A FRAMEWORK FOR AGROFORESTRY DESIGN

by

R.J. CARNE

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Statement of Originality

This thesis is my own work. All sources used have been acknowledged.

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ABSTRACT

The successful establishment and functioning of agroforestry systems will depend to a large extent on design procedures which reflect a clear understanding of the basic concepts of design and an appreciation of the complexities of agroforestry land use. Both aspects are addressed in this thesis in order to provide a framework for agroforestry design. The latter is established with reference to (a) concepts derived from landscape design (b) an analysis of agroforestry land use, and (c) a review of existing design approaches applicable to agroforestry, and includes first, an explanation of design in the context of agroforestry, and second, an outline of a three-phase design procedure applicable at the farm-scale. This procedure recognizes the need for a thorough consideration of socioeconomic conditions, and the importance of providing a synthesis of biophysical and socioeconomic factors in order to resolve the design context.

The proposed procedure, and the explanation of associated concepts, represents an initial statement on agroforestry design. This clarifies a previously ill-defined, but potentially important design field, and establishes a framework for further developments.

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CHAPTER ONE

Introduction

1.1 The Nature of Landscape Design: Some Preliminary Comments.

The landscape is fundamentally a 'composite of natural and man-made features that characterize the surface of the land .....' (Marsh and Dozier, 1981:612), and, in the general sense, design 'implies purpose: the adaptation of means to an intended objective. It implies change from that which has been to that which will be under new circumstances' (Colvin, 1974:8) Thus, design in the context of landscape can be considered to be concerned with man-induced landscape changes, intentionally directed towards fulfilling some particular objective or set of objectives. More specifically, landscape design involves the formulation and presentation of proposals for the alteration and modification of natural and/or man-made landscape features.

From the viewpoint of landscape ecology, a landscape also comprises a cluster of interacting ecosystems (see Forman and Godron, 1981; 1986; Forman 1982). Therefore, landscape design must, to some extent, also be involved with the alteration of ecosystems.[1] However, as Lyle (1978:6) points out, 'as ecosystems, most of our man-shaped landscapes are failures; at best they are crude facsimiles of the rudimentary systems that nature uses in the early phases of succession ...... More often than not, they are unstable, dependent on large imports of materials and energy, destructive to other species, and damaging to other systems both nearby

1. The term 'ecosystem' refers to units of biological organization including all the organisms in a given area, their encompassing abiotic environment, and the associated material cycles and flows of energy (Odum, 1976).

and far away'. Recognition of this fact has led to attempts to provide an ecological basis for landscape design (eg. Lyle, 1978; 1985a; Bradshaw and Handley, 1982; Ruff and Tregay, 1982; Goldstein, Gross and Marston, 1985). Such developments are still in the formative stages, nonetheless, they represent an awareness that landscape design facilitates not just changes in easily observable landscape features, but also, in the more subtle properties of ecosystems. Thus, from an 'ecological viewpoint', the process of landscape design takes on an added significance. Clearly, design procedures need to be set out in detail and examined critically before being applied in the landscape.

Landscape design procedures have been specified in a variety of forms (see Lyle, 1985a; 1985b), and while Vanicek (1974) suggests that survey and analysis should precede the design process, it is more usual to include these preliminaries, along with 'synthesis' and post-design 'evaluation', as part of the design process itself. Thus, in its simplest form, the landscape design process is often expressed as RESEARCH - ANALYSIS - SYNTHESIS - DESIGN - EVALUATION. However, as Lyle (1985a: 127) notes, this sequence of steps 'tells little more than that we need to know something about the subject matter before attempting to reshape it.' Therefore, there is a need to elaborate on this basic 'design sequence' in order to more fully understand the nature of landscape design. A clear statement on the latter is particularly important in the context of this thesis, since it is considered to provide a basis on which a framework for 'agroforestry design' can be developed.

1.2 Statement of Aims of Objectives

The aim of this thesis is to provide a systematic procedure for the design of agroforestry systems. This procedure is an attempt to establish a framework from which more detailed design procedures applicable to specific agroforestry systems and landscapes can be developed. Pursuant to this aim are two major objectives. These are, first, the specification of the landscape design process as a rational sequence of steps in order to provide a basis upon which an agroforestry design procedure can be developed, and second, the incorporation of a systematic approach to land evaluation as a means of accomplishing the research, analysis and synthesis stages of design.

1.3 Outline of Thesis

In the following chapter the landscape design process is examined in detail, a systematic design procedure outlined, some introductory remarks made in regard to the nature of agroforestry design, and relevant 'design-scales' identified. Then, in Chapter 3, the concept and practice of agroforestry is analysed in order to draw out those characteristics which would require consideration in a design procedure. Following this, Chapter 4 reviews some existing design approaches applicable to agroforestry, and provides an appraisal of each in the light of the preceding chapters.

Finally, a framework for agroforestry design is outlined. This builds on the general design procedure established in Chapter 2 by first taking into account the major characteristics of agroforestry as elucidated in Chapter 3 and the main strengths of the 'agroforestry design procedures' reviewed in Chapter 4, and second, by incorporating a 'land evaluation' procedure which offers a comprehensive and systematic approach to the early stages of design.

CHAPTER 2

Conceptual Background

2.1 Introduction

This chapter is concerned to provide a conceptual background to agroforestry design, as yet, an ill-defined and little developed field of study despite its undeniable importance to the successful establishment and functioning of agroforestry systems.

The precedence for a systematic approach to agroforestry design can be found in the established field of landscape design. Thus, it is useful to examine the latter in some detail, first, by considering design in the context of landscape planning, and second, by identifying landscape scales at which design operates (Sec. 2.2 and 2.3 respectively). The nature of the design process is then examined and specified as a sequence of steps (Sec. 2.4). Finally, some preliminary remarks are made regarding the fundamentals of agroforestry design (Sec. 2.5).

2.2 Landscape Design in the Context of Landscape Planning

Khosla, Prakash and Revi (1986: 402) consider that landscape planning is a design activity 'concerned with the design of spaces, from small individual gardens, through neighbourhoods, sites and metropolitan areas, to large-scale change at the continental and planetary level'. However, it is more common to view planning as more than simply a 'design activity' (eg. Hackett, 1971), since its scope of concern tends to encompass that of design. Nonetheless, planning and design may be seen as closely related activities. Both lead to changes in the landscape and have a common aim, that is, 'to improve the original situation and to find the optimum relationships between man and his environment ...' (Van der Poel, 1976: 369). Thus, in a general sense, the terms 'planning' and 'design' can be used interchangeably to describe the process of formulating proposals for landscape changes. However, in the context of this thesis it is necessary to be more specific about what constitutes design. The first step is to differentiate the respective roles of planning and design in the 'formulation of landscape changes'. While it is difficult to make a clearcut division between the two it is possible to draw some distinctions.

The term 'design' is often used to refer to the specification of small-scale construction details, whereas 'planning' is applied to the process of formulating landscape changes at larger scales (Lyle, 1985a). For example, Kassler (1964) suggests that the evaluation of large portions of land to assess suitability for uses is planning, while the selection of elements (materials and plants) and their combination 'as solutions to limited and well-defined problems' (Kassler, 1964: 10) is design. However, the scale at which design becomes planning is ill-defined. Moreover, authors such as MacHarg (1969) and Steinitz (1978) use the term 'design' in the large-scale regional context, while Lynch (1971) uses 'planning' to describe activities at the small-scale site level. Clearly, attempting to differentiate planning and design on the basis of the scale of activities is far from satisfactory.

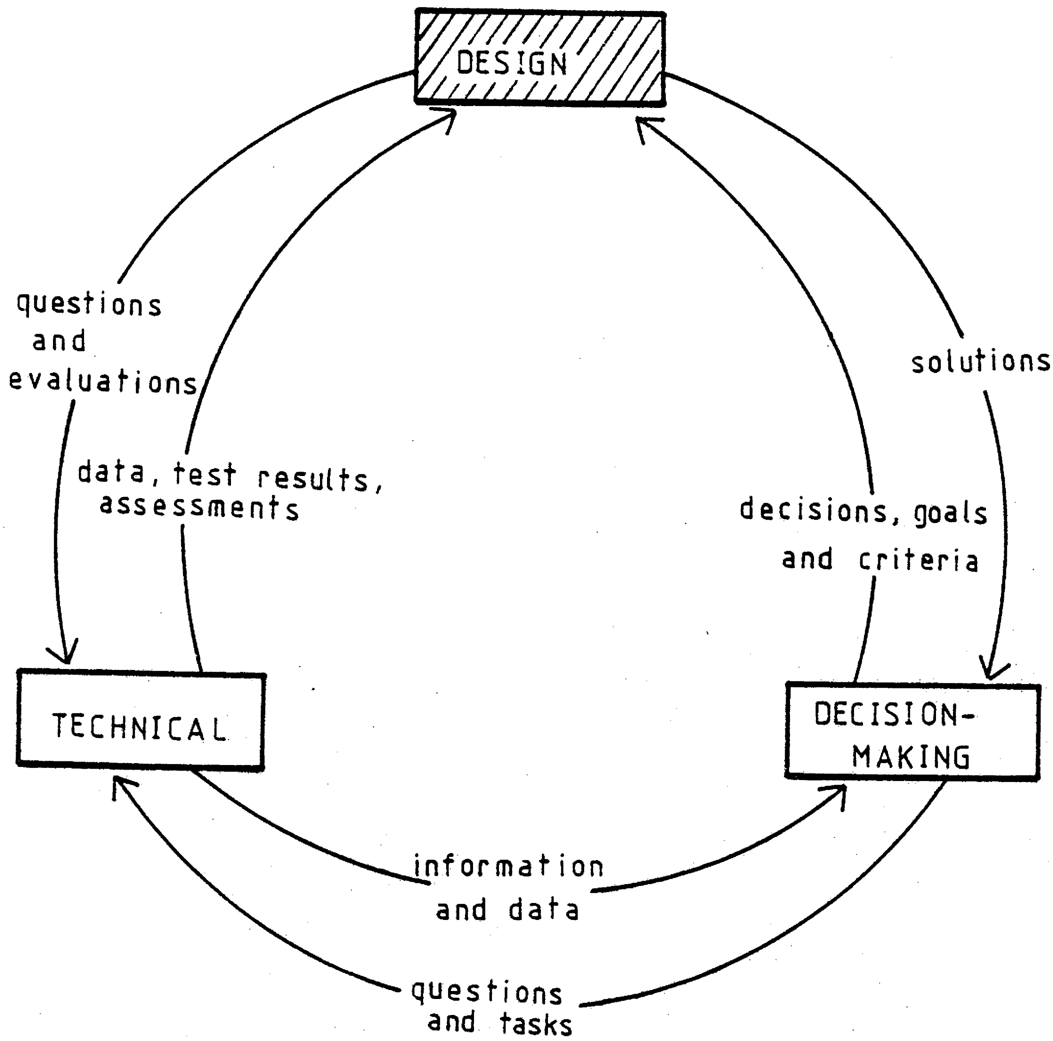
Laurie (1975) clarifies the issue somewhat by suggesting that design should be regarded as a part of the landscape planning process. The latter is considered to be the process by which portions of land are allocated to meet the demands and predicted needs of society. The 'qualitative and functional' arrangement of those land portions are then regarded as being the province of design. In other words, design and planning are distinguished on the basis of the nature, rather than the scale, of respective activities.

Similarly, Marsh (1983) views design as a component within landscape planning. The other major components are suggested to be 'decision-making' and 'technical'. The former is predominantly a political process (formal or informal) involving such activities as definition of goals, formulation of relevant policies, legal and administrative arrangements, and the examination and selection of design proposals, whereas the latter is primarily concerned with environmental inventories and impact assessment. Design, described as 'the process of devising the physical solution to a planning decision' (Marsh, 1983: 22), is closely linked to both the decision-making and technical components (Fig. 1). These three components comprise the 'landscape planning process' which is aimed at providing a rational basis for directing land use changes (Marsh, 1983).

It should be noted that there is considerable overlap between the activities associated with each component. For example, a more-or-less standard sequence of steps for landscape design may be specified as (i) research (ii) analysis (iii) synthesis (iv) design and (v) evaluation (Lyle, 1985b). Steps (i) and (ii) may involve considerable input from the technical component, whereas step (v) is likely to be ultimately the concern of the decision-making component. Therefore design should not be viewed as a completely discrete activity within the planning process. Rather, it operates in a parallel and complementary fashion to other planning activities.

Thus, landscape design can be viewed as a component of landscape planning. It has close interactions with the decision-making and technical components of planning, and is primarily concerned to provide physical solutions to the problems posed by those components. Design activities can be considered to operate in both the urban and rural con-

fig 1



Design in the context of landscape planning.

(adapted from Marsh, 1983.)

text across a range of landscape scales.

2.3 Design Scales

As pointed out in the preceding section design activities are not limited to any particular landscape scale. However, in practice certain scales frequently provide the focus for design. In descending order of size these are, the plan unit, the project area, the site, and the construction area (Lyle, 1985a). The major characteristics of each are briefly outlined in the following:

(i) Plan unit; has existing definable boundaries (physiographic or political), and is small enough to permit accurate detailed consideration of landscape attributes.

(ii) Project area; part of the plan unit under the fiscal control of a single entity, and small enough to facilitate the precise determination of land-uses.

(iii) Site; the scale at which the physical environment is specified in complete detail. It is usually small enough to be seen entirely from a single viewpoint.

(iv) Construction area; that portion of the site where physical reshaping actually occurs. Techniques pertaining to planting and the use of materials are specified at this scale. Also, detail of the arrangement of plants and materials which may have been precluded by the scale of the site plan are shown.

Larger scales of concern include the region, subcontinent and whole earth (Lyle, 1985a). Design at the regional scale is rare, and the subcontinent and the whole earth as operational design scales can only be regarded as futuristic possibilities.

2.4 The Design Process

The foregoing has placed design in the context of landscape planning and a number of design scales have been identified. However, little has been said about the design process itself. The latter needs to be clearly explained in order to provide a conceptual base for agroforestry design. In the following an attempt is made to outline the fundamentals of the landscape design process.

