Philip Tow · Ian Cooper
Ian Partridge · Colin Birch *Editors*

Rainfed Farming Systems

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FERTILISER
SEED
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Foreword

Few books have attempted global surveys of farming systems. Hans Ruthenberg's *Farming Systems in the Tropics* (3rd Edition, 1983) is a classic that has long been out of print but is still widely cited. John Dixon and colleagues' *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World* (2001) a more recent effort, takes a broader view of farming systems, but is also out of print. This book *Rainfed Farming Systems* is the most ambitious effort to date and fills major gaps in our knowledge; it covers both commercial farming in the developed world and small-scale, often subsistence-oriented, farmers in developing countries.

Rainfed Farming Systems is also most timely given that rainfed agriculture will be under pressure to help supply the 70% increase in food production required by 2050 as water available for irrigated agriculture is increasingly limited.

My own involvement in rainfed farming systems dates from growing up on a cereal–sheep farm in the upper north of South Australia where my family continues to farm. There I learned that the two greatest challenges facing rainfed farmers are making the best of available moisture and dealing with high levels of climatic risk.

In the 1970s and 1980s, I worked with the International Maize and Wheat Improvement Center (CIMMYT) where, in the wake of the Green Revolution in irrigated areas, we turned to the challenges of rainfed farming. We employed a farming systems approach that necessarily involved looking at the system rather than at single commodities, bringing together the perspectives of natural scientists and social scientists. Most importantly, we worked hand-in-hand with farmers and their advisory services to gain a better understanding of the circumstances under which new technologies would be used. We also learned the importance of putting farmers at centre stage when defining and testing new technologies in their fields.

All of these elements are well covered in *Rainfed Farming Systems*, which goes well beyond our rather rudimentary approaches of only two decades ago. The farming systems perspective has continued to evolve and this is seen in the following chapters where sustainability, resilience and equity are all now central dimensions of successful farming systems. The multi-disciplinary perspective represented here is impressive, with strong disciplinary chapters covering soils, weeds, pests and diseases, tillage, genetic–management–environmental interactions and crop–livestock interactions as well as economic, social and cultural aspects.

The book highlights the critical importance of strong partnerships between scientists and farmers with each learning from the other. An especially valuable contribution is in the number of chapters authored or co-authored by farmers themselves in a series of farm case studies in Part V.

In spite of the natural, social and economic challenges of rainfed farming across the world, the unfolding story here is that much progress is being made. Rainfed farming systems have continued to evolve and adapt in a rapidly changing world. The chapters show that change has been evolutionary, generally involving complex interactions within farming systems. In some cases, productivity gains in rainfed systems have been higher than in irrigated areas; however, crop yields continue to be too low, and nowhere more so than in Sub-Saharan Africa where our understanding of local farming systems is still far from perfect. Even in seemingly successful systems, new problems continue to arise, requiring the search for solutions which, as always, have to be evaluated within a systems perspective.

The huge effort by the editors and authors of *Rainfed Farming Systems* to provide a comprehensive systems framework and bring together a rich and diverse set of experiences will be a valuable resource for future generations of scientists, students, advisers, policy makers, and farmers.

Member, Science Council,
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and Strategy Adviser, World Bank

Derek Byerlee

Preface

Rainfed Farming Systems provides a comprehensive collection of principles and applications, covering most aspects of rainfed farming system structure, operation, management and improvement. These aspects are expressed as relationships among the many components of farming systems and between components and the external factors that influence them. They are also expressed in terms of such characteristics as productivity, profitability, efficiency, flexibility, resilience and sustainability. Rainfed farming systems are defined in this book as those that normally experience suboptimal rainfall and significant water deficits in at least part of the growing season, thus limiting agricultural production. For this reason and to keep a workable scope to the book it does not deal with tropical agricultural systems, except for a brief discussion of systems in the semi-arid tropics. Temperate rainfed (but largely rainfall adequate) farming systems such as in Europe and New Zealand are also omitted.

