, stock movement and herd (population) structure
Plant population	Good	Sowing, selective herbicides, stocking rate and stock movement
Defoliation	Good	Stocking rate and stock movement
Nutrition	Fair	Fertilizer application where economic or where species respond
Pests and diseases	Variable, usually poor	Ranges from good short term control in intensive situations to control relying on plant resistance in extensive systems
Moisture	Poor	Irrigation: selection between existing wetter and drier sites and use of cultivars that have development patterns to match available soil water; farmer can use mechanical aids (contour furrows, drains, etc.)
Soil structure	Poor	Tillage and stocking affect particle size distribution, etc. but knowledge is empirical (e.g. don't plough when soil is 'too wet'): farmer can select between existing soils, and make amendments, e.g. add gypsum
Temperature	Indirect	Selection of sites with different aspects; selection of species with different growth responses to temperature, or alteration of time of sowing

regime it will tend to 'melt' back into dynamic fluidity where there is rich but labile order, one that is inherently unstable and open to change.'

Quantitative modelling

Quantification of processes within grassland systems models aids both research and management. We refer to quantitative models extensively in this text, usually as algebraic equations or statistical relationships. As with all models these are a simplification and include assumptions made by the modeller; they are used mainly to predict the behaviour of some aspect of the system being considered and they require some form of validation. An understanding of this area of modelling may be gained from the schema proposed by Wilson (Fig. 1.8).

Deterministic models include any algebraic relationship; they are well suited to problems concerned with the allocation of some limited resource (e.g. land, money, labour, fertilizer) where many alternatives exist. Linear programming is a well-known form of a steady state deterministic model. It involves numerical optimizing and has been frequently used by agricultural economists to study complex problems such as the minimization of costs or the maximization of profits, by animal nutritionists for determining the least cost or profit maximizing rations (e.g. Sauvant, Chapoutot & Lapierre, 1983) and more recently with the development of powerful algorithms for integrating biological and economic data from whole farming systems. Linear programming is also an appropriate tool for studying the integration of new grassland systems and cattle management options (e.g. Teitzel,

Table 1.4 *Modelling: the purposes for which a model might be used and a four-step modelling procedure that enables the development of a common perspective by different discipline groups involved in problem-solving or research in connection with pastoral systems*

Purposes	
1. Exploration	Objectives are very often general or intuitive, usually with no specific criteria for meeting them; the main aims are insight, clarification and understanding of the factors that contribute significantly to system behaviour
2. Explanation	The general objective is to understand the structural and functional relationships between components and sub-systems that explain the pattern of interconnections within the system and generate system behaviour; specific objectives are related to the level of resolution and the level of the study; system, sub-system, and component levels
3. Projection	The objective is to examine the dynamic behaviour of system variables at any level (i.e. component, sub-system or system) and the effects of changes in the values of parameters or variables and their variability; variability in the occurrence of events and making of decisions; the patterns of behaviour represented in the dynamic relationships among variables are more important than the actual values of the variables
4. Prediction	The specific objective is to estimate future values of particular system variables and/or the nature and timing of events and decisions; emphasis is on the accuracy and utility of the prediction, and the reasonableness of the explanation of the prediction
Procedures	
1. Formulation	The development of ideas, problem statements, and approaches to solutions by conceptualization, definition and design
2. Clarification	The formal expression of objectives, model structure, functional relationships, etc. through organization, documentation and accounting
3. Analysis	The interpretation and explanation of model and system behaviour through statistics, simulation and system analysis
4. Application	The use of the results of analysis and of models through communication, experimentation and technology transfer

Source: Adapted from Rykiel (1984).

Monypenny & Rogers, 1986). The technique of linear programming is described by, for example, Gass (1985).

Steady-state non-deterministic models apply where the mechanisms governing behaviour are not known, but where it can be assumed that certain variables are wholly or partially dependent on others. Seed yield, for instance, may be wholly or partly dependent on plant density (Chapter 4). Regression relates variables of interest. In its simplest form, e.g. seed yield (y) may be related linearly to plant density (x). The constants in linear regression, curvilinear regression, multi-linear regression and multiple regression are derived to minimize the sum of the errors squared at the discrete data points. Wilson (1984) includes probabilistic modelling as a variant within steady-state quantitative modelling. Models with some element of randomness, to which we may assign a probability, are called stochastic models.