Lyle (1985a) suggests that design is a process in which form is given to physical phenomena. Form relates to the spatial arrangement and shape of the phenomena in question. In landscape design the latter is the landscape itself, comprising 'the surface of the earth and all its phenomena, including landforms, vegetation and man-influenced attributes ... (Vink, 1983:2). Thus, the landscape design process can be considered to be basically concerned with the specification of the form of landscape. This involves, as Van der Poel (1976: 369) puts it, 'creating plans for the outward appearance of landscape'. Such plans will show the spatial arrangement and shape of the component parts of the landscape.

In design terminology landscape components are often identified as 'elements' (e.g. Hackett, 1971; McCluskey, 1985). The term refers to visible, surficial aspects of landscape readily distinguishable at the particular scale of concern. Landscape elements may be natural or man-made, biotic or abiotic. The term does not have the more precise meaning accorded to it in geomorphology (see Speight, 1984) and landscape ecology (see Forman and Godron, 1981; Forman, 1982) although it is used in a somewhat similar sense. Suffice to say that elements are the fundamental units of concern in the design process.

In view of the above, the landscape design process can be seen to be concerned with specifying the spatial arrangement and shape of landscape elements. At the plan unit scale (see Sec. 2.3) the latter may include, for example, a forest, timber mill and access road. In this instance spatial arrangement is likely to be primarily concerned with relative location. At the 'project area' scale, landscape elements may include a pasture and shelterbelt, in which case it is not only relative location (the shelterbelt in relation to pasture and prevailing winds) that is important but also the shape (cross-sectional profile) of the shelterbelt (see Brown and Hall, 1968).

Alexander (1964) points out that the design process is also an attempt to achieve 'fitness' between form and context. In regard to landscape design the biophysical attributes of landscape and its associated socioeconomic conditions can be considered to provide the context for design. That context will, to a large extent, define the design problem. Form may then be considered as a solution to that problem. The degree of 'fitness' between form and context is dependent on the design proposals' visual and ecological empathy with the landscape and its relevance to socioeconomic conditions. Context is also set by specified design goals which are framed with reference to biophysical and socioeconomic conditions. The form of elements needs to facilitate the attainment of these goals, in other words, form needs to be functional.

Thus, the landscape design process may be described as the specification of the form of landscape elements[2] which are visually,

2. In practice, specialized fields will be involved in the detailed specification of particular elements, for example architecture with building and civil engineering with roads and bridges, nonetheless, the form of such elements within the context of the landscape is a legitimate concern of landscape design.

ecologically and functionally appropriate within the context of particular landscapes, socioeconomic conditions, and design goals. The process is shown as a sequence of steps in Fig. 2. The 'specification of the form of landscape elements' is noted as the 'design proposal', which is usually shown by plan and section drawings. These are evaluated with respect to visual, ecological and functional aspects which may be presented as a set of specific evaluatory criteria developed in the light of the stated design goals (Fig. 2). If evaluation shows the design proposal to be unsatisfactory it is necessary to return to an earlier stage of the process, otherwise, it is possible to proceed to the implementation stage. The design process can be considered to end with the production of working specifications at the beginning of this last stage, which also incorporates the establishment of plant materials, structures, paths etc., and where applicable, the formulation of management plans. However, these aspects are not normally considered as part of the design process.

The design proposal may be seen as a response to specific design problems which become clear as the design context is clarified. The latter is defined with reference to design goals, and by the synthesis[3] of information derived from the research and analysis of biophysical and socioeconomic conditions (Fig. 2). The formulation of realistic design goals requires cognizance of the existing situation (biophysical and socioeconomic), and subsequent modification as more precise information becomes available (Fig. 2).

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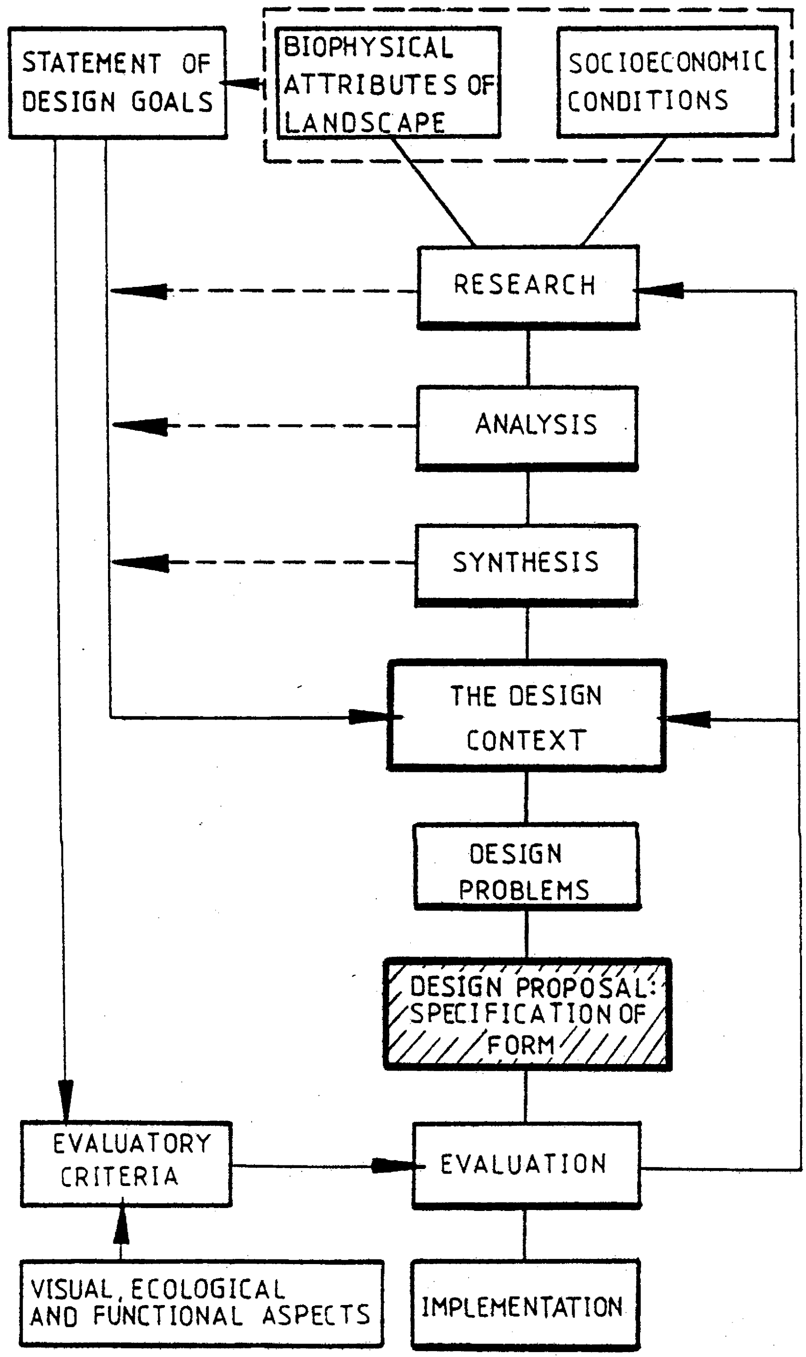
3. The 'synthesis' stage is of particular importance, and while considerable progress has been made toward solving the conceptual and methodological problems associated with achieving a 'landscape synthesis' (see Geoforum, 1983), in practice, there has been a general neglect of this aspect of the design process (Berger, 1987). The problem of synthesis receives attention in Chap. 5.

fig 2



The design process.

The outline of the design process builds on the basic research-analysis-synthesis-design-evaluation sequence as noted in Sec. 2.2, and essentially represents the rational problem - solving paradigm which has been adapted from the systems approach (see Lyle, 1985a). While the sequence of steps is referred to as a 'design process', it is clear that in the early and late stages other planning components are involved (see Sec. 2.2). It is taken as understood that the design process cannot be completely isolated from other activities which might be more properly considered as 'technical' or 'decision-making'.

Rational design procedures can be criticised as unrealistic, since in practice design rarely proceeds through the linear step-by-step sequence as suggested by Fig. 2 (Lyle, 1985a; 1985b). More importantly, as Lyle (1985b: 9) points out, 'taken too literally and followed too rigorously, a formal design process can close out creativity, the driving force of design, and this can lead to disaster, or more commonly, to mediocrity'. Nonetheless, the kind of approach shown in Fig. 2 has gained wide currency as a response to the increasing demand for design processes to be logically defensible (Lyle, 1985a).

The procedure outlined here is not intended as a definitive statement on the correct approach to design, rather it is presented as an example of the way design is commonly approached. The procedure is not a formal process but a framework in which the various steps mark stages in a rough progression towards the design proposal. It does not imply that frequent iteration is not required.

2.5 Agroforestry Design : Introductory Remarks

The concept and practice of agroforestry is detailed in the following chapter. Suffice to say at this stage that 'agroforestry' refers to 'land management systems involving many interdependent components including trees, agricultural crops, and domestic animals in any or all combinations' (Gold and Hanover, 1987: 110). Such systems can be considered an integration of forestry and agriculture, and involve the introduction of crops and/or livestock to forest lands, or more commonly, the introduction of trees to agricultural systems. In either case considerable changes in the rural landscape may ensue. Clearly, a rational basis for directing such changes is required.

Thus, the formulation of proposals involving landscape change for agroforestry is the province of rural landscape planning. This does not necessarily imply that such planning would involve a formal process directed by government or private agencies. However, it does suggest that, even if planning is carried out by the individual landowner, decision-making, technical, and design activities are required (see Sec. 2.2). Together, these three components will direct the course towards the creation of an agroforestry system. The success or failure of the latter will be largely dependent on a thorough consideration of each planning component.

Oates (1984) and Reid and Wilson (1985) have stressed the need for planning in agroforestry. However, planning procedures are outlined in a very simple and rudimentary fashion. Moreover, little is said about the actual process of agroforestry design. Oldemans (1979: 29) salutory comment on the latter is worth noting: 'Up till now, one often gets the impression that the design of bio-ecological production systems has been considered as something easy and elementary. One has only to plant and it grows. In reality, such systems are more complicated than most of our industrial complexes'. In view of this, it is clear that agroforestry design procedures must have a 'capacity for complexity', which in design terminology means the ability to accommodate 'a great deal of information from a variety of sources on many different subjects from diverse disciplines' (Lyle, 1985b: 8). The broad scope of the possible inputs is indicated by Gold and Hanover (1987: 110): 'Agroforestry might be considered as the meeting point for a confluence of disciplines, both applied and basic in nature. Within its broadest scope it draws on the accumulated knowledge of many separate disciplines including forestry, agronomy, animal husbandry and horticulture for its major inputs, with necessary additional inputs coming from soil science, microbiology, ecology, plant breeding, chemistry, economics, sociology, agriculture engineering, and others'. For the most part, these disciplines are 'technical' in nature, thus, their potential input is likely to be more dependent on design being set within an overall planning framework (see Fig. 1), rather than on the design procedure *per se*. This aside, the design process itself can have characteristics which either discourage or encourage a 'capacity for complexity'. Characteristics in the latter category and already specified in the design procedure shown in Fig. 2 include, first, a design context which is resolved with reference to both socioeconomic and biophysical conditions, and second, a requirement that the specification of form involve ecological and visual, as well as, functional considerations.

Since ill-conceived design approaches clearly have the potential to produce detrimental landscape changes, which, in many instances, may not be easily rectified, there is a need for procedures to be established, specified in some detail, and examined critically in order to establish 'defensibility'. The latter refers to the existence of a clear and correct logical framework, and like the abovementioned 'capacity for complexity' criteria, is now commonly applied to landscape design in general (Lyle, 1985b). These criteria have also become evident within the broader context of project planning, where the need for 'accountability' has resulted in formally specified procedures such as the 'logical framework approach' (Australian Development Assistance Bureau, 1986).

The position taken in this thesis is that agroforestry design can be modelled on the landscape design process as outlined in Sec. 2.4. Thus, as a first approximation, agroforestry design, like landscape design, can be considered to involve 'the specification of the form of landscape elements which are visually, ecologically and functionally appropriate within the context of particular landscapes, socioeconomic conditions and design goals'. This would seem an appropriate view of design in the light of Nairs' (1979: 275) assertion that agroforestry land use should be 'ecologically desirable, practically feasible, and socially acceptable to the farmers'. Thus, the design process as shown in Fig. 2 can be considered as an appropriate starting point from which to develop an agroforestry design procedure characterised by 'logical defensibility' and the 'capacity for complexity'.

The procedure, as developed in the following chapters, addresses land use changes at the level of the 'farm unit'. This is roughly parallel to the 'project area' design scale (see Sec. 2.3). At this scale landscape elements will include shelterbelts, production plantations, pasture, crops, livestock, access tracks, buildings, fences and dams, and the central design problem is the spatial arrangement of these elements in relation to each other and the landscape. Larger and smaller design scales can be considered to be 'the catchment' (largely synonomous with the 'plan unit'; see Sec. 2.3) and 'site' respectively. The central design problem at these scales are briefly noted in the following:

(i) The Catchment Scale; catchments are regarded as natural planning units characterised by dynamic interrelationships between water, land and people (Irwin and Williams, 1986). The protective role of trees, the importance of management decisions on individual farms, and the need for comprehensive resource inventories as a basis for rational management have been recognized (Clarke, Irwin, Marshall and Wakefield, 1986; Breckwoldt, 1986a; Short, 1986). Agroforestry design at this scale needs to consider these aspects. In particular, the reconciliation of overall design strategies with the needs of individual management units (e.g. farms) is a central problem. For example, streamside protection planting, which may well be part of agroforestry design at the farm scale, may be limited in effectiveness at the catchment scale if plantings do not extend upstream and downstream from the eroded site (Carne, 1986). Clearly, the resolution of problems at this scale require an awareness of land-use practices on individual farms or management units, and at the farm scale, a recognition of the implications of land-use for the catchment as a whole. In practice, the preparation of agroforestry 'master plans' at the larger-than-farm scale (e.g. Rocheleau and Hoek, 1984) is required against which farm design can be checked to ascertain possible conflict.