This book provides an understanding of rainfed farming systems that will lead the reader to work more effectively with them in research, development, consulting and extension, policy making and field practice. This will be done in the context of many challenges for agriculture: climatic variability and long term climatic change; degradation of most agricultural soils; spread of diseases, pests and weeds; rapid innovation in technology in some countries but inadequate technology and infrastructure in others; and the interaction of market and political forces at both local and global levels. *Rainfed Farming Systems* will cover the principles required to deal with these challenges, but it will also be particularly concerned with the broader issues faced by farmers, of fitting all the components together into a workable system that is productive and profitable, in the context of local climate and soil, of economic opportunities and constraints, of family and community expectations and of government policies. It is also generally recognised that this must be achieved while maintaining or even improving the resource base of soil, water, desirable genetic features of farm plants and animals. Frequently other assets such as wildlife and natural vegetation must be conserved as well. Systems that combine these attributes are often described as 'sustainable'.

For these purposes, the book is presented in five inter-related, system-oriented parts.

Part I deals with individual, but systems-related disciplines of agriculture, it deals with the universally important topics of climate; soil (physical and chemical aspects, soil biology and soil carbon); water supply and use; pest management, economic and social aspects, crop-livestock relationships, and system design.

Part II aims to provide an integrated understanding of some important rainfed farming systems around the world, from parts of China, south Asia and west Asia, northern and southern Africa, Canada, the USA, South America and Australia. Chapters seek to provide a broad understanding of the systems they depict, and may include case examples to illustrate their themes, principles and applications.

Part III delves into some aspects of the structure, operation and management of rainfed farming systems to show how these systems can be improved.

Part IV deals with the combination of research, development and education or extension, and shows how the 'systems approach' of past decades is moving towards a 'participatory systems approach' involving all concerned, from farmers, to researchers, advisers and policy makers. One chapter describes subsistence agriculture in Tanzania where science may be less important than community culture and tradition, and improvement in such farming systems is slow. In contrast, progress in soil management under conservation farming, is impressive in several countries.

Part V contains farm case studies which show how farmers have responded effectively to a range of challenges and external changes over time, and kept their systems productive, profitable and environmentally sustainable.

Chapter 50 allows the editors to sum up their conclusions from the wide range of important information and understanding provided by the authors.

In developing this book, the editors worked with authors from a wide range of developed and developing countries and from national and international organizations. They aimed to achieve the broadest possible coverage of rainfed farming systems, and above all to be informative and stimulating. The editors wish to acknowledge the valuable contributions made by authors towards achieving the goals of the book, with accuracy, comprehensiveness and depth. These contributions give us confidence that the book will be interesting, relevant and useful to agricultural professionals, practitioners and students of rainfed farming systems throughout the world, and to the community as a general reference book.

Philip Tow, Ian Cooper, Ian Partridge, and Colin Birch
Editors

Acknowledgments

The Editors wish to acknowledge the work of the authors in providing a valuable understanding of the science, technology and practice of Rainfed Farming Systems around the world. The critical comment of others on drafts of chapters of this book is also appreciated. We are most grateful for the support of our employers, and of our families and friends. We also acknowledge the pictorial contrast, provided by artist Sid Woon, of agriculture dependent largely on labour and that dependent much more on science and technology.

Contents

Part I
Principles and Their Application

The 14 chapters of Part I deal analytically with individual disciplines of agriculture. Systems-orientation is provided through use of appropriate examples and applications. Part I seeks to make clear the major principles and concepts for the operation and management of farming systems. It therefore provides a basis for the other, more holistic Parts (II–V) of the book.

Part I assumes a basic knowledge of agricultural disciplines. Specialised terms are defined in a Glossary, to which the reader is referred in all chapters of the book.

Chapter 1 provides definitions, principles and concepts related to farming systems structure and operation and to the important, central topics of efficiency of use of water, nutrients and energy, including ecological concepts of energy (emergy) evaluation.

Chapter 2 provides a classification of rainfed farming systems based broadly on Climate as a key determinant and then on the levels of Productivity and Farming Intensity, as determined by a range of other factors, which apply to all farming systems.

Other chapters in Part I deal with the universally important agricultural topics of climate, soil (physical and chemical aspects, soil biology and soil carbon), water, weeds, diseases, insect pests, impact of technology, economic and social aspects, crop-livestock relationships, and farming system design.