Steady-state modelling is sometimes described as empirical modelling. Empiricism involves attempting to fit some model or equation to data and then making deductions about the mechanisms involved. The opposite to this is mechanistic modelling, which attempts to understand the response of biological systems in terms of mechanisms. Mechanistic models are constructed by looking at the structure of the system and dividing it into its components in an attempt to understand the behaviour of the whole system in terms of the actions and interactions of its components (Thornley, 1976).

Dynamic, deterministic models include differential equations. Differential equations allow the simulation of situations in which time dependence can be represented continuously. State variables, i.e. variables that describe quantities or amounts (e.g. pasture dry matter, livestock weight, nitrogen content) are each associated with a rate variable which describes change with time (t), e.g. pasture growth rate, livestock growth rate, rate of nitrogen cycling. The value of a state variable at any point in time (T) can be derived by integration which, when repeated many times, completes the simulation of interest.

$$\mathrm{RATE}\,(T-1) = t\,[\mathrm{STATE}\,(T-1)\ldots] \tag{1.1}$$

$$\mathrm{STATE}\,(T) = [\mathrm{RATE}\,(T-1) \times DELT] + \mathrm{STATE}\,(T-1) \tag{1.2}$$

where RATE and STATE refer to any rate and state variable respectively, *DELT* is the time interval over

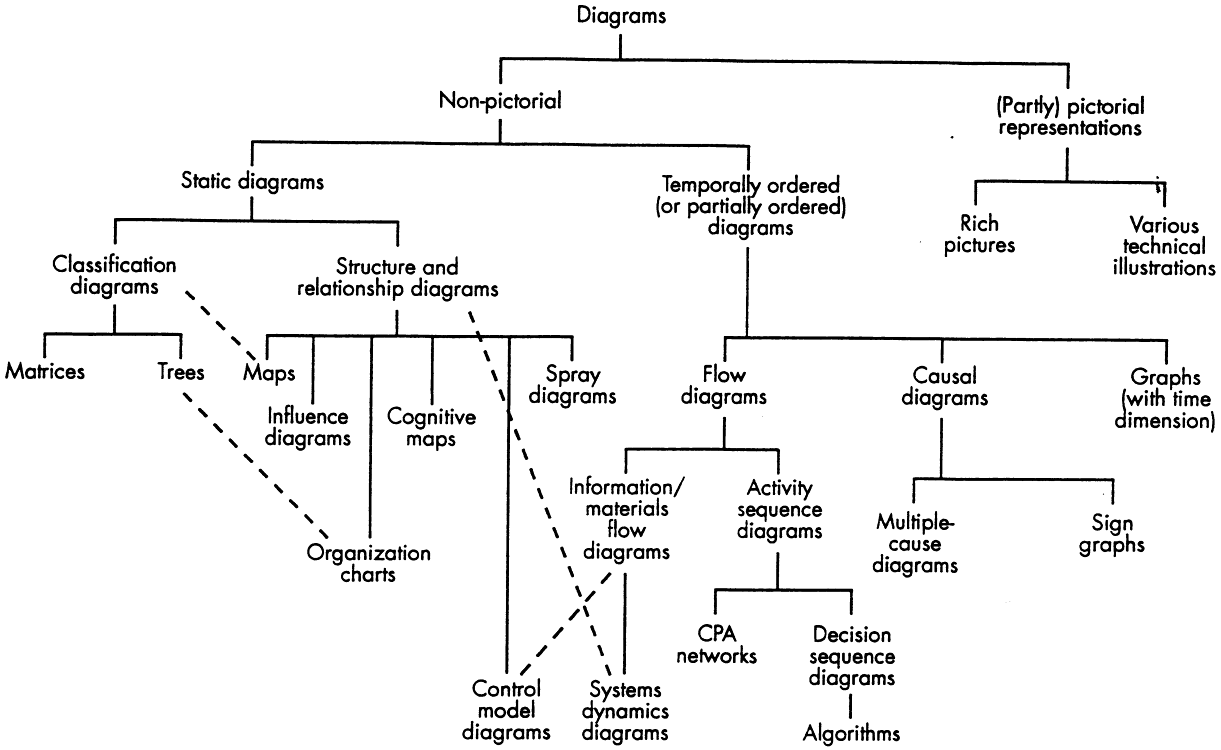


Fig. 1.7 *A schema depicting the different forms of diagrams that can be used in conceptual modelling. (Source: Open University, 1991.)*

which integration occurs, the length of which is determined by the type of model.