(ii) The Site Scale; at the site level the central design problem is the spatial and temporal arrangement of plants. In practice design specifications would be expressed in a 'silvicultural regime' (see Shepherd, 1986). At this level of agroforestry design it may be possible to derive design principals from studies of natural forest ecosystems. Attempts to derive workable concepts have begun (e.g. Oldeman, 1979; 1983; Hart, 1980; Brunig and Sander, 1983; Brunig,

1984) but the translation to practical design guidelines is difficult.

2.6 Conclusion

In broad terms, agroforestry land use can be described as an integration of forestry and agriculture. Clearly, its' adoption will result in considerable change in the rural landscape, and therefore, it is a legitimate concern of landscape planning. The latter can provide a rational basis for directing such change, and involves decision-making, technical, and design activities. Design is essentially concerned with the specification of the form (shape and spatial arrangement) of landscape elements.

The 'specification of form', shown as a 'design proposal', is facilitated through the design process. The latter can be described as a sequence of steps, which while indicating a certain linearity should not be interpreted as meaning that iteration does not occur. Indeed, frequent iteration is more a rule than exception in design. Nonetheless, the value of linear step-by-step descriptions is that they provide a logical framework within which design problems can be systematically approached. Such descriptions essentially represent a rational problem-solving approach to design, which, in the context of this thesis, is considered appropriate for agroforestry.

In view of the above, a systematic landscape design procedure has been outlined and proposed as an appropriate model from which an agroforestry design procedure can be developed. The procedure has been shown in general form and described as 'the specification of the form of landscape elements which are visually, ecologically and functionally appropriate within the context of particular landscapes, socioeconomic conditions and design goals'. Also, it has been suggested that agroforestry design procedures, in common with landscape design approaches in general, should have the 'capacity for complexity' and be 'logically defensible'.

Design activities operate across a range of landscape scales, the largest of which is typically the 'plan unit', and the smallest the 'construction area'. The focus of attention in this thesis is the 'farm-unit', which in most instances will be intermediate to these extremes, being more-or-less synonomous with the 'project area' design scale. At this scale, the precise determination of land uses is possible, and the form of associated landscape elements such as windbreaks, pastures, and production plantations can be specified in detail. The central design problem at this scale is the spatial arrangement of elements in relation to each other and the landscape. More detailed specifications, such as the arrangement of individual plants, is the subject of design at the 'site' or 'construction area' scales. These small-scale design problems will not be further considered in this thesis. Similarly, design at the large-scale, such as a major catchment incorporating several farm-units (synonomous with the 'plan unit'), will not receive further attention.

Clearly, in order to provide a design procedure specifically for 'farm-scale' agroforestry some detail needs to be added to the general landscape design process as outlined here. This requires a comprehensive understanding of agroforestry land use. Thus, in the following chapter the major aspects of the concept and practice of agroforestry are analysed in order to identify the essential features which require consideration in a design procedure. It will then be possible to provide a more specific statement on the nature of agroforestry design at the farm-scale.

CHAPTER THREE

Agroforestry: Concept and Practice

3.1 Introduction

This chapter attempts to elucidate the concept and practice of agroforestry and thus provide the necessary background against which the notion of 'agroforestry design' can be developed. Following some preliminary comments concerning agroforestry as a land use and field of study, the term 'agroforestry' is defined (Sec. 3.3). Attention is then drawn to some of the more important implications associated with the agroforestry concept (Sec. 3.4), and the classification of agroforestry systems is discussed (Sec. 3.5). Finally, some typical Australian agroforestry practices are briefly outlined (Sec. 3.6).

3.2 Preliminary Comments

The term 'agroforestry', despite some confusion over its exact meaning and difficulties in translation to other languages (Combe and Budowski, 1979; Stewart, 1981), is now widely used to describe the growing of trees with agricultural crops and/or livestock on the same piece of land. To some extent, this represents an integration of forestry and agriculture, both of which are normally recognized as distinct land-use activities. However, as Adeyoju (1980: 157) points out, 'forestry and agriculture were, for centuries in simple societies, a common vocation wherein the farmer, hunter, and woodsman were nearly always the same', and Raintree (1984), while recognizing that agroforestry is a relatively new field of organized scientific activity describes it as an 'ancient land use practice'. The interplanting of trees with crops and the grazing of domesticated animals in forests are, for example, practices having a long history (Douglas, 1967; Adams, 1975; Borough, 1979a; Commonwealth

Agricultural Bureaux, 1982).

Clearly, integrated land-use involving forestry and agriculture is not a new concept. However, its newness as a scientific field of study bridging, as Raintree (1984: 253) puts it, the 'artificial but time-honoured disciplinary no man's land between agriculture and forestry', is underscored by the fact that the International Council for Research in Agroforestry (ICRAF) was formed as recently as 1977.

Agroforestry, as a distinct and legitimate field of study, is considered by Jorgensen (1986) as a branch of 'community forestry' aimed at providing environmental and social benefits for rural populations. In the urban context, the provision of 'environmental and social benefits' is suggested to be the aim of 'urban forestry'. In the case of the latter the main products are amelioration of urban living areas with regard to climate, hydrology, air quality, noise control and aesthetics, and the provision of land for recreational and educational use. In regard to agroforestry, Jorgensen (1986) lists the main products as increased land productivity due to soil conservation, wood for energy, and animal fodder for food production.

Although it is useful to identify agroforestry as essentially a rural activity providing a range of particular products, its inclusion as a branch of community forestry is questionable. Basu (1984) considers that 'community forestry' involves the active involvement of the local community. The needs and aspirations of the latter are suggested to be a foremost consideration, which together with biophysical and socioeconomic conditions should direct the formulation and implementation of forestation activities. However, it is clear that in cases of freehold tenure individual land use decisions can be made in almost complete isolation from the desires of the rural community-at-large. Thus, it would be difficult to apply the concepts of 'community forestry' to agroforestry in these situations.

Nonetheless, the importance of agroforestry as a rural land-use lies in its potential to utilize and stabilize 'fragile' or 'degraded' ecosystems, which in the tropical world occupy about 65% of the land and support 35% of the population of the developing countries (King, 1979a). The critical state of such ecosystems is indicated by severe land degradation which manifests in problems of soil erosion, salinity, soil micronutrient deficiencies and reductions in the carbon to nitrogen ratio, and sedimentation in reservoirs and watercourses (Bowonder, 1987). These problems are closely associated with alarming rates of deforestation (see Myers, 1985; UNEP, 1987) as a result of fuelwood demand, shifting cultivation, overgrazing, large-scale wood extraction for paper and pulp, conversion of forest land to agricultural uses, and poor efforts at forest regeneration (Bowonder, 1987). In the developed countries there is increasing evidence of land degradation. For example, in the U.S.A. 1/3 of croplands is now undergoing a marked decline in long-term productivity as a consequence of soil erosion (Myers, 1985). In Australia, Woods (1983) suggests that 51% of agricultural and pastoral land is seriously degraded, and Grose (1982) has noted the concomitant widespread extent of tree decline (Plates 1 to 3). Indeed, it has been estimated that some 87 million hectares of forests and woodlands have been cleared since European settlement (Wells, Wood and Laut, 1984). This amounts to approximately 36% of the original cover. Those stands which have survived the onslaught of the early settlers (see Bolton, 1981) and contemporary non-conservative agricultural practices are now typically restricted to roadside verges and riparian corridors (Plates 4 and 6). These, along with the odd patch of

PLATE 1: Gully erosion; a typical form of rural land degradation (near Bredbo, N.S.W.).

PLATE 2: Hillslopes, almost completely cleared of trees, are a common feature of the rural landscape in the Bega Valley, N.S.W.

PLATE 3: Farmland near Hamilton, Western Victoria; the low-lying area (centre of photo) has severe salinity problems as a result of overclearing and the concomitant high water-table.

PLATE 4: Roadside verges; woodland remnants in the rural landscape of central Victoria.

PLATE 5: A well-vegetated riparian strip stands in stark contrast to a background of cleared hillslopes (Murrumbidgee River, A.C.T.).

PLATE 6: Stand of E. camaldulensis in the Murray River corridor near Mildura, Victoria; such surviving remnants are subject to various man-induced environmental pressures, including that associated with recreation (as indicated by the vehicle tracks in foreground).

forest left intact on private farming or grazing land, and the forest remnants associated with stock route reserves, are recognized as invaluable components of the rural landscape (e.g. Breckwoldt, 1986). Nonetheless, various studies indicate a continuing decline in these surviving remnants (e.g. Devonshire and Greig, 1980; McMurray, 1984).

In view of the above, it is clear that the need for rural reforestation can be found in both the developed and developing countries. Moreover, there is a general need for alternative, sustainable land use practices to halt the current widespread extent of environmental degradation. Agroforestry can be seen as one such alternative which would promote the reestablishment of a tree-cover for both protection and production. Obviously, agroforestry is not a panacea for all environmental problems, but, as Young (1985: 11) points out, 'there are clear grounds for supposing that the introduction of trees in land use systems can be of particular benefit in areas which have suffered some form of environmental degradation'. In particular, soil erosion and fertility decline can be mitigated by certain agroforestry practices (Young, 1987). These, along with other environmental problems which agroforestry has the potential to alleviate are shown in Table 1.

Even in landscapes which show little or no degradation, a change to agroforestry is likely to result in a better use of land. In Australia, for example, there are farm landscapes which have been reasonably well-maintained, but due mainly to inherent low soil fertility have relatively low land capability rankings for forestry and agriculture (Plates 7 and 8). For such areas, 'agroforestry capability' is of course unknown, nonetheless, they are likely to be suitable for some form of agroforestry. Moreover, with the appropriate choice of agroforestry practice (see Table

TABLE 1. Environmental problems which agroforestry has a potential to alleviate

Environmental Problem	Potential Agroforestry Practices and Functions
Soil erosion by water	Agroforestry practices for erosion control; barrier hedges, trees on soil conservation works, alley cropping, multistorey tree gardens, plantation crop combinations.
Soil erosion by wind.	Windbreaks and shelterbelts.
Low natural soil fertility or fertility decline (physical, chemical and biological degradation).	Agroforestry practices for maintenance and improvement of soil fertility; alley cropping, multistorey tree gardens, plantation crop combinations, biomass transfer (transport of tree foliage from forests to cropland), planted tree fallows, trees on cropland, trees on pastures.
Forest clearance and degradation.	On-farm production of fuelwood.
Pasture degradation.	Fodder production from trees; pasture improvement through trees.
Drought hazard.	Agroforestry practices for micro-climatic modification and moisture conservation; role of deep-rooting trees.
Degradation of river flow.	Agroforestry as an element in watershed management.
Pest attack.	Trees for pest inhibition.

Source: Young (1987)

PLATE 7: (and 8): Farm landscape near Braidwood, N.S.W: windbreak plantings (middle-ground), the retention of some trees on pasture, and a grassed dam wall and fencing to control stock (below), are indicative of relatively well-managed land. Nonetheless, grazing is limited (Class VI; moderate grazing), and capability for forestry is Class IV (site index 80). Landscapes such as this, less than optimal for agriculture or forestry alone, are likely to benefit greatly from some form of agroforestry.

PLATE 8:

1), and the judicious selection of tree and/or shrub species, soil fertility could be enhanced and maintained in the long term.

Thus, agroforestry has the potential to bring about improvements in biophysical conditions of both seriously degraded and relatively well-conserved environment. Concomitant improvements in social conditions could be expected, and may occur as a result of a raised level of human well-being through increases in the quality and quantity of food, or more simply, as a consequence of improvements in environmental amenity (shade, shelter, aesthetic values etc.). Therefore, agroforestry could be considered a form of 'social forestry', which while clearly providing a social benefit may or may not involve the active community participation characteristic of 'community forestry' (Basu, 1984).

Indeed, a 'social forestry context' for agroforestry is made clear in ICRAF's charter. Ultimate objectives are stated as: 'to improve the nutritional, economic and social well-being of the peoples of developing countries by the promotion of agroforestry systems designed to result in better land use without detriment to the environment' (ICRAF, 1983: 3). While this relates specifically to the developing world, there are many parts of the so-called 'developed world' where such objectives would be entirely appropriate. For example, in the Australian context, Oates (1984: 166) suggests that agroforestry is 'the management of land for increased net social benefit, by the simultaneous production of farm and forest products.'

To conclude these preliminary comments it is worthwhile noting the following remark by Raintree (1986: 3): 'Many people today have great expectations for agroforestry, some of which would seem to be justified on technological grounds. However, if current efforts to understand, develop and disseminate agroforestry technology are to have any hope of meeting even a reasonable proportion of current expectations, its deployment, as a newly organized branch of applied science, must take place with a clearer than usual view of the human context of supposed land-use improvements'. Clearly, the integration of forestry and agriculture is more than just a question of biophysical possibilities. If the potential of agroforestry to redress environmental degradation and provide a viable alternative land use is to be realized, thorough consideration must be given to the social and economic circumstances of rural populations. This is particularly important in land use system where managed trees and shrubs represent a new inovation. As Lundgren and Raintree (1983:39) point out, in these situations social and cultural attitudes may hinder the adoption of agroforestry practices, and moreover, the 'period between planting a tree and achieving appreciable benefits from it involves risks that farmers with limited resources may not be prepared to take'.

3.3 Definition of Agroforesty

A large variety of rural land-use practices exhibit, to greater or lesser degrees, an integration of forestry and agriculture. Inevitably, regional terminologies have been devised to describe such practices. Examples include, from New Zealand, 'integrated farm forestry' (Tustin and Knowles, 1975), from southern Africa, 'three dimensional forestry' (Douglas, 1967; 1968), from central Morocco, 'sylvo-pastoral systems' (Montoya Oliver, 1986) and from Nigeria, 'agri-silvicultural systems' (Olawoye, 1975). In southeast Asia, the terms 'swidden' and 'taungya' describe tree/crop systems (Awang, 1985; Vergara, 1985). The term 'tree gardening' with its two main variants 'pekarangan' and 'talun-kebun' has also been applied in this region (Wiersum, 1982; Christanty and Iskandar, 1985). Other authors, refer to the same systems as 'tropical homegardens'

(Fernandes and Nair, 1986) or 'multi-storied gardens' (Freeman and Fricke, 1984). In the West Indies, somewhat similar forms of land-use (see Innis, 1961) are referred to as 'kitchen gardens' (Brierley, 1976).