Chapter 1
Principles of a Systems Approach to Agriculture

Some Definitions and Concepts

Philip Tow, Ian Cooper, Ian Partridge, Colin Birch, and Larry Harrington

Abstract A systems approach is needed to understand and manage a 'farm'. This chapter examines the definition and concepts of farm systems, their structure, operation and management, the relationships among internal and external factors, response to changing circumstances, and modifications to deal with change. Study of a system requires definition of goals and objectives, boundaries and the structure and function of its components. Feedback mechanisms and interactions are important features of farm system structure and operation. Farm systems can often be better understood through analysis and the study of their sub-systems; and circle or problem-cause diagrams can assist this. Farmers design their systems to make best use of the prevailing climate and soil but a wide range of technological, commercial, social, political and personal factors determine farmers' goals and management. Important characteristics of systems include: productivity, profitability, efficiency, stability, sustainability, equity, flexibility, adaptability and resilience. Efficiency of resource use should be optimised, bearing in mind Liebscher's Law of the Optimum. Efficient use of energy and water are necessary for profitable production.

Keywords System • Systems approach • Farming system • Farm system • Subsystem • Open system • Goals • Boundary • Feedback • Interaction • Productivity • Profitability • Efficiency • Stability • Sustainability • Equity • Flexibility • Adaptability • Resilience

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1.1 Introduction and Definitions

Farmers in both developed and developing economies continually seek and apply solutions to particular problems and challenges confronting them. These problems include climatic variability and climate change; soil degradation; pests, diseases and weeds; increasing costs and market instability or access. In rainfed farming, rainfall uncertainty and the risk of soil moisture deficits are continual challenges.

Such matters can rarely be considered in isolation since farmers have to coordinate farm activities and enterprises into a workable whole or 'system' to achieve their **goals**. These goals must also be considered together since some may have higher priority, others may be of equal priority, interdependent or conflicting. Thus a farmer's goals may include a combination of such factors as: increasing food production, maximising profit and achieving stability of income under a variable climate while also improving the soil, conserving fauna and flora and achieving a chosen family/community lifestyle.

Natural systems which are free of significant human impact exhibit many internal relationships. Together these produce a coordinated whole where different plant and animal species compete or complement and eventually balance each other. Unlike farm systems, they are not subject to human management nor produce significant outputs. However, both are reliant on flows of energy as discussed further in the supplement to this chapter.

Managing the whole requires an understanding of how the various parts of the farm 'system' can operate together in the context of local climate, soil, available technology, economic opportunities and constraints, family and community expectations and government policies. This 'workable whole' may be termed a 'sustainable system' if it operates at the required level of productivity and profitability and continues to do so over extended time, while allowing for some modification of the 'system' to meet changing circumstances and without degradation of the resource base. Achieving this requires a **Systems Approach**.

Such matters form the theme of this book. It deals with the definition of farm systems, their structure, operation and management, the relationships among internal and external factors, response to changing circumstances, and modifications to deal with change. In this chapter, we shall introduce the systems approach and define many of the concepts used in the book.

Initially we will define a farm system simply as a number of parts that are related by their influence on each other. Figure 1.1 shows a simple example of a farm system with four sub-systems, each comprising a number of components. Any operational unit in agriculture may be defined as a system if it shows an overall response to an influence applied to any part of it. What is done in one part of the system will eventually have consequences that influence the system as a whole. Examples include:

- Restricting the types of crops which can be grown in one field in order to control weeds or diseases will influence the crops and management decisions on other fields and also the overall productivity and profit.