Dynamic, non-deterministic models are concerned with simulation of discrete events using difference equations (as opposed to differential equations). Quantitative models range over all levels of biological organization (Fig. 1.4). Morley & White (1985) describe quantitative models relevant to grassland agronomy ranging from ones concerned with nitrogen fixation at the cellular level to whole farm and national sectoral models. One useful division of models according to their use is between predictive, and explanatory or experimental models (P. Martin, 1986, personal communication):

(i) Predictive models. These are frequently concerned with grassland productivity and efficiency and thus with input/output relationships, the environment and production interactions and economics. This form of modelling contributes to estimations of the reliability of feed options, the answering of farm management questions such as 'how to use a given forage most efficiently with what type of animal?' and/or to estimations of the effect of variability in the weather and prices on enterprise performance. Predictive models also aid farm development decision-making by simulating development under variable conditions. The general structure of one such predictive model (McKeon & Rickert, 1986) begins with a water balance model, predicts monthly grassland growth and then considers a feed year, simulated on a seasonal time step (*DELT*, Eqn (1.2)).

(ii) Explanatory or experimental models. Predictive models can be run and re-run using e.g. historical climatic data and by varying the growth rate of the forage, the stocking rate, forage allocation and animal age classes (e.g. O'Leary, Connor & White, 1985). This allows experimentation on a whole farm basis and manipulation of variables which would be impracticable and too expensive to investigate with field research. From rerunning a model with differing inputs or input/output relationships the researcher can predict how the output of the model might respond to varying factors. Hypotheses may be formulated, e.g. that fodder crop yield is dependent on the sowing date, and then tested by re-running the model.

	Steady state	Dynamic
Deterministic	Algebraic equations	Differential equations
Non-deterministic (stochastic)	Statistical and probability relationships	Discrete event simulation

Fig. 1.8 *Forms of quantitative modelling that are used in the study of grassland systems. (From Wilson, 1984.)*

Concluding remarks on modelling of grassland systems

The modelling of grassland systems has adopted all of the approaches outlined above. Most grassland models have tackled specific aspects of grass or animal production; rarely have there been attempts to model the entire system mechanistically, even for a specific locality. One attempt at comprehensive modelling of grassland systems was the United States Grassland Biome study, which generated the model described by Innis (1978).

All modelling is heuristic: it provides a learning experience which furthers investigation. Thus the researchers involved in modelling learn about the system or area they are attempting to model and where deficiencies in knowledge and understanding exist; these may be further explored by making predictions from the model or formulating hypotheses and testing them by conducting field or laboratory experiments or further modelling. Once constructed the models may also be used to help others learn, e.g. extension officers, farmers, other researchers. Such models need to be 'user-friendly'; one typical form is the 'what if?' model which, if formulated to, say, respond to user manipulation or farmers' questions about fertilizer application strategies, helps the farmer understand the dynamic interaction of fertilizer application rate, price, stocking rate, beef output and profit. The processes by which models are developed and then used has, however, received less attention than is warranted.

Problems relevant to grassland system modelling have been reviewed by Smith (1983), Freer & Christian (1983), Emmans & Whittemore (1983), Bennett & Macpherson (1985), Ison (1993*a*), Seligman (1993) and Stuth *et al.* (1993). Authors conclude that modelling has yet to achieve its potential, largely because of the lack of appreciation by modellers, biological researchers and administrators of many of the concepts and processes of modelling outlined above. We believe that future grassland agronomists will rely heavily on models, but it is worth noting three views with regard to the future: (i) that the usefulness of the output from models is the key issue in modelling but to date little has been done about checking that the outputs are useful and that they are worth the modelling effort (Bennett & Macpherson, 1985); (ii) DSS assist managers in dealing with complex problems, but a fundamental requirement of a successful DSS is understanding the human learning process and involving users in their development (Stuth *et al.*, 1993); and (iii) there is a rich array of non-computer based models and DSS which have a role in the sustainable management of grassland systems (Ison, 1993*a*).

1.5 Purposes of grassland systems

The purpose for any grassland system is determined by those who participate in the construction of the system. Future grassland agronomists will undoubtedly participate in the design of novel grassland systems that reflect changing ways of thinking and cultural values (Chapter 9). This will require innovative and creative thinking (Carter *et al.*, 1984; Buzan & Buzan, 1993) that also values, and is able to work with, social and biological diversity. In this book we focus on seven measures of performance of grassland systems (Fig. 1.9). Each is a measure related to one aspect of system purpose, which is often a unique combination of measures reflecting the preferences and trade-offs made by those involved in constructing and managing the system (Bawden & Ison, 1992).