All the abovementioned systems have in common the integration of woody perennials with herbaceous plants and/or livestock. However, great diversity occurs in the plant species utilized, the scale of land-use, products, and temporal and spatial arrangement of plantings. Much of the confusion as to 'what agroforestry is' is no doubt due to the difficulty of elucidating the term by proferring examples of what are at first glance disparate land-use practices. Clearly, if the term 'agroforestry' is to be applied to such diverse practices the definition needs to be comprehensive, without being so broad as to be useless from a scientific point of view.

King (1979b) suggests that agroforestry should be considered a generic term embracing the following components:

(i) Agrisilviculture; the use of land for the concurrent production of agricultural crops (including tree crops) and forest crops.

(ii) Sylvopastoral systems; forests managed for the production of wood and the rearing of domesticated animals.

(iii) Agrosylvopastoral systems; a combination of (i) and (ii)

(iv) Multipurpose forest tree production systems; forest tree species managed for production of wood and leaves and/or fruit suitable for food and/or fodder.

A number of practices can be recognized as characteristic of each of these components (see Nair, 1985). These include, for example, in agrisilviculture, hedgerow intercropping, multistorey crop combinations, multipurpose trees on farmlands, shelterbelts and windbreaks, and shade trees for commercial plantation crops. In sylvopastoral systems the use of trees over pasture and 'living fences' are characteristic, while agrosilvopastoral systems typically exhibit tree-crop-livestock combinations around homesteads and woody hedgerows for browse, mulch, green manure and soil conservation.

Numerous attempts have been made to provide a concise definition to cover these components and practices (e.g. Editorial, 1982), and, as the Commonwealth Agricultural Bureau (1982:1) notes, 'There are probably as many definitions of agroforestry as there are users of the term'. However, the following definition proposed by Lundgren and Raintree (1983) has been adopted by ICRAF (see Fernandes and Nair, 1986) and is accepted for the purposes of this thesis:

> 'Agroforestry is a collective name for land-use systems and technologies where woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals, in either a spatial arrangement or a temporal sequence, there being both ecological and economical interactions between the different components'.

As Fernandes and Nair (1986) point out, this implies first, agroforestry normally involves two or more species of plants (or plant and animal), at least one of which is a woody perennial, second, an agroforestry system always has two or more outputs, third, the cycle of an agroforestry system is always more than one year, and fourth,even the most simple agroforestry system is more complex, ecologically (structurally and functionally) and economically, than a monocropping system.

As suggested in the above, 'woody perennials' (trees, shrubs, palms, bamboos, etc.) are a characteristic element of agroforestry systems. These are almost always 'multipurpose'[4] (Young, 1986), that is, they 'provide

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4. See Turnbull (1986) for examples of 'multipurpose' Australian Trees and shrubs.

more than one significant contribution to the production and/or service functions (e.g. shelter, shade and land sustainability) of the land use systems they occupy' (Huxley, 1985a: 13). Annual agricultural crops are sometimes included with pasture plants under the collective term 'herbs'[5] (Young, 1986). These comprise the second major element in agroforestry, the third being animals, which in most instances will be domesticated.

The first element, that is, woody perennials, are found in all agroforestry systems, and the second, herbaceous plants, are found in most, with the possible exceptions of certain agrisilvicultural systems in which the agricultural crop is produced by trees and/or shrubs (see Nair, 1985), in multipurpose forest tree production systems (see King, 1979b), or in forest apiculture and mangrove aquaculture, both legitimate, though somewhat difficult to classify agroforestry forms (see Nair, 1985). The third element, namely 'animals', is present in some agroforestry systems usually designated as 'silvopastoral' and 'agrosilvopastoral' (see Nair, 1985).

The above definition notifies that elements may be arranged in either a spatial arrangement or temporal sequence. The former includes zonal or mixed arrangements, while the latter may be concomitant, sequential, coincident, interpolated, or overlapping (see Nair, 1985). Examples of the various combinations of spatial and temporal arrangements which characterise particular agroforestry systems are shown in Appendix 1.

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5. The term 'herbs' is used here in the botanical sense to mean those plants with no persistent parts above ground (as distinct from shrubs and trees).

The need for economic and ecological interactions is also indicated in the definition. Economic interactions can involve, for example, a tree harvest providing capital for crop production, or more simply, the tree and herb component providing part of the farmers' needs (Young, 1986). Ecological interactions are many, and include the soil conservation function of trees, utilising litter from nitrogen-fixing trees as fertilizer, and using fodder from trees to feed cattle and then applying manure to crops.

Under the foregoing definition it is difficult to maintain the distinction between 'farm forestry' and 'agroforestry' as suggested by the Commonwealth Agricultural Bureaux (1982). The term 'farm forestry' is considered to be applicable to systems in which farming and forestry activities are integrated horizontally within a farm (e.g. woodlots and shelterbelts; Plates 9 and 14), and 'agroforestry' to systems in which farming and forestry activities are consciously combined vertically and/or temporally on the same piece of land. However, the above definition proposed by Lundgren and Raintreee (1983) implies that the integration of trees and crops and/or animals may occur in a horizontal spatial arrangement and qualify as agroforestry if there are economic and ecologic interactions between components.

Typical 'farm forestry' practices such as shelterbelts (Moore, 1986), clearly a horizontal integration of farming and forestry, have considerable interaction with other farm components. Such interactions may be of an economic and/or ecological nature, be positive or negative, and direct or indirect. For example, shelterbelts control wind erosion, reduce evaporation from dams, improve pasture growth, reduce lambing mortality, and increase milk and crop yields (see Moore, 1986; Brown and

PLATE 9: Farm woodlot (Pinus radiata) near Canberra; the trees are not fenced-off from the adjacent grazing land, thus livestock have access to shelter. This, and the following examples (Plates 10 to 14), illustrate simple forms of 'horizontal integration'.

PLATE 10: Farm woodlot (Eucalyptus spp.) near Marulan, N.S.W.; as in the above, trees afford protection for livestock.

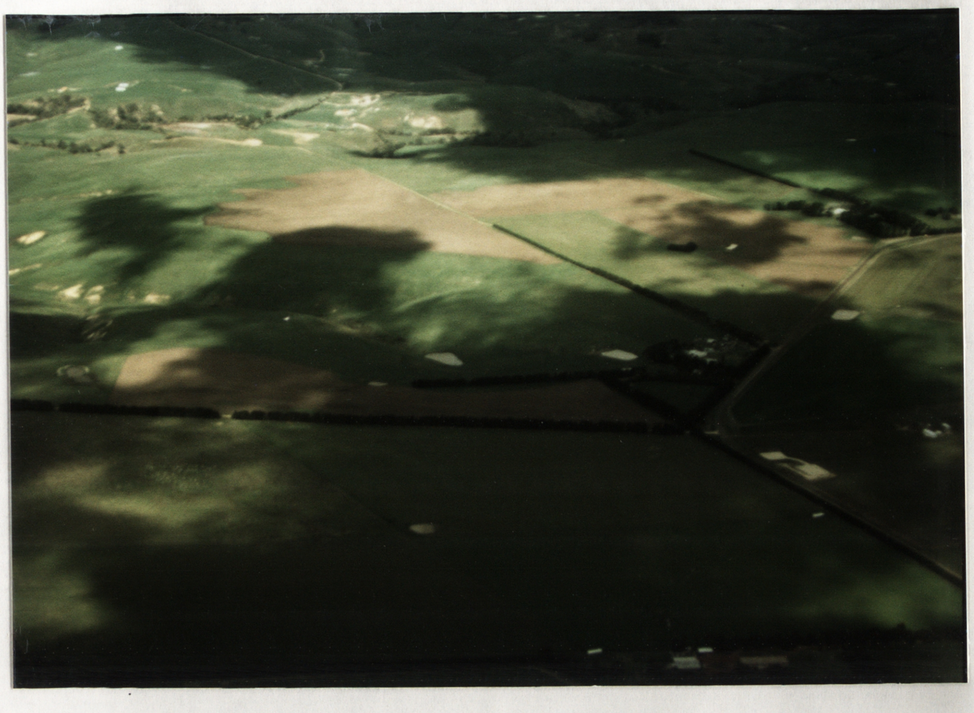

PLATE 11: Shelterbelt system on farmland in Victoria.

PLATE 12: Three year old, three-row windbreak comprising *Melaleuca ericifolia* and *Eucalyptus spp.* (cattle stud near Bega, N.S.W.).

PLATE 13: Single-row windbreak near Braidwood, N.S.W.; even structurally simple windbreaks afford some shelter for livestock.

PLATE 14: Newly-planted three-row windbreak (*Pinus radiata*) near Braidwood, N.S.W.; with careful management, densely planted windbreaks such as this can yield useful products (Christmas trees and small diameter poles from thinnings), as well as provide protection for livestock.

Hall, 1968). Other positive effects are clearly contingent on the species which comprise the shelterbelt. For example, if fodder producing shrubs are used in the shelterbelt assemblage and placed close to the protective fence-line (Plate 15 and 16), livestock have some access to supplementary feed. Negative effects include the loss of land for crops and grazing, and a reduction in crop yields adjacent to the shelterbelt (Brown and Hall, 1968). The reciprocal action of crops and livestock on shelterbelt may be negative, for example, where pasture plants compete with young trees for moisture and nutrients (Borough, 1979b) or stock damage trees by rubbing or browsing. Positive effects, while somewhat more indirect, could include the use of animal manure and composted leguminous pasture as fertilizer and mulch for shelterbelt trees.

Thus, clear distinctions between agroforestry and farm forestry characterised by use of shelterbelts are difficult to make. Indeed, Wilson and Reid (1985) accept shelterbelts as coming under the aegis of agroforestry. Similarly, Nair (1985) lists shelterbelts and windbreaks as typical agroforestry practice in agrisilvicultural systems.

This kind of definitional problem essentially concerns the intimacy of the tree/crop/livestock mixture required in order to distinguish agroforestry from other systems where agriculture and forestry are zoned or occupy adjacent but distinct blocks (e.g. farm woodlots). King (1979b: 3) suggests 'that agroforestry might be considered to be practised whenever trees and agricultural crops are grown in mixture, provided that the combined widths of the rows of agricultural crops do not exceed the heights, at maturity or at the end of the selected rotation, of the forest tree crops with which they are grown in mixture; provided further that the combined widths of the rows of the forest tree crops do not exceed the height of the tree crops at maturity or at some selected rotation'. This

PLATE 15 (and 16): Tagasaste (Chamaecytisus palmensis), a fodder producing shrub in three-row shelter belt; the protective fence is close enough to allow stock to browse the high-protein stem tips. Taller plants in the middle-ground (Plate 15) are Eucalyptus spp. (near Hamilton, Western Victoria).

PLATE 16

suggestion omits sylvopastoral systems (pasture + trees + livestock), and moreover, as King (1979b) indicates, is simply a 'working hypothesis'. Thus, the problem of distinguishing agroforestry by specifying spacing remains largely unresolved. In view of this the distinction between agroforestry and farm forestry remains somewhat blurred. Suffice to say that under the definition used in this thesis farm forestry characterized by the use of shelterbelts is more properly considered as agroforestry.

3.4 Implications of the Agroforestry Concept

Leaving problems of definition aside, it is apparent that the concept of agroforestry implies more than the strict definition suggests. Firstly, it could be expected that agroforestry systems, to some degree, would yield the same kind of benefits as those derived from forest ecosystems. The latter are recognized as having protective, regulative and productive functions (UNESCO, 1978). These include, for example, soil protection by the absorption and deflection of radiation, precipitation and wind, regulation of the hydrological cycle by the absorption, storage and release of water, and production of wood and fruit. Conservation of soil and water, and the supply of food and raw materials are the immediate benefits man derives from these functions.

The multiple functions of forested lands have been recognized for some time (e.g. Kittredge, 1948), and recently numerous authors have emphasized protective and regulative functions as being of particular importance (e.g. Cassels, 1984; Evans, 1984; Houghton, 1984; Riedl, 1984; Willmott, 1984; Clarke, Irwin, Marshall and Wakefield, 1986). Whether or not the full range of forest functions are realized in agroforestry systems depends to a large extent on design and management. Nonetheless, the recognization that forests have functions other than production is implicit in the concept of agroforestry (e.g. Pereira, 1979; King, 1979b; Glencross, 1979; Barnhart, 1982; Merwin and Esbenshade, 1982). Indeed, Raintree (1984:257) suggests that in agroforestry 'conservation objectives are on a nearly equal footing with production objectives'.

The second major implication is that agroforestry has the potential to be a particularly productive use of land. This is due directly to the combination of two or more tiers of productive plants on the same piece of land (vertical integration) or the juxtaposition of shelterbelts and productive components (horizontal integration), and indirectly, to the aforementioned conservation benefits.

The potential exists for total yields to be higher per unit of land than that obtained under forestry or agriculture alone. A relative increase in harvests is of course dependent on beneficial plant interactions. Clearly, it is possible to conceive of situations where interplant competition is such that total yields are lower than that obtained from a monoculture. However, 'forest environments' have the capacity to influence the growth of other associated plant types positively via the creation of favourable microclimates (see Geiger, 1950). The reduction in wind velocities, interception of heat and light, and the reduction of heat loss during the night may be beneficial to particular 'agroforestry understoreys'. A consideration of the forest's influence on microclimate leads King (1979b) to suggest that trees grown in mixture with agricultural crops, might *a priori*, be a productive form of land use. Indeed, productive forms of agroforestry such as tropical multistoried gardens (see Michon, Bombard, Hecketsweiler and Ducatillion, 1983) are suggested to be examples of deliberate microclimatic management in order to create conditions similar to those found in forests (Wilken 1972; 1977). While productivity could be attributed in part to favourable microclimates, it must also be contingent on the plant combinations used. In this regard, King (1979b) has made some suggestion as to desirable attributes of agroforestry tree species.