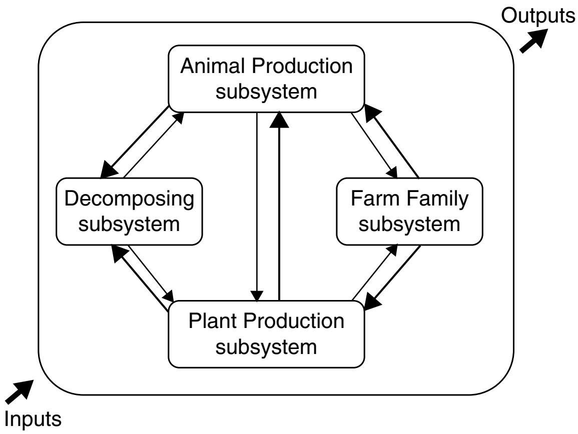

Fig. 1.1 A generalised farm system

- Preferential allocation of resources to a particular enterprise, unit or location on the farm will have consequences in resource allocation and management for all enterprises and locations in the short and longer term.
- Re-sowing pasture on one field will initially place increased grazing pressure on the other pasture fields but decrease it once the improvement is complete.
- In southern Africa, there is in many maize-based systems, competition for early season labour. Early-sown fields need weeding about the time that farmers also wish to sow additional fields. If the labour is used for weeding, less area is sown. If the labour is used for planting, yields in early-sown fields are reduced due to weed competition.

A farm may be regarded as a system if it satisfies the criteria just discussed. It may also be regarded as an **agroecosystem** because it is a collection of organisms (plant, animal and microbial) that inter-relate with each other and with their physical environment and have been modified by humans to produce agricultural products. (see also Chap. 21 – Case Study). When we are dealing with the design of an agricultural system which has been clearly defined and probably analysed and compared with others, we shall talk about a **'farming system'**. When referring specifically to an individual farm, we can also use the term **'farm system'**.

All parts of a farm may not necessarily be considered part of the same system. Thus a piggery or a seed-cleaning plant may be part of a predominantly crop-production farm, but not part of an overall farm system unless there are material flows and feedbacks between these enterprises and the crop production area. For example, livestock housed in a farm feedlot or piggery and fed from farm produce would be considered as being part of a farm system if their manure is returned to the soil that produced the feed or if the finance and labour allocated to the livestock influenced allocation to the cropping areas. In mixed cereal–sheep farming, as in southern Australia, wool production can be considered part of the same farm system as crop production because the sheep and crop inter-relate through their use of the same land. Sheep graze the legume-based pasture and the crop benefits from the legume nitrogen remaining in the soil after the pasture phase. Sheep also benefit from grazing the cereal residues.

To study systems, we must be able to define the **goals** or **objectives** of the system managers. These may be both short-term and long-term, and have financial, technological and personal features. Financial goals may have a high priority, but goals such as maintaining the resource base of soil, water, livestock genetics and natural vegetation will also be important. In developing countries, farm family goals and objectives are often sequential—the first priority is to achieve food grain self-reliance, the second is to seek sources of cash income. The influence of the farm family's goals on the system is further explored in Chap. 12

In order to operate a farm system well, we must also be able to describe its structure, analyse its operation or function and evaluate its performance. The first step is to define its **boundary** which is determined by the purpose of the system; its position is critical for appropriate analysis (Kelly and Bywater 2005). Olsson and Sjöstedt (2004) argue that defining what should be included in the system and what should be left out is the crucial issue in applying a systems approach.

Spedding (1988) also stressed the importance of defining the boundaries of farm systems, as well as the feedback mechanisms which operate within the boundary (See the definition of system near the end of Sect. 1.1). He defines **feedback** as the carrying back of the effects of a process to their source so as to modify those effects (Fig. 1.2). To understand this, consider a flock of sheep grazing an area of pasture (*the source*) within the *boundary* of a fence. A feedback mechanism operates here through the *effect* of the sheep on the pasture by the grazing *process* (eating, trampling, and recycling nutrients). This effect is on the growth, botanical composition and quality of the pasture, which then affect the grazing process, the intake of nutrients and the productivity of the sheep and again the pasture. A feedback may have a positive or negative effect.

In a rainfed situation, and considering available soil moisture as the *source,* for crop growth, provision of ample nitrogen early in the growing season may cause rapid crop growth (*process*) and utilisation of moisture *(effect).* If soil moisture is not replenished by further rain, the feed back effect (to the source) will be depletion of available moisture, with moisture stress and retardation of crop growth at an earlier stage than if nitrogen and available moisture were better balanced.

Feedback effects may occur over a longer time: for example, animals with a high reproductive rate (*source*) will experience high demands for lactation, with resultant high grazing pressure (*process*) and reduced pasture availability (*effect*). This could produce a feedback of lower pasture availability for the animals, resulting in a loss of body condition and hence a lower reproductive rate in the following year (Anderson and White 1991).