Some of the outputs from a grassland system are measured in units of meat, milk, wool, hide or money. This is called production. In this book we define productivity (Fig. 1.9a) as the output per unit of time, e.g. kg beef per year or kg beef per ha per year. Productivity is a 'rate variable', i.e. a measure of the dynamic nature of the system, or how it operates. Rate variables contrast to state variables such as the amount of standing feed, which tell us only what a particular grassland system looks like at a particular point in time.

Defining the units of biological output from a grassland as kg of beef, etc. does not, however, indicate, even in biological terms, whether the system is operating successfully or efficiently. Success is usually measured in terms of the short-term (seasonal or annual) output relative to inputs. Here we call this a measure of the efficiency of grassland production (Fig. 1.9b). Of equal importance is the stability of the system, i.e. its ability to return to an 'equilibrium state' after a temporary disturbance (Fig. 1.9c). Our

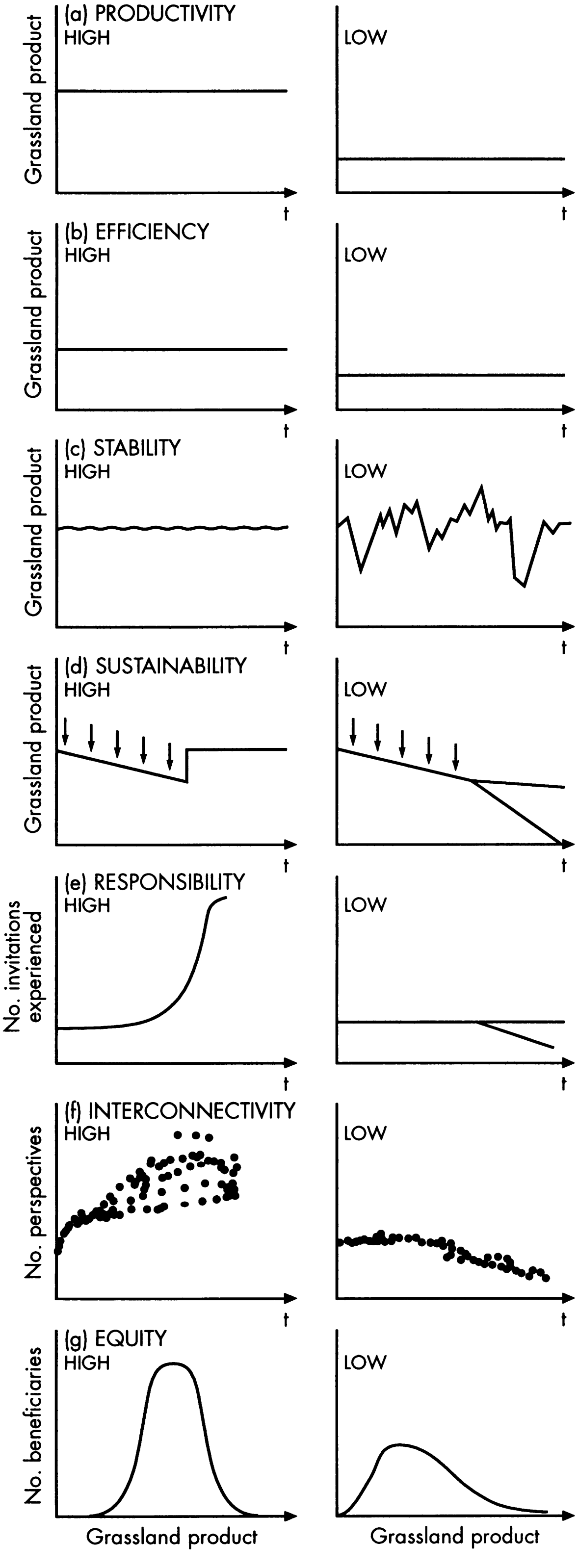


Fig. 1.9 *The properties of grassland or pastoral systems defining generalized situations of high (left-hand column) and low (right-hand column) productivity (a), efficiency (b), stability (c), sustainability (d), responsibility (e), interconnectivity (f) and equity (g). The x-axis in a–f is time, t. (Adapted from Conway, 1993.)*