The third implication concerns the notion of 'sustainability', which as Raintree (1984) notes is virtually axiomatic to agroforestry. Furthermore, 'sustainability' is often incorporated into definitions of agroforestry (see Editorial, 1982), and Reid and Wilson (1985:8) suggest that 'Agroforestry has become an important part of a new thrust to develop more sustainable land use to replace destructive techniques used since the (agricultural) revolution'. Strange (1983) has listed four major requirements of a sustainable agriculture. These are (i) it must produce more energy than it consumes, (ii) it must not destroy its own base, that is, the soil, (iii) it must meet local needs, and (iv) it must gain its own nutrients on site. While the first of these is clearly untenable since no system can produce more energy than it consumes under the Laws of Thermodynamics (see Rifkin, 1981), the other three are at least theoretically attainable in agroforestry systems. First, the conservation of soil, as discussed previously, is achievable under protective tree cover and recognized as part of agroforestry land use, and second, the provision of local needs is coherent with the notion that agroforestry is a form of 'social forestry' (see Sec. 3.2). Finally, the requirement that agroforestry systems obtain all nutrients on site is a possibility. Some precedence for this can be found in traditional tropical agroforestry systems (Terra, 1954; Igbozurike, 1971; Soemarwoto, 1975; Freeman and Fricke, 1984) and recent attempts to derive 'natural ecosystem analogs' for the design of agroforestry systems (Hart, 1980).

However, ultimately, sustainable land-use can only be achieved by depending on resources which are essentially inexhaustible (e.g. sunlight), renewable (soil, flora and fauna), or re-usable or re-cyclable (Dasmann, 1985). This situation must remain a future ideal for many agroforestry systems, since external energy subsidies in the form of fossil fuels are very much a part of day-to-day operations. Nonetheless, Dasmann (1982: 216) suggests that such non-renewable resources 'should be used consciously to bridge a transition toward reliance on a sustainable supply, and thereafter used sparsely and wisely when supplies are limited'.

3.5 Classification of Agroforestry Systems

It is necessary to classify agroforestry systems for a number of reasons. First, there is the need to clarify and bring order to the phenomena in order to facilitate systematic study. This need is common to all scientific fields. Second, a classification is required to reduce confusion over 'what agroforestry is' (Vergara, 1985), and thus enhance international communications on the subject. Third, and of more immediate concern, is the need to provide a framework for evaluating agroforestry systems in order to develop action plans for their improvement (Nair, 1985).

Vergara (1985) outlines a classification which begins by dividing agroforestry systems into those based on (i) a temporal arrangement of crops (crop rotation systems) and (ii) a spatial arrangement of crops (intercropping systems). The former include 'swidden' or 'shifting cultivation' and 'taungya', and the latter 'border tree planting' (e.g. live fences, windbreaks), 'alternate row' and 'alternate strips' (e.g. alley cropping, hedgerow cropping), and 'random mix' (e.g. tropical homegardens). An attempt is then made to distinguish between 'agrosilviculture', where agricultural crops dominate over forest trees, and 'silvi-agriculture', where forest crops dominate, on the basis of the percentage of land allocated to agricultural and forest cropping. The livestock component is then considered and distinctions drawn between agrosilvicultural, agrosilvipastoral, and silvipastoral systems. The first representing a combination of agriculture and forestry, the second a combination of agricultural crops, forestry, and livestock, and the third, a combination of forestry and livestock.

This classification is somewhat unwieldy since three criteria, namely, temporal and spatial arrangement, percentage allocation of land, and combination of components (forestry, agriculture, livestock) are not combined into a single classificatory approach. In reality, this 'system' represents three kinds of classification, any one of which is incapable of including all forms of agroforestry.

A more comprehensive and coherent classification is outlined by Nair (1985). It is suggested that agroforestry systems can be grouped under four major criteria. These are:

(i) Structural basis; this refers to the composition of components, including the spatial admixture of the woody component, vertical stratification of the component mix and temporal arrangement of the different components.

(ii) Functional basis; refers to the major function or role of the system, mainly of the woody components. These can be productive, for example, production of food, fodder or fuelwood, or protective, for example, shelterbelts or soil conservation.

(iii) Socio-economic basis; this refers to the level of inputs of management (low or high) or intensity or scale of management, and commercial goals (subsistence, commercial or intermediate).

(iv) Ecological basis; refers to the environmental condition and ecological suitability of systems. This is based on the assumption that certain agroforestry systems are more appropriate than others for particular ecological conditions. Thus, agroforestry systems may be denoted as 'arid', 'semi-arid', 'tropical highlands', 'low-land humid tropics' etc.

As Nair (1985) points out no single criteria is universally applicable. It is therefore suggested that the first step is to make a preliminary categorization as either (i) agrisilvicultural (crops + trees), (ii) silvopastoral (pasture/livestock + trees), (iii) agrosilvopastoral (crops + pasture/livestock + trees), or (iv) other. The latter category includes specialized systems such as multipurpose tree lots. Then, each category can be subdivided according to any of the four criteria mentioned above. The first criteria, that is, 'structural', has of course already been partly specified by the preliminary categorization.

Agroforestry systems can then be distinguished as, for example 'silvopastoral system for cattle production in tropical savannas', and, 'agrisilvicultural system for soil conservation and food production in tropical highlands' (Nair, 1985). Examples of this kind of classification using all four criteria as given by Nair (1985: 116-125) are shown in Appendix 2.

3.6 Agroforestry in Australia

In Australia, grazing livestock in partially cleared forest has been a part of rural land use since European settlement. Borough (1979a; 1985) suggests that this can be regarded as an early form of agroforestry. The tree component providing shade and shelter for livestock, fencing and building materials, fuelwood, habitat for wildlife and aesthetic values. Similarly, the leasing of grazing rights for the use of native production forests has been practiced for many years and is in essence a form of agroforestry (Borough, 1985). In such situations, the livestock exert a beneficial effect through grazing and the concomitant reduction in fire hazard.

Land use practices involving a deliberate and carefully managed combination of forestry and agriculture are fairly recent developments in Australia, and constitutes the modern form of agroforestry (e.g. Woodruff, 1978). For the most part, the latter are represented by silvopastoral systems with productive functions dominant (see Costantoura, 1985; Reid and Wilson, 1985). These are commercial operations with wood and livestock (cattle and sheep) the principal products. However, in the early stages of plantation establishment it is not uncommon for crops to be cultivated while livestock are excluded (e.g. Reid and Wilson, 1985: 141-142). In these instances, agroforestry practice represents a progression from agrisilviculture to a silvopastoral system. Examples of the establishment of agrisilviculture as a final, rather than transitory agroforestry land use, while perhaps rare can nonetheless be found. The system shown in Plates 17 to 20 is an attempt to integrate tree crops (stone-fruits, citrus and nuts) with forest crops (woodlots for timber and fuel). Other components include vegetable crops, windbreaks, and bird-attracting plant assemblages. Domestic animals are completely excluded.

In regard to the more common form of agroforestry land use, that is, silvopastoral systems, two basic forms can be identified (Smethhurst, 1984).The distinction is drawn on the basis of the productive functions of the tree crop component, that is, non-timber or timber production. The combination of walnut trees and pasture/livestock is one of the few examples of the 'non-timber' category (see Hawley, 1977). In contrast, silvopastoral systems involving timber production appear to be common (see Reid

PLATE 17 (and 18): Agrisilviculture near Tanja, Bega Valley, N.S.W (see also Plates 19 and 20); windbreak plantings mark the perimeter of a small holding (approx. 15 acres) comprising woodlots, tree crops and annual crops. A newly established eucalypt plantation can be seen in Plate 18 (middle-ground, right-hand side).

PLATE 18:

PLATE 19: Fruit and nut trees (leafless trees in middle-ground) sheltered by windbreak; the low shrubs in the fore-ground (Chamaecytisus palmensis) will be continually pruned to provide a nitrogen-rich mulch for the tree crops.

PLATE 20: Red cedar (Toona australis) comprise part of the woodlot plantings; the three-year old, 1.5m tall specimens shown here are well-sheltered by the perimeter windbreak.

and Wilson, 1985), with poplars or pines (mainly Pinus radiata) typically comprising the tree component. Many other tree species are likely to be suitable for Australian silvopastoral systems. However, as Bartle (1979) points out, lack of information on likely performance is a major problem. Nonetheless, a number of tree species are currently under consideration (see Andersen, Harvey and Nicholson, 1984; Garthe, 1984; Powell and Master, 1984; Reid and Wilson, 1985; Ryan and Lewty, 1984).

3.7 Conclusion

Agroforestry is essentially an integration of forestry and agriculture, and as such is a land use practice having a long history. However, it is a relatively new field of scientific activity, which it is suggested can be coherently accommodated within the broader field of 'social forestry'. If social benefits are to accrue from agroforestry, and indeed, if it is to be accepted as a viable productive and protective land use option, there is a clear need to consider the socioeconomic circumstances of the rural population. In other words, agroforestry must be seen as more than simply a question of what is biophysically possible.

Throughout the world there are many land use practices which exhibit to a greater or lesser extent an integration of forestry and agriculture, and an array of terminologies have arisen to describe these. Nonetheless, the term 'agroforestry', broadly defined, is capable of accommodating such apparent diversity. The definition states that agroforestry is a collective name for land use systems and technologies where woody perennials are deliberately grown on the same land management unit as crops and/or animals. This may take the form of a spatial arrangement or temporal sequence. In either case, to qualify as 'agroforestry', there needs to be economic and ecological interactions between the woody and non-woody elements. This definition makes it difficult to maintain the often made distinction between 'farm forestry' and 'agroforestry'. It is suggested that farm forestry characterised by the use of shelterbelts is more properly considered as 'agroforestry'.

The notion that forests have functions other than production is recognized in the concept of agroforestry. In particular, conservation and sustainability are considered important aspects of agroforestry land use. Also, it is recognised that agroforestry has the potential to be a particularly productive form of land use. Total yields can be higher than that obtained in monocultures.

Major agroforestry systems can be identified as 'agrisilviculture' (crops + trees), 'silvopastoral' (pasture/animals + trees), and 'agrosilvopastoral' (crops + pasture/animals + trees). These terms essentially describe the structural nature of particular systems, and form the basis of a classification system which can also include functional, socio-economic and ecological criteria. In Australia, agroforestry systems are typically examples of silvopastoral systems orientated toward the production of timber and livestock.

Finally, it is clear that in both concept and practice agroforestry is a relatively sophisticated form of land use. In theory it has the potential to provide social benefits through the sustainable production of food and raw materials and the conservation of natural resources. To fully realize its potential and avoid costly mistakes careful design is necessary. This involves specifying the form of agroforestry elements within the context of particular landscapes, socioeconomic conditions and design goals. Before attempting to outline a design procedure to accomplish this, it is useful to first review some existing design approaches which are relevant to farm-scale agroforestry. This is done in the next chapter. Four procedures are explained and assessed against the concept of design and agroforestry land use as presented in the preceding Chapters.

CHAPTER FOUR

The Design of Agroforestry Systems: A Review

4.1 Introduction

This chapter is primarily concerned with the description and assessment of four approaches to the design of agroforestry systems at the farm scale. 'Design approaches' are identified where a series of well-defined steps are specified as a means of arriving at an arrangement of 'agroforestry elements' (e.g. trees, pasture, structures etc) within the landscape.

As discussed in the preceding chapter, agroforestry includes a wide range of land use practices described by a diverse array of terminology. It is not surprising, therefore, to find relevant design approaches under names other than 'agroforestry'. Two are discussed here, namely, 'forest farming', and 'permaculture' (Sec. 4.2.1 and 4.2.2 respectively). It is seen as necessary to first justify their inclusion as an 'approach to agroforestry design'. The third approach, suggested by Wilson and Reid (1985) to be applicable to agroforestry, represents little more than a summary of the 'whole farm planning concept'. Thus, the latter is outlined in detail to provide a fuller explanation (Sec. 4.2.3). The fourth approach has been devised by ICRAF specifically for agroforestry systems. Some brief comments are made regarding the major characteristics of this method (Sec. 4.2.4).

4.2 Four Approaches to Agroforestry Design

4.2.1 Forest Farming

Douglas and Hart (1978) have outlined a land-use system involving the integration of forestry and agriculture which aims to maximize yield and optimize conservation. The authors use the term 'forest farming' to describe the concept. Their ideas are clearly built on Smith's (1950;

1978) observations and suggestions regarding the use of tree-crops in agriculture, and represent a development of the earlier concept of 'three-dimensional forestry' (Douglas, 1967; 1968). A forest farm would consist of large belts or blocks of economic trees interspersed with narrower grazing strips of grasses or herbage. Livestock would be supported by both pasture and the cereal-substitutes harvested from the trees (Douglas and Hart, 1979:43). It is also suggested that crops could be raised within the plantation until the trees begin to yield (Douglas and Hart, 1978:79). Thus, 'forest farming' would initially represent an agrisilvi-culture system. At some point, when the trees are bearing produce and able to withstand grazing pressure, the introduction of livestock and the cessation of crop cultivation would mark the transition to a silvopastoral system.

Forest farming is considered to be 'three-dimensional'. First, trees are used as a source of timber, for soil conservation, and factors in climate amelioration. Second, trees are utilized as sources of fodder for livestock. Third, the livestock become available for sale or else produce goods for sale (e.g. milk, butter, meat). Therefore, 'forest farming' is presented as a silvopastoral system aimed at both conservation and production, the latter including timber, fodder and livestock.

The spatial arrangement of elements shows both horizontal and vertical integration, the former exhibited in the juxtaposition of tree plantations and pasture, and the latter by livestock grazing within plantations. Also, a temporal sequence of elements can be considered to characterize the initial developments with the transition from trees plus crops (agrisilviculture) to trees, pasture and livestock (silvopastoral).