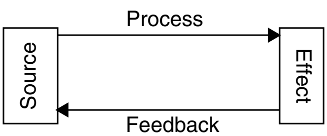

Fig. 1.2 The feedback cycle

Another feedback of long-term significance is related to either soil carbon accumulation (as when there is no tillage and crop and pasture residues are left to accumulate) or carbon depletion (as when soil is cultivated annually and plant residues are removed). Carbon accumulation improves soil structure, water-holding capacity, soil fauna and flora populations, and possibly plant nutrient availability (See Chaps. 6 and 14). These are important components of what may be termed 'soil health' (the *source*), which benefits plant production. The lowering of soil carbon (*effect*) by the *processes* of cultivation and residue removal may degrade these attributes of soil health and ultimately reduce plant production.

Having defined the boundaries of a system, we can then specify its **components, structure and function. Components** of a farm system may be located on, above or below the ground and may be plants, animals, micro-organisms, soil components (biological, nutrients, moisture, air), water supply, machines, fences and sheds and other 'capital' items. Components may be classed as **resources** if they contribute directly to system productivity. There may be multitudes of components in an ecosystem so, in practice, we should aim to manage those that are likely to have a significant effect on system performance. Farm system **structure** is how the system is organised and is closely related to the **function** of the system. It includes the components and their patterns of organisation as enterprises and rotations. The **operation** of the system includes production and management and the flow of materials, energy, information, labour, machinery, and capital into, out of and within the system, and the annual *calendar of activities*. Farmers usually set **priorities** for their operations, both short-term (even daily) and long-term.

We have to distinguish between component parts of the system and **external factors** or **influences** that act on the system from outside. External factors include climatic features such as solar radiation, rainfall and temperature. These are not originally within the farm system boundary as there is no feedback to them from the farm. Some external factors such as new pests enter the farm system uninvited. Others are introduced purposefully to the system, often at some cost, because they are considered useful for the operation of the system; these include seeds, fertilisers, pesticides, fuel and other materials and are usually termed **inputs**. The combination of system components and external influences can be referred to as **elements** of the system. The elements may be used to characterise or **define a farm system**, to pin-point essential features of management and to enable comparison with other systems (See Chap. 2).

External influences also include such factors as market conditions, legal frameworks, government policies, institutional structures and other social influences, education, availability of various types of technology (such as information, training or equipment), availability of finance, and the appearance of new pests, diseases and weeds. These are part of wider systems that the farmer must deal with. In some societies, organisations which are part of such wider systems include in their operations a *quadruple bottom line* of financial gain, environmental improvement, society welfare or viability, and protection of cultural heritage. More recently, a fifth bottom line has been proposed, food security—a necessity for subsistence farmers or encouraged by governments. These concepts will be developed in Chap. 12.

However, this does not remove the need to understand the physical and biological farm system to ensure its productivity and sustainability.

The **farmer/farm family** may be regarded as an external influence that has an input of labour, finance and management or as an integral part of the system in which feedback mechanisms operate between the farmer/farm family and the biological/physical components in the field. Either of these choices is acceptable, depending on the purpose of the system study or analysis. For some purposes, it is useful to regard the farmer as part of a wider system, interacting both with the farm system and various other family, economic, cultural, social, political, environmental and technological issues. Particular goals of the farmer and farm family will also affect the way the system is operated, and these may include features such as family wellbeing and environmental values. Advice from farm consultants and researchers could also be considered an input. Members of farm families may support the farm by off-farm work or contracting, thus providing an 'input' of capital.

There may be an interactive relationship between researchers, advisers/consultants and farmers. Farmers, researchers and advisers may form a group to initiate, plan and execute research and participate in its application in the management of the farm (See Chaps. 36 and 37). As there is two-directional or multi-directional feedback of information, time and resources for experimentation resulting from these relationships, the organisation could be regarded in part as a component of the farm systems.