approach, which does not differentiate between the social and biophysical aspects of grassland systems, enables us to consider three further measures of system performance. The benefits of grassland system outputs may flow disproportionately to those who have, or wish to have an interest in the system. This raises questions of equity and the need to consider how innovation and technological change may affect the distribution of benefits (Fig. 1.9g). As participants in the construction, the bringing forth, of grassland systems we also have an ethical responsibility. Responsibility, the extent to which the system enables individuals to participate and to be responsible is thus our next measure of performance (Fig. 1.9e). It is possible to speak of the extent to which participants can be responsible and we propose as a measure the number of people experiencing an inviation to participate. Equity and responsibiliy are affected by the extent to which there is interconnectedness in the grassland system. Interconnectivity is a measure of the relationship between participants and the relationship they have with animals and land. It encompasses notions of self-identity and stewardship and the satisfaction humans derive from these. As a measure of interconnectivity we propose the extent to which diverse perspectives are involved in the design of future grassland systems (Fig. 1.9f). Finally, some ecologists would differentiate sustainability, i.e. the ability of a system to maintain itself or the degree of difficulty of management required to maintain it (Fig. 1.9d). Others would wish to define sustainability more broadly (Bawden & Ison, 1992); in this book we recognize both the ecological perspective on sustainability as well as the view that sustainability is not an endpoint, but is an emergent property of an ongoing process.

Throughout the book we consider these measures of performance in more detail and in the light of differing historical perspectives on grassland systems and contemporary environmental issues in which grassland systems feature. We examine how particular models of understanding have arisen and how they shape interventions and technological change. Most of this book, however, is devoted to the principles that underly the biological operation of the grassland system, particularly those principles that relate to the dynamics of the biological system. Because farmers have a diversity of forage sources from which they may draw to sustain animal production, grassland agronomists will increasingly be concerned with the integration of forage sources, including crop and agro-industrial residues, into animal production systems. Accordingly, some economic principles and likely future roles of grasslands in farming and environmental systems are discussed. A feature of this book is that we situate this biological understanding in a broader social context commencing in Chapter 2.

Notwithstanding our emphasis on a systems view of grassland agronomy, we are bound by the fact that books start at the beginning and end at the last page, to structure this book in a catenary fashion. The first part of the catena is generation (Fig. 1.5, Chapter 3). This comprises the dynamics of the bank of seed in the soil, seed germination and vegetative generation from stolons and rhizomes, leading to plant emergence. Generation leads to vegetative growth (Chapter 4) and the life cycle of grassland plants ends with seed production (Chapter 5). Nutrition (Chapter 6) links the plant and animal components of the system. The quality and quantity of feed available from living, dead and conserved pools determines animal intake (Chapter 7). The animal in turn affects the productivity and composition of the grassland (Chapter 8). Finally, the agronomist, economist, farmer and other relevant stakeholders integrate the principles of pasture development, growth and utilization into the design and management of the grassland system. Management is associated with farmers' goals, which vary within socio-cultural systems and between them; where management interventions are made to improve the quantity or quality of herbage (e.g. saving, fertilizing), there is a need for managers to estimate the likely annual cycle of production of grasslands and the requirements of the farm livestock. These must be matched, making allowance if necessary for the conservation or purchase of feed, in a way that ensures some return on the initial investment. Such returns are usually economic (Chapter 9), but in some societies they may be social or cultural rewards. Consequently this book, although mainly devoted to biological aspects of grassland agronomy, does conclude with a systems perspective of some of the environmental, economic and social issues that are pertinent to grassland agronomy (Chapter 9).

In describing the biological aspects of the system our bias is towards assessing productivity, efficiency, stability and sustainability, but particularly productivity and efficiency. This unequal emphasis usually leads technologists to the conclusion that grassland agronomy should become more productive: that there are large areas of native grasslands, scrub or forest that could be 'improved' and that productivity could, and should, be increased in grassland systems that are currently based on sown pastures. For example, it has been calculated that there are 300 million ha of 'improvable' grasslands in both humid temperate regions and the wet-and-dry tropics of South America and we might estimate that there are a further 100 million ha in Africa. Thus the total area of practically improvable grassland, if we include Asia and Australia, probably exceeds 700 million ha (Norman, Pearson & Searle, 1995). Much of this 700 million ha is in a belt of high potential net primary productivity (NPP; Chapter 4). The biological advantages of intensification of productivity are well documented (Henzell, 1983). However, in Chapter 9 we explore whether intensification is necessary technically or appropriate socially.

1.6 Further reading

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