Certain interactions could be expected to occur between elements. For example, the trees provide shelter and fodder for livestock and, in turn, animal manure is returned directly to the land as plant fertilizer (Douglas and Hart, 1978:43). Although Douglas and Hart (1978) suggest that the system would constitute a 'natural biological cycle', and thereby imply interactions between all elements in the system (including man), they do not specify how this would be achieved. Nonetheless, the system does exhibit an integration of trees, pasture and livestock in a particular spatial arrangement, and some degree of interaction between elements could be expected. Initial trials in southern Africa have shown some success (Douglas, 1967; 1968; Douglas and Hart, 1978) although Savill (1985) has severely criticised the concept on the basis that it is inapplicable to many parts of the world. On the basis of the available literature it is considered that 'forest farming' can be regarded as a form of 'agroforestry' as defined in Chapter 2.

Douglas and Hart (1978) suggest a four stage design process is applicable for forest farming at the farm scale:

(i) Initial survey and collection of information relevant to tree crops; the survey is divided into three major parts, (a) ecology, (b) economics, and (c) silviculture/pasture/livestock. The form of survey as suggested by Douglas and Hart (1978:60-62) is shown in Appendix 3.

(ii) Preparation of a base map; this shows property boundaries and main physical features

(iii) Identification of one or more 'focal-points'; the latter are "sites possessing such facilities as actual or potential water sources, convenience of ingress and egress and adjacent expansion zones, in other words, all the attributes that are commonly looked for in a centre of operations" (Douglas and Hart, 1978:50).

(iv) The preparation of a 'land usage' map; this shows the location of proposed forest blocks and belts, grazing and herbage strips, access roads and tracks, watering points and storage areas. This final stage represents a 'design proposal' prepared with regard to the preliminary survey and location of focal points, and could be shown as an overlay on the base map.

In the 'initial survey stage' of this procedure there is clearly an attempt to resolve the design context with reference to both biophysical and socioeconomic conditions. However, there appears to be an emphasis on the former, with the latter receiving a comparatively superficial treatment; economic factors (markets and costs) and 'situation' (locality, transport facilities) are considered only (see Appendix 3). Other factors which are of crucial importance but apparently neglected include labour availability, skills and expertise available, land tenure and land rights, current level of living[6], availability of government subsidies, and the availability of capital and equipment. In contrast, biophysical conditions are covered in much more detail; the nature of the existing natural vegetation and climatic, physiographic, edaphic, and biotic habitat factors require analysis (see Appendix 3). Clearly, this imbalance in the detailing of biophysical and socioeconomic factors will lead to difficulties in producing a clear resolution of the design

6. 'level of living' refers to the factual circumstances of well-being, the actual degree of satisfaction of needs and wants (see Knox, 1975:23-31). This is clearly important in determining whether production should have a subsistence or commercial orientation.

context, which, as suggested in Chapter 2, is a fundamental requirement of design. Moreover, it is not specified how a synthesis of information (biophysical and socioeconomic) is to be achieved. This is a major impediment to accomplishing early design stages as presented in the general model of the design process (see Fig. 2). In addition, there is no evaluation stage, and no statement of design goals. Both are of course important in systematic design procedures.

Overall, the design procedure as presented by Douglas and Hart (1978) would result in a less than comprehensive representation of the design context, and is therefore likely to also result in an inadequate design proposal, which, moreover, is not subject to systematic evaluation. Clearly, this procedure has a number of weaknesses which make it inappropriate as an approach to agroforestry design. Perhaps the most unsatisfactory aspect is the lack of emphasis on socioeconomic conditions. As pointed out in Chapter 3, agroforestry can be considered a form of 'social forestry'. This, along with the need to gain social acceptance for any proposed land use change, suggests that an analysis of socioeconomic circumstance should be given a high priority.

On the positive side, the 'identification of focal-points' is a useful stage which requires incorporation in an agroforestry design procedure. A recognition of points in the farm landscape which will make on-the-ground implementation more-or-less difficult is important in prioritizing developments, and should therefore be indicated on the design proposal. Also, focal points, sometimes called 'centres of development' in design terminology, can aid in the initial conception of the design proposal (see Wang, 1979).

4.2.2 Permaculture

Once again, some doubt might exist as to whether 'permaculture' is a form of agroforestry. Mollison and Holmgren (1978) use the term to describe their concept of a 'perennial' or 'permanent' agriculture. They define permaculture as 'an integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man' (Mollison and Holmgren, 1978:1). While the emphasis is on perennial plants the authors suggest that annual cultivation would also be an integral part of the system. The major aim of permaculture is to minimize maintenance input and maximize product yield (Mollison, 1980).

Perhaps the most comprehensive definition is provided by Permaculture Nambour (198:1). They state that permaculture is 'a permanent, self-sustaining system of agriculture, adaptable to both rural and urban situations, designed to produce an efficient, low-maintenance, optimally productive integration of trees, plants, animals, structures and human activities within specific environments, with ultimate goals of ecological stability and diversity in a system designed for conservation of soil, water, energy and all other natural resources'. This definition incorporates the notions of sustainability, production and conservation, and notifies that the integration of elements (trees, plants, animals etc) is central to the concept. In this, permaculture bears strong resemblance to agroforestry. However, unlike agroforestry, permaculture is suggested to be applicable to both urban (e.g. Ball, Jervis, Mansell and Okamoto, 1985) and rural situations.

Nonetheless, Reid and Wilson (1985) consider that permaculture can be comfortably accommodated under the aegis of 'agroforestry'. Design sketches of proposed permaculture plant assemblages show a vertical integration of food producing plants (see Mollison and Holmgren, 1978:30-31) closely resembling the 'tropical homegarden' form of agroforestry (see

Michon, Bompard, Hecketsweiler and Ducatillion, 1983; Fernandes and Nair, 1986). Similarly, sketch plans of a 'permaculture farm' at Marangba, Queensland (Honnef, 1986) shows the integration of trees, annual crops and livestock which is characteristic of 'tropical homegarden agroforestry'.

Clearly, permaculture, at least as applied in the rural context, can be considered a form of agroforestry. The integration of woody perennials with annual crops and livestock is central to the concept and concordant with the definition of agroforestry as previously noted (Sec. 3.3; Chap. 3). Moreover, Reid and Wilson (1985) regard the work of the Permaculture Institute (Stanley, Tasmania) as important to the future development of integrated farming systems. Similarly, Quinney (1984:54) indicates the potential importance of the concept: 'Although permaculture setups are still in the experimental stages, I believe that - with some modifications - these concepts form the backbone of a truly sustainable agriculture'. Recently, Cane and Stanley (1985) have suggested the permaculture concept as appropriate to land use in Central Australian desert regions. Permaculture may therefore be an important new development in agroforestry.

Mollison and Holmgren (1978:6-7) suggest that there are seven basic characteristics of a 'permaculture system'. These are:

(i) Small scale land-use patterns are possible.

(ii) Intensive, rather than extensive land-use patterns are intended.

(iii) Diversity in plant species, varieties, yield, microclimate and habitat are likely to be achieved.

(iv) Long term land-use is intended, possibly involving an evolutionary process spanning generations.

(v) Wild or little-selected species (plant and animal) are integral elements of the system.

(vi) Integration with agriculture, animal husbandry, extant forest management and animal cropping become possible, and landform engineering has a place.

(vii) Establishment on steep, rocky, marshy or marginal lands not suited to other systems is possible.

In practice, permaculture is envisaged as an agricultural system in which a large variety of plants, most of which are perennial, are placed in a pattern defined by zones and sectors. Placement in zones enables energy to be used efficiently within the system since those plant assemblages requiring frequent attention (e.g. the annual garden) are placed nearest the settlement centre, while low maintenance tree-crops are located in more remote zones. The concept is aimed at minimizing labour and reducing fossil-fuel inputs associated with transport to site by creating a spatial planting arrangement in which intensity of cultivation decreases as distance increases. Details of the characteristic activities within each zone are given by Mollison and Holmgren (1978:53-57). Plantings are summarized briefly in the following:

Zone 1: Intensive vegetable garden.

Zone 2: Dense planting comprising relatively few large trees but with complex understorey composed of small fruit trees and herb layer.

Zone 3: Fodder producing trees and shrub understorey with self-perpetuating herbage or pasture. Other plantings include hedgerows and windbreaks.

Zone 4: Tree culture and open pasture. Timber production is carried out in this zone.

Zone 5: Uncultivated native bushland.

Sector planning is then superimposed on the zonational arrangement enabling the system to contend with energies entering from outside, that is, sun, wind and fire. The landscape is divided into wedge-shaped areas which radiate from the settlement point. The sun sector is identified by reference to solar azimuth for the particular latitude, a wind sector by local wind rose data, and a fire sector by a combination of local knowledge, air photos and records of local authorities.

The placement of plant assemblages within each zone can then be considered with regard to the defined sectors. For example, fruit trees requiring maximum insolation are placed in the sun sector portion of Zone 2, protective shelter belts established in the wind sector portion of Zone 3, and timber production in Zone 4 preferably excluded from the fire-sector portion. Plants are not the only elements to be accounted for in this system, man-made structures and animals are similarly arranged according to the dictates of the 'zonal-sectoral' pattern.

The foregoing description clearly indicates that integration takes the form of a particular spatial arrangement. However, temporal sequences are not ruled out. Indeed, sequences analogous to successional trends in natural plant communities are suggested by Mollison and Holmgren (1978:29-34. An example is provided by Quinney (1984:57) in the form of a system incorporating beans, plums and walnut trees. The final crop, walnut, will eventually shade out the lower growing species which in the meantime provide income and some degree of protection for the young walnut trees.

The definition of agroforestry provided in Chapter 3 specifies interactions between the woody and non-woody components (see Sec. 3.3). Whether or not this is realized in permaculture systems is dependent to a large extent on design, and in particular, on the integration of plants within and between zones. 'Within-zone' integration may take the form of a combination of tree-legumes with pasture, with the aim of using the nitrogen-fixing characteristics of the trees to encourage pasture growth. 'Between-zone' integration is conceivable if, for example, tree-crops in Zone 2 are used to provide wind shelter for Zone 1 annual crops.

Thus, permaculture in its essential features can be considered a form of agroforestry and could be described as an agrosilvopastoral system (crops + pasture/animals + trees) for production and conservation. In the context of this thesis 'permaculture design' warrants investigation, since Mollison (1979:6) contends: 'If there is a single claim that I could make, in order to distinguish permaculture from other systems of agriculture, with the notable exception of keyline concepts[7] it is that permaculture is primarily a consciously designed agricultural system'. Quinney (1984:55) supports this view: 'The primary characteristic that distinguishes permaculture systems from conventional agriculture is the emphasis on skilled design. The placement of elements in a landscape, their relationships to each other, their evolution over time, and the ability of the system as a whole to meet the realistic goals of its managers should all be taken into consideration.'

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7. The keyline concept: the principal aim is to increase both the depth and fertility of soil. This is achieved primarily by the manipulation of overland water flows using storage dams and linking channels sited according to 'keylines'. The latter are identified by contour analysis. Full details given by Yeomans (1978).

Permaculture design has a number of basic aims. These are listed by Strange (1983:89-90) as follows:

(i) Emphasis on perennial rather than annual crops, with tree crops replacing annual crops for winter animal fodder and some human food.

(ii) High species diversity, often with close planting.

(iii) Combination of diverse activities, for example, gardening, commercial farming, grazing, poultry, aquaculture, water management, tree and shrub planting.

(iv) Use of small scale machinery and hand tools.

(v) Layout which minimises walking and transportation.

(vi) Recycling of all materials.

(vii) Use of three dimensional space by placing trees, shrubs, vines and low-growing plants in a multi-tier system.

(viii) Close relationship between land usage and climatic features and the location and design of buildings and their functions.

Quinney (1984) has outlined a six stage design process to achieve these aims:

(i) Define goals; this involves very specific statements related to time scale for developments, expected cash return, total capital outlay and man-hours per week involved. For example, over 'x' years, a net income of'y' dollars is required for 'z' man-hours per week with a capital outlay of $'y'_0$ dollars.

(ii) Identify resources; this includes a survey of on-site resources (soils, climate, water sources, topography, solar access, existing vegetation, microclimate, and geology) and identification of local or 'off-site' resources. These include animal wastes (as a source of fertilizer), the expertise of skilled farmers and tradespeople, and local markets. At this stage problem areas, such as eroded hillsides, swampy land and saline sites are identified. The goals as stated at stage(i) are then examined in the light of available resources and potential problems. In this way it is possible to ascertain the chances of attaining the desired goal. It may be necessary to reformulate goals or look for resources not initially recognized.

(iii) Functional analysis; at this stage landscape elements (settlement centres, roads and tracks, windbreaks, woodlots, tree/pasture systems, dams, plant nurseries) are considered in terms of the following:

(a) Inputs and outputs; each element should be located so that its inputs are provided and outputs used, (e.g. plant nurseries need to be located close to water sources and settlement, and adjacent to access routes to plant establishment sites).

(b) Integration; elements should be placed so that outputs from one become inputs to another with little or no labour or energy used in the transfer (e.g. siting water storage uphill of irrigation sites so that water can be 'gravity-fed' to the plantation site).

(c) Recognition of function; the potential functions of each element need to be clearly recognized (e.g. windbreaks can be used to produce fuel-wood and fodder as well as shelter crops and livestock). Recognition of all functions thus creates options for the placement of other elements.

After consideration of these factors it should be possible to produce a 'design proposal' showing location of the various elements. The spatial relationships between elements can then be re-examined, possible problems identified, and if necessary a new or modified design produced.

(iv) Species selection; this stage essentially involves the matching of required functions and site characteristics with species tolerances and characteristics. Management constraints need also be considered in the light of available resources (labour and money). The aim should be to minimize management requirements.

(v) Staging; this requires an implementation plan detailing a schedule for the establishment of the various elements. Clearly, the relationship between elements needs to be considered again. For example, in areas of high wind exposure, protection needs to be established before annual crops or orchard species.

(vi) Budgeting; at this stage budget estimates need to be prepared showing capital costs, annual operating costs, and expected returns.

This design procedure, like that reviewed in the preceding section, would appear somewhat deficient in resolving the design context. Although, at stage (ii), there is an attempt to consider both biophysical and socioeconomic conditions, it is apparent that biophysical factors receive relatively greater attention, while the consideration of socioeconomic factors is restricted to an analysis of available skills and local markets. This imbalance would be redressed to some extent by the formulation of design goals at stage (i), since if they are to be realistic socioeconomic factors need close examination. However, at stage (ii) it is implied that additional information be used to refine design goals.