The outcomes of supplying inputs and of operating the farm system are the **products**. In subsistence agriculture, the farm family largely consumes these. Commercial agriculture has sometimes tended towards the subsistence type in periods of great economic difficulty (due to drought or economic depression). However, on the whole, the aim is to sell products outside the system. Such products can be termed **outputs** of the system. They represent a loss to the system of mineral elements that may have to be replaced by inputs from external sources. This is in contrast to natural ecosystems where nutrients are usually **recycled** within the system. An agricultural system is often described as an **open system**. In some systems, crop and pasture residues and animals manures have been regarded either as wastes or products that are removed for use elsewhere (see Chaps. 2, 15, 16, 22 and 38). In other systems residues and manures are retained to recycle some of the carbon and nutrients they contain, as well as to improve other aspects of soil health (see Chaps. 26, 33, 34 39 and 40).

Interactions are important in farm systems. **Interaction** occurs when the effect of one factor varies with the level or strength of another factor. A commonly encountered interaction is that between two types of plant nutrients (usually applied as mineral fertilisers), e.g. a phosphorus (P) x nitrogen (N) interaction. Figure 1.3 shows the interaction by means of two response lines with different rates of P application.

A further example would be the way the relative yielding ability of crop varieties (genotypes) varies with some seasonal variable such as rainfall; one variety may be more favoured than others in a high-rainfall year, but perform relatively poorly in a low-rainfall year. This is further complicated by the interaction with time of planting. For example, the choice of the most appropriate variety may depend on the ability

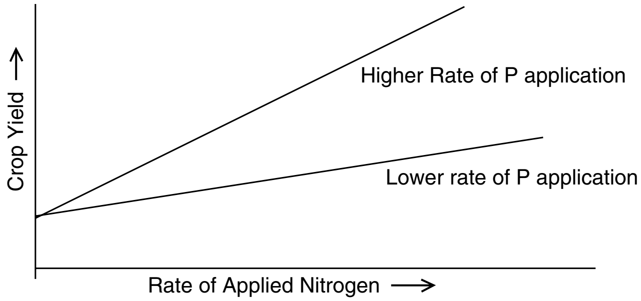

Fig. 1.3 Response of crop to nitrogen at two levels of phosphorus application

of the farmer to plant a crop at a particular time. The best results from early planting will come from varieties which grow and develop over a longer rainfall season whereas, with late plantings, an early-flowering variety may be better. This is an interaction of maturity type and time of planting. Selection of variety is also influenced by the expected amount of rainfall in the growing season so that a variety x rainfall x planting date interaction is important. Even more complicated interactions may occur when choice of variety or crop species is influenced by other factors such as soil type and frost incidence at different locations on the farm, or the susceptibility of varieties to diseases and pests.

Interactions become particularly important when they relate to the operation and management of farm systems. Both farmers and researchers need to be aware that the outcome of applying an input or management factor may vary not only with the level of that factor but also with the level of a second factor, or more. All relevant factors must be at appropriate levels to gain desired results. An example of this is where the response to one nutrient increases when other nutrient deficiencies are corrected (as in Fig. 1.3), provided rainfall is adequate for a full response.

Keeping in mind the definitions of previous pages, the following modification of a definition of a system by Spedding (1988) is a useful guide adopted in this book:

> A system is a group of interacting components, capable of reacting as a whole to external stimuli applied to one or more components and having a specified boundary based on the inclusion of all significant feedbacks.

Underlying this definition is the understanding that what happens to one part or component of the system will have ramifications (large or small) for other parts, even if the effects are delayed. Thus defining the boundaries and significant components of the system is important in its operation and management.

Because of the various feedbacks and interactions in a farm system, it is not always possible to study the system as a whole. It is sometimes necessary to reduce it to its components or at least its **sub-systems** and study them separately. We could study the effects of different tillage methods on crop establishment and production in a small plot of ground. Aspects of animal nutrition could be studied with animals in a pen. Weed control methods may be compared in small plots, and so on.

In this way, we should learn something about each aspect of production, but very little about how various factors operate when they are all ‘thrown in’ together, inter-relate and participate in feedback loops. To study a farm system, it is necessary at some stage to see it all in operation as a whole, to see how the various factors act on each other. Some factors may be more important than others, and their relative importance can only be seen when they are acting together. In this book, we shall study farming systems as a whole as far as possible, while also analysing them and studying important aspects separately where that helps in the understanding of principles.