Clearly, there would seem to be little additional socioeconomic data to facilitate goal assessment. It is not until stage (iv), after the design proposal has been produced, that socioeconomic conditions are considered again. Moreover, as for the 'forest farming' design approach (Sec. 4.2.1), there is no indication as to how a synthesis of socioeconomic and biophysical information is to be achieved.

In view of the above, there are clearly difficulties in the early design stages. The socioeconomic data, suggested in previous chapters to be an essential input into the resolution of a design context for agroforestry is inadequate, while the problem of synthesis appears not to be considered. Nonetheless, the 'functional analysis' stage is potentially useful in the context of agroforestry design, where the spatial arrangement of elements should be specified in such a way as to engender interaction. The latter is by definition a characteristic of agroforestry systems (see Sec. 3.3).

4.2.3 The Whole Farm Planning Concept

Reid and Wilson (1985:86-88) emphasise the need for farm-scale planning in the development of agroforestry systems. Design stages are given as:

(i) A 'whole farm inventory' involving the preparation of a property plan showing location of fences, dams, existing vegetation and problem areas etc.

(ii) A consideration of farm subdivision and an attempt to reorganize the farm into discrete management units based on soil type, topography, aspect etc.

(iii) A tree planting proposal roughly outlined as the establishment of native plants on the poorest sites, productive tree crops with pasture on marginal agricultural land, and a restricted high value tree component on the most productive land.

(iv) The development of an implementation plan involving consideration of costs in terms of both money and labour.

Clearly, these suggestions derive from the concept of 'whole farm planning', an approach developed as a response to land degradation rather than agroforestry *per se*. Various aspects of the concept have been outlined by Houghton (1984) and Stephen and Marshall (1986), but probably best developed under the aegis of the Potter Farmland Plan (see Campbell, 1986; 1987a). The design procedure is summarized as follows (Campbell, 1986):

(i) Farm layout is examined in the light of natural boundaries and particular management or degradation problems, and inappropriate subdivisions are modified to create a new layout which also takes into account access, land capability and fire protection.

(ii) Land use constraints are identified for each management unit, and a water supply strategy is prepared to complement the new layout.

(iii) A revegetation plan is devised. Erosion-prone, saline or discharge areas are excluded from stock and revegetated where appropriate, as are primary recharge zones where they can be identified, using combinations of trees and deep-rooted pastures. Shelterbelts, woodlots, clumps, natural regeneration and individual trees are located and linked to provide shade and shelter, wildlife habitat and farm wood supply in a pattern which is in harmony with the landscape.

In practice this design procedure involves four major stages (Campbell and Farrell, 1986; Campbell, 1987b). These are outlined briefly below:

(i) Preparation of a base map using air photos; a scale of 1:5,000 is suggested to show location of residence, sheds and other structures, fencelines, access tracks, power lines, water sources, firebreaks, and unused road reserves and other public land.

(ii) Farm analysis stage; using the base map and local knowledge management areas based on natural land systems are identified. This requires a consideration of soil types, recharge zones, natural drainage lines and ridge lines, and remnant native vegetation. Problem areas are also identified, for example, areas characterised by poor access, shallow or boggy soils, wind exposure, steep slopes, poor productivity, high salinity, soil erosion, poor water supply, frost pockets, or high fire danger. At this stage the farm can be divided into a number of classes based on 'land capability classification' (see Emery, 1986).

(iii) Development of whole farm plan; a new base map is prepared showing only the title boundaries, existing fences, buildings and drainage lines. A clear plastic sheet is then placed over the base map, and the 'whole farm plan' developed with reference to the information obtained in the previous stages. It is suggested to begin by examining the existing fence layout to ascertain its compatibility with natural management units and problem areas. The plan will show, for example, the location of new fences, areas of natural regeneration, areas to be direct seeded or planted, areas for general grazing or cropping, areas requiring contour cultivation etc.

(iv) Costing and implementation; a schedule of work is developed with regard to estimated expenditure and labour availability.

'Whole farm planning' is described in essentially the same form in Riemer (1986), Campbell (1987c), and Oates and Clarke (1987). Recently however, Heinjus (1987) has produced an outline of a procedure which appears more comprehensive than that described above. At present, it is in draft form only and subject to review (pers. comm., Heinjus, 1987). Thus, the following description is intended only as a brief indication of what is proposed. Heinjus (1987) suggests that the initial farm inventory should involve the production of separate map overlays for man-made features, natural features, and problem areas respectively. The 'whole farm plan' is then begun by first considering possible land use changes in the light of this inventory. Next, on the basis of the location of problem areas and changes to the existing land use, separate project areas are demarcated and given a priority ranking with respect to the stated tree-planting objectives. Socioeconomic constraints are then identified and priority areas re-examined to gauge feasibility. At this stage, project areas may need to be divided into smaller units to facilitate implementation. Consideration is then given to establishment techniques, site preparation, vermin control, maintenance, monitoring, and expenses. A noteable feature of the procedure is the use of checklists at each 'design stage' to ensure a systematic consideration of the numerous aspects relating to tree-planting. For example, the checklist of objectives includes seventeen potential functions of farm trees with numerous suggestions for possible applications. Functions include those related to production, protection, conservation, and environmental amenity.

While the specific design procedures associated with 'whole farm planning' vary somewhat between authors, the common aim is to produce designs which reflect both the potentials and constraints of the farm landscape in order to achieve a balance between production and protection/conservation. Map overlays and 'land capability classification' are commonly utilized to help achieve this aim. The former is a common method of analysis in landscape design and has a long history of use (see Steinitz, Parker and Jordon, 1976), and the latter a standard method of rural land assessment based on the biophysical attributes of the landscape, the extent to which these constrain certain kinds of land use, and the available land management technologies (see Emery, 1986). The use of both in the context of farmland design is well-illustrated in Teese (1985).

There are certain aspects of the use of overlays and land capability classification which have important implications for 'whole farm planning' as a design procedure. These need to be clearly recognized in order to judge the procedures worth in the context of agroforestry design. In the following, the use of overlays is considered first.

Map overlays are used to reduce the complexity of the farm landscape. This is done by selectively mapping individual features (eg. soils, vegetation) or groups of features (eg. man-made, natural). Essentially, this represents the breaking down of the landscape into its component parts, and as such is a simple form of 'analysis' (see Naveh and Liebermann, 1984). However, the inaccuracies inherent in overlay mapping (see MacDougall, 1975) make it inappropriate for the accurate delineation of land use and precise positioning of landscape elements. Thus, it is important to realize that a design proposal derived from overlays can only represent a rough positioning of land use and associated elements. In most instances, this is sufficient to produce a 'master plan' showing a general schematic layout. From this, detailed working plans are produced to facilitate implementation.

In lieu of detailed plans, considerable individual judgement may be required in the field to ensure the successful siting of particular tree species, and to delimit land use where environmental conditions change very gradually. These points are not sufficiently emphasised in the 'whole farm planning' methods. Generally, 'whole farm' plans represent master plans derived from overlays (eg. Campbell and Farrell, 1986), and are therefore difficult to translate directly to the field situation. Thus, in practice, the implementation stage would require considerable input from the designers themselves. Clearly, problems are likely to occur where resources do not permit the designer to be personally involved with on-the-ground planting/construction work. In these situations the plan needs to be clearly communicable to the contractor or landowner. Detailed working plans are the way to achieve this.

The other characteristic feature of 'whole farm planning' is the use of 'land capability classification'. This provides a systematic means of land assessment as a basis for developing the 'whole farm plan'. However, the 'land capability' approach was devised for agriculture (cultivation and grazing) and soil conservation rather than forestation. Where large scale tree-planting is envisaged, such as is likely to be the case in agroforestry projects, the approach is inappropriate since in the six classes of land designated as suitable for agriculture 'tree-growing capability' is not assessed (see Emery, 1986). Of the remaining two possible land classes, one is suggested as having potential for forestation. Even then, this is primarily for protection rather than production. As Young (1984a) points out, the implicit assumption is that agricultural use is to be preferred wherever possible. For these reasons, 'land evaluation' (see Chap. 5) has largely superceded land capability classification as a means of site selection in forestation projects (Young, 1984a). Even though tree-planting is integral to the 'whole farm planning' concept the land capability approach persists. There are possibly two main reasons for this, first, it is a relatively simple method of land assessment compared to land evaluation, and second, land capability maps are often already available at the farm-scale, or, the assistance needed to compile such maps is fairly readily obtainable (eg. Soil Conservation Service of N.S.W.).

It should also be noted that land capability classification, to a large extent, ignores socioeconomic factors (Gelens, 1984). Other than the understanding which is implicit in the consideration of current management technologies (see Emergy, 1986), there is no facility to comprehensively incorporate socioeconomic data into the assessment procedure. This partially accounts for the lack of emphasis on the socioeconomic setting in 'whole farm planning'. Aside from consideration at the 'costing and implementation' stage (eg. Campbell and Farrell, 1986), or during the identification of constraints on project implementation (eg. Heinjus, 1987), socioeconomic factors receive little attention. This is not to say that the 'whole farm' designers know nothing of the socioeconomic setting in which they work, undoubtedly much information would be gained during the course of routine biophysical investigations and informal discussions with landowners. However, the 'whole farm' approach as presented in the literature does not appear to recognize that a clear recognition of the design context requires a synthesis of both biophysical and socioeconomic data before the design proposal is developed (see Fig. 2). This shortcoming may not be a significant hindrance to developing workable plans to address land degradation, however, in the context of agroforestry, where design problems are more complex, a lack of socioeconomic data is likely to result in unrealistic design proposals.

4.2.4 Diagnosis and Design Methodology

Raintree and Young (1983) have devised a comprehensive design procedure for agroforestry systems. In general, the aim of their 'Diagnosis and Design Methodology' is to produce designs characterised by productivity, sustainability and adoptability. While productivity with sustainability is clearly a desirable attribute, and indeed is widely recognized as a potential benefit of agroforestry (e.g. King, 1979b; Vergara, 1985; Reid and Wilson, 1985), 'adoptability' is often overlooked. However, it is a particularly important aspect, since, as Raintree (1984:258) points out, 'no technology, no matter how efficient or elegant it may be, will have an appreciable impact on the landscape unless it is adopted by a significant percentage of the intended users'.

The procedure is a 'diagnostic' approach to design in the sense that initially emphasis is placed on defining the problems and potentialities of the existing land-use system. On this basis design specifications are derived to address specific problems and capitalise on the system's potential. The analysis of constraints and potentials, as they apply to both the existing land-use system and the candidate technologies, is central to the approach (Raintree, 1984). The methodology can focus on the farm level or at a larger scale (e.g. a catchment) where significant problems and potentials for agroforestry may exist but not be approachable at the farm scale.

The 'Diagnosis and Design' method can be considered as having four main stages, namely, 'prediagnosis', 'diagnosis', 'technology design', and 'follow-up planning'. The basic questions and key factors to consider are summarized in Table 2, and the sequence of steps required to arrive at each design stage and the major factors to consider at each step are noted briefly in Appendix 4. The reader is referred to Raintree and Young (1983) and Raintree (1984; 1987) for a more detailed account.

Table 2 indicates the broad scope of the procedure. Agroforestry design is seen to be concerned not only with the 'specification of the form of landscape elements' (see Sec. 2.5; Chap. 2), expressed in the 'technology design stage' as the location and spatial arrangement of components and their combinations (see Step 8; Appendix 4), but also with the viability of the candidate land use technologies. The methodology does not assume such technologies are known and proven. Thus, much effort may be directed towards specifying research to develop and test agroforestry practices appropriate to the given socioeconomic and biophysical conditions. As Young (1984b:20) points out, 'diagnosis and design is directed towards designing a research programme that will, if successful, be capable of implementation in land use planning. It is true that parts of a D&D report may give the impression of being a project plan, but this is because of its requirement that a viable land use design, capable of being implemented by the farmers, should be formulated as a basis for design of research'. In the context of this thesis, agroforestry design is orientated towards direct implementation (see Fig. 2) rather than research. The latter is considered primarily the domain of the technical and decision-making components of planning (see Fig. 1). While the 'Diagnosis and Design' methodology does make provision for direct implementation if the land use technologies are proven (Young, 1984b), the scope of activities and emphasis on delineating research requirements suggests a concept of design somewhat broader than that outlined in Chapter 2. Indeed, 'design' appears to take on the wider range of concerns normally

TABLE 2. Summary of questions and factors to consider in 'Diagnosis and Design'.

Design Stage	Basic Questions	Key Factors
Prediagnosis	definition and selection of the focal land use system; how does the system work?	distinctive combinations of resources, technology and land user objectives; production objectives and strategies
Diagnosis	how well does the system work?	problems in meeting system objectives; casual factors, constraints and intervention points.
Technology design	how to improve the system?	specification for problem-solving or performance enhancing interventions.
Follow-up planning	what to do to develop and disseminate system improvements; how to adjust the plan of action to new information?	research and development needs, extension needs; feedback from field trials.

Adapted from Raintree (1987)

associated with 'planning' (see Sec. 2.2).

4.3 Conclusion

Four design approaches relevant to agroforestry at the farm-scale have been described. The first three, namely, those pertaining to 'forest farming', 'permaculture', and 'whole farm planning', are concluded to be unsatisfactory for agroforestry, since all fail to resolve the design context in the comprehensive manner suggested in Chapter 2. Two main problems are evident in this regard. First, there is insufficient emphasis on the analysis of socioeconomic conditions, which is all the more serious given their importance in the acceptance and successful establishment of agroforestry systems. As pointed out in Chapter 3, agroforestry land use is much more than simply a question of biophysical possibilities. The second major problem concerns the synthesis of biophysical and socioeconomic information, suggested in Chapter 2 as necessary in the preliminary design stages, but neglected in these approaches.