1.2 Understanding Farm Systems Through Analysis and the Study of Sub-Systems

Analysing a system helps towards our understanding of how the parts relate to the whole, and to its major or **central output(s)**. This is useful if it helps in specifying significant inputs and outputs and the relationships between factors which determine the outputs. Defining a **sub-system** helps in studying the effect of part of the system on the central output. This is often necessary because of the complexity of the whole system. One simple but useful tool for achieving both aims is the ‘circular diagram’ of Spedding (1988).

The method starts analytically with placing in the centre of the diagram an **output of central interest**, e.g. crop production, livestock production or income. The major factors thought to influence this output are then grouped in a ring about this centre, with appropriate arrows pointing inwards. However, there may also be effects of these factors on each other, in the same ring, and arrows travelling around the circle indicate these. All factors on this ring are in turn controlled or influenced by ‘secondary factors’ which can be arranged in a second, outer ring, with arrows used as before. A decision needs to be made, based on available knowledge, as to what are **major determinants** of the central output. These are included while others may be left out. A third ring or even more may be added, providing a further expansion of the **analysis** and, it may be expected, a better grasp of the whole system for its management. Information in any one ring provides an analytical understanding of the factors connected to it in the next inner ring. Construction of the diagram and its use over time may reveal deficiencies in knowledge of relationships that will need to be investigated.

The use of circular diagrams is illustrated in Figs. 1.4 and 1.5. The first provides an analysis of production from an annual pasture legume used in a crop–pasture rotation in the Mediterranean-type environment of South Australia. The second is for a simplified cereal–pasture–livestock system in a similar climatic environment in the Kingdom of Jordan. The latter system has three major outputs, with major influencing factors and components in outer rings. Influences also operate across the three major groups, as shown by connecting arrows. For maximum value to management, the inputs, outputs and relationships should be quantified in various ways. However, even with minimal quantification, construction of the diagram allows us to express our understanding of system structure and important relationships.

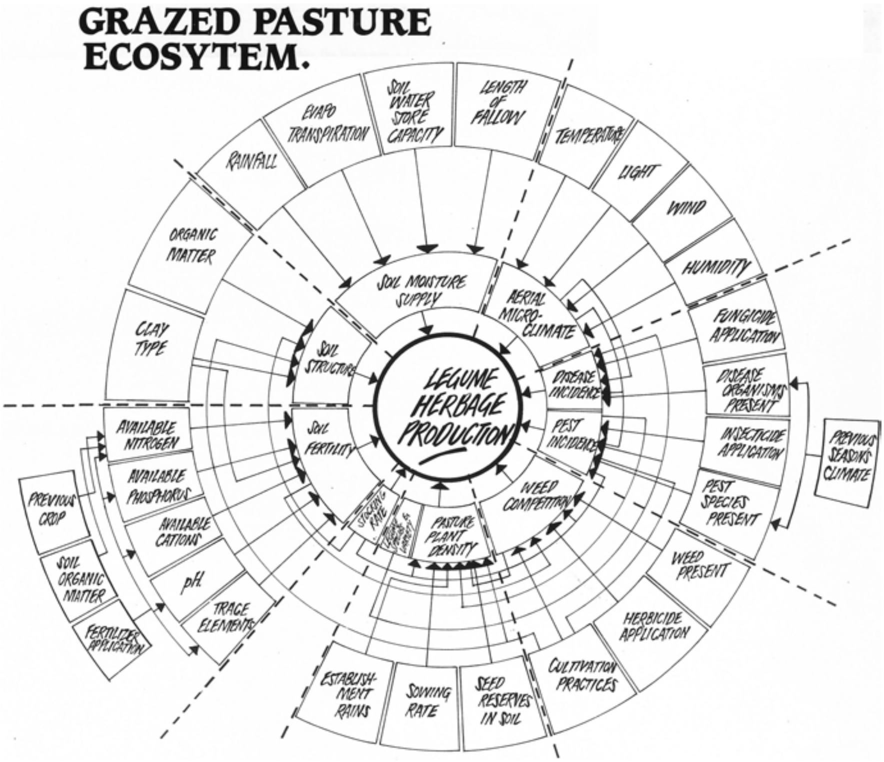

Fig. 1.4 Factors affecting the production of annual legume herbage (Tow unpublished)

The diagram also provides a means of defining sub-systems for special study, and of breaking down the complexity of the whole system. A **sub-system** can be specifically described as being concerned with the effects on the central output of changes in one component of the system. The sub-system then consists of the centre, a component in one of the rings and all of the factors that are linked between the two. Spedding suggests thinking of parts of a sub-system as if wires link them so that the sub-system can be lifted out of the whole for study on its own. In this way, only those factors in the system that influence the way in which the selected component affects the centre will be included.

In the Legume Herbage Production diagram (Fig. 1.4), it is seen that the 'stocking rate' affects herbage production directly and also through its effects on soil fertility, pasture plant density, weed competition and pest incidence. The 'cultivation practices' factor affects herbage production directly and also through its effects on weed population, pasture plant density, soil structure and pest incidence (when cultivation maintains the soil surface in a form unattractive to certain insects). In contrast, the 'soil moisture' sub-system is depicted as being simple, with no connections to Legume Herbage Production via other factors. This indicates that the study of this sub-system

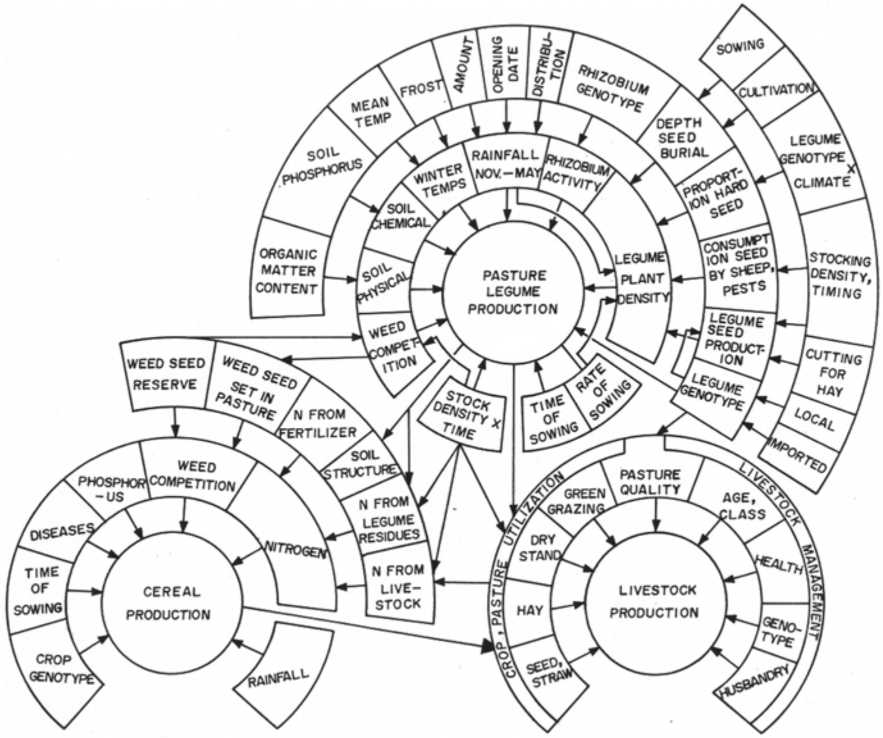

Fig. 1.5 A simplified whole cereal–pasture–livestock system (Tow and McArthur 1988)

would involve measurement of only soil moisture and herbage production. It could also indicate that the diagram needs to be re-considered, for example, if there is an interaction between water supply and weed competition.

The circular diagram will be useful if it involves the system manager or scientist in searching for information, examining it critically and systematically, and then using it to help modify the farm system to better achieve goals.

Another tool for analysing systems is the **Problem-Cause or Cause-Effect** diagram (Fig. 1.6 Tripp 1991). It helps to determine and display the likely causes of problems and to identify intervention points for solving these through technology or policy change. A similar tool has been described by Pearson and Ison (1997) showing how various problems are linked.

1.3 Systems Approaches

Farm situations may lead to a variety of 'systems' approaches. Where there is a declared objective that is agreed as desirable, a **hard-systems** methodology (HSM) is often called for. The analyst works back from the objective and endeavours to