Furthermore, in regard to biophysical factors, only one of the three approaches, namely, 'whole farm planning', appears to approach the problem of land assessment in a systematic way. Even then, the 'land capability' approach which is adopted has serious deficiencies in the context of agroforestry, the most obvious being that the approach does not differentiate land on the basis of its' suitability for forestation. In addition, the use of map overlays as a method of analysis, while commonly used in design, does have drawbacks in regard to the accurate specification of form. While this may not have become apparent in the context of 'whole farm planning', it needs to be recognized in agroforestry design that the general schematic layout, or 'master plan', which can be produced from overlays is generally an unsatisfactory specification for on-the-ground implementation. Nonetheless, the use of overlays in 'whole farm planning' is at least a systematic approach to analysis, which, in both the 'forest farming' and 'permaculture' approaches is conspicuously absent.

The fourth design approach reviewed, namely, the 'Diagnosis and Design' methodology, was devised specifically for agroforestry system. However, given the concept of design as developed in Chapter 2, it is clear that this procedure represents a total landscape planning approach rather than a design procedure *per se*. Indeed, there is still a need within the 'Diagnosis and Design' framework for a design procedure as understood in the context of this thesis.

Thus, in the following chapter an attempt is made to outline such a procedure. This will need to develop in more detail the general design procedure established in Chapter 2, and take into consideration the major features of agroforestry land use as analysed in Chapter 3. In particular, there is a need to incorporate a systematic approach to resolving the design context, which, as pointed out in the foregoing review is a major deficiency in some of the existing design approaches. Nonetheless, some aspects of the latter have been identified as potentially useful in agroforestry design. These are the 'identification of focal points' and 'functional analysis'. Both are incorporated in the design procedure developed in the following.

CHAPTER FIVE

A Framework for Agroforestry Design

5.1 Introduction

In the preceding chapters the landscape design process has been outlined and suggested as a model for agroforestry design, the concept and practice of agroforestry has been discussed, and a number of design approaches reviewed. It is now possible to be more precise about the nature of agroforestry design. First, general design implications are drawn in the light of the preceding discussion (Sec. 5.2), and second, the question of what is required to 'specify the form of landscape elements which are visually, ecologically and functionally appropriate within the context of particular landscapes, socioeconomic conditions and design goals' is addressed with particular reference to farm-scale agroforestry; the design context (socioeconomic and biophysical conditions, design goals, and the role of 'land evaluation' in the research-analysis-synthesis sequence), visual, functional, and ecological 'appropriateness', and the 'specification of form' are discussed in Secs. 5.3, 5.4 and 5.5 respectively. Finally, an agroforestry design procedure is proposed and outlined (Sec. 5.6). This represents an elaboration of the general landscape design procedure established in Chapter 2, and incorporates a systematic approach to 'land evaluation'. The latter is seen as a satisfactory way to resolve the design context.

As pointed out in Chapter 2, it is difficult in the early and late stages of the design process to clearly distinguish between 'design', 'technical', and 'decision-making' activities (see Sec. 2.4). For example, the land evaluation procedure outlined in the following (Sec. 5.3.4), could be considered as part of the technical component of landscape planning (see Fig. 1). However, it is detailed here for the reason that it is the kind of work which designers will often be engaged in (see McHarg, 1969; Lyle, 1985a). Indeed, it is highly desirable that they are involved, in order to gain an intimate familiarity with the design context. This is a necessary prerequisite for good design. Similarly, design goal formulation could be considered as 'decision-making' rather than 'design' (see Fig. 1), nonetheless, input from the designer(s) is likely, particularly at the stage where specific design goals are required. For this reason, agroforestry design goals are discussed in Sec. 5.3.3.

However, the evaluation of the design proposal (see Fig. 2), unlike land evaluation and design goal formulation, will in most situations be outside the province of 'design'. Where a landscape planning framework is operational, evaluation will be the concern of the 'decision-making' component (see Sec. 2.2), or, in less formal circumstances, it will be a matter for the client (individual landowner, farmers group, village community etc.) to resolve. In general, the aim should be to assess first, how well the design proposal matches the design context, and second, the likelihood of the design goals being achieved. Conceptually, this requires that evaluatory criteria reflect visual, functional, and ecological 'appropriateness' (see Sec. 5.4), and specified design goals. Although the 'evaluation stage' is not further discussed, it is noted in the proposed agroforestry design procedure (Figs. 6 and 7). This is intended to underscore the necessity for evaluation, rather than imply that it is 'design' as understood in this thesis.

5.2 Agroforestry Concept and Practice: General Implications for Design

In Chapter 3 a number of points have been made in relation to the concept and practice of agroforestry. These are listed below with the implications which must follow for agroforestry design.

(i) Agroforestry involves the integration of forestry and agriculture; it follows that the design process must have the capacity to incorporate information from a variety of sources pertaining to the biophysical and socioeconomic aspects of both forestry and agriculture. The requirement that design should draw on diverse disciplines is well-established for landscape design in general, and the extent to which a design process is capable of doing this is suggested by Lyle (1985b) to be one criteria by which its' effectiveness can be judged.

(ii) Agroforestry can be considered within the context of 'social forestry'; an understanding of socioeconomic conditions is clearly a prerequisite in any attempt to provide social benefits to rural populations. Thus, the design process must be capable of accommodating socioeconomic data and information, and in the light of this, formulating design goals in accord with community needs. This is particularly important if the design proposal is to gain acceptance and have any chance of successful implementation. In other words, the proposal must be 'adoptable' by the farmers in question. 'Adoptability' is regarded as one of the criteria for good agroforestry design (Raintree, 1984), and, it is suggested here, is likely to be achieved by giving close attention to socioeconomic conditions. Consideration of the latter flows naturally from a 'social forestry view' of agroforestry.

(iii) Agroforestry covers a diversity of land use practices; while all agroforestry systems represent some form of integration of forestry and agriculture, they differ considerably in the detailed patterning of elements. This will occur not only across the major systems, namely agrisilvicultural, silvopastoral, and agrosilvopastoral, but also within any one system as a result of differing social needs and variations in landscape constraints and opportunities. Design procedures applicable to a wide variety of situations are therefore required. This necessitates, in the first instance, a broad design framework within which more specific statements relating to, for example, 'agrisilviculture design', can be developed. Further refinements could then lead to particular methodologies following the already established classificatory framework (see Sec. 3.5). Thus, methodologies for 'silvopastoral design for cattle production in tropical savannas', or 'agrisilvicultural design for soil conservation and food production in tropical highlands', could be developed.

(iv) Agroforestry is characterised by ecologic and economic interactions between the woody (trees) and non-woody (crops, pasture livestock) elements; agroforestry design must be concerned to create beneficial interactions between elements. As Lyle (1978 :7) points out, 'For designers, a key to shaping an ecosystem is to define the elements and predict the interactions. Design is, to some degree, a search for mutually beneficial, or symbiotic, interactions'. This comment is clearly pertinent to agroforestry design. Studies of 'tree/crop interfaces' (see Huxley, 1985b), for example, are required to provide the information necessary to produce design guidelines.

(v) Agroforestry is concerned with conservation and sustainable production; recent press comment in Australia associated with the bicentennial of settlement has suggested that many agricultural areas will not sustain productivity for a further two hundred years. In regard to intensive forestry, loss of production has been shown to occur in some situations (e.g. Keeves, 1966). While Dasmann (1985:214) suggests that sustainability 'appeals most to people who see some continuity with the past and future', and who therefore have 'a sense of stewardship over the lands they occupy and the resources they use', all land users have a vested interest in conserving the lands' productivity. Nonetheless, differences of opinion occur as to the time period over which 'sustainability' is thought important. For agroforestry, long-term sustainability (centuries rather than decades) should be a major concern. Indeed, agroforestry can be seen as a means of redressing some of the problems resulting from short-term, exploitative land use (see Chap. 3). As noted in Sec. 3.4, sustainability is ultimately dependant on eliminating the use of non-renewable resources. For many land use systems this must be regarded as virtually impossible without incurring substantial production losses. From a practical viewpoint, it is more useful to consider sustainable land use as the continued use of land without severe and/or permanent deterioration in the qualities of the land (FAO, 1976). The first step in achieving this involves soil and water conservation, directed towards maintaining (and enhancing) land qualities such as soil moisture and nutrients, resistance to erosion, and water quality and quantity. These qualities relate directly to the productivity of crops, trees and livestock (see FAO, 1976:13), and thus, as the FAO (1985:24) point out, 'the conservation (long-term benefits) versus production (short-term benefits) dichotomy is a false one. Production is related to conservation and vice versa; they are not independent of each other'. Hence, conservation and sustainable production are inextricably intertwined. Eventually, they must become the concern of land management, nonetheless, the design proposal must provide the opportunity for their realization. This can be done by 'specifying form' which is functionally and ecologically appropriate within the design context. These aspects are discussed in Secs. 5.4.2 and 5.4.3 respectively.

5.3 The Design Context

It has been suggested that the 'design context' is set by biophysical and socioeconomic conditions, and specified design goals (see Sec. 2.4). The definition of the design context is of fundamental importance, since it has direct bearing on the quality of the design proposal. However, as Vink (1983: 230-231) notes, 'It is a major problem to find suitable methods for the effective use of basic research data and their interpretations in the designs'. This problem can be largely resolved within the 'land evaluation' framework proposed by the F.A.O. (1976), which, in the context of this thesis, is seen as a systematic and comprehensive way to accomplish the research, analysis and synthesis stages of design which is required to resolve the design context (see Fig. 2). Its' incorporation within an agroforestry design procedure is one of the major objectives of this thesis (see Sec. 1.2). This needs to be achieved in order to redress some of the unsatisfactory aspects of the design procedures reviewed in Chapter 4, in particular, their failure to clearly resolve the design context as a result of insufficient attention to socioeconomic conditions and incapacity to synthesize data and information (biophysical and socio-economic).

Land evaluation and its' role in the research-analysis-synthesis sequence is, therefore, of considerable importance and is discussed in some depth in Sec. 5.3.4. This follows some general comments on the three major components which define the design context, namely, socioeconomic conditions, biophysical conditions, and design goals. (Secs. 5.3.1, 5.3.2 and 5.3.3 respectively). For the first two, a form of primary survey is suggested. This would represent an 'analysis of the general situation', which is a part of the 'initial consultations' stage of the land evaluation procedure (see Fig. 3).

5.3.1 Socioeconomic Conditions

As indicated in the preceding chapter, agroforestry systems are found at many locations throughout the world, in both developed and lesser developed countries. It is therefore difficult to generalize about the kind of socioeconomic settings which might be conducive to agroforestry land use. Nonetheless, it would be correct to say that the first requirement must be a perception that agroforestry is a viable land use option. In the Australian context, Borough (cited Reid and Wilson, 1895:11) suggests that uncertainties about economic viability, perceived complexities of management, and the attitudes and apprehensions of landowners and government workers, are factors hindering the realization of the potential of agroforestry. Undoubtedly, there are considerable social barriers to land use change (see McTaggart, 1979). For these sorts of reasons, several authors (Lucas and Linden, 1970; Tustin and Knowles, 1975; Glencross, 1979) regard the integration of forestry and agriculture as more a socioeconomic than biological problem.

Therefore, there is a clear need for a consideration of socioeconomic conditions in agroforestry design. This requirement is further emphasised if agroforestry is to be considered an effective form of social forestry. Aside from the landowners perception of agroforestry and attitudes to land use change, which obviously must be favourable to allow the design process to proceed, the following socioeconomic aspects need consideration in order to resolve the design context:

- potential demand for agroforestry products
- location of markets
- economic infrastructure (eg. roads, services)
- basis of present farm economy
- labour availability and current wage rates
- skills and expertise available
- general level of costs and prices
- land tenure and land rights
- current level of living (ie. the factual circumstances of well-being, the actual degree of satisfaction of needs and wants; see Knox, 1975:23-31)
- availability of government subsidies
- availability of capital and equipment.

5.3.2 <u>Biophysical Conditions</u>

Biophysical conditions can be described in terms of nine major components, namely, climate, geology, landforms, hydrology, soils, vegetation, fauna, disease, and land use. While all are relevant to agroforestry, they can nonetheless be grouped in a rough order of relative importance as, first, climate and soils, second, landform, hydrology, vegetation, fauna and disease, and third, geology and land use (Young, 1985). To these, the fundamental considerations of location, and level of environmental degradation should be added. The former is clearly of first order importance, and while the latter is undoubtedly of special significance to agroforestry (see Sec. 3.2) it cannot readily be assigned a category of importance, since its' relevance is dependent on the degree of degradation and the type of agroforestry system (i.e. its structure and function; see Sec. 3.5) which is envisaged.

Clearly, there are numerous ways (classifications, descriptive terms etc.) to describe each of these biophysical components. It is suggested that the guidelines presented in ICRAF's 'Environmental Data Base for Agroforestry' (Young, 1985) be utilized to achieve some kind of uniformity in the collection and presentation of such data and information, and thereby enhance international communication on the wide variety of design contexts in which agroforestry systems may be set. The environmental data base consists of 'an identified set of environmental variables, and classification systems, by which to describe the conditions of a site or area ...' (Young, 1987), and contains information in greatest detail on climate and soils, moderate detail on landforms (especially slope), hydrology (especially drainage and depth to water table), vegetation, fauna, and disease, and the summary features of geology and land use (see Young, 1985; 1987). Location, in terms of latitude and longitude, distance and direction from major population centres, and elevation above sea-level is included, along with comments on environmental degradation in relation to hydrology, soils and vegetation.

Three levels of detail are provided within the data base, namely, a summary level, an intermediate level (level 1), and a detailed level (level 2). This is intended to meet the requirements of different users.

For example, at the summary level, climate would be classified according to the Koppen system (for Australia, see Gentilli, 1977:29; Linacre and Hobbs, 1977; for a world summary, see Marsh and Dozier, 1981:129-137), at level 1, detail on rainfall regime, annual temperature, annual rainfall, number of dry months, and altitudinal zone is added, and at level 2, the description is expanded to include mean monthly rainfalls, temperature of hottest and coldest months, rainfall for driest month, frost incidence, mean annual Eo (open-water evaporation), humidity index, and growing period (see Young, 1985). Much of the detail at levels 1 and 2 can be summarized in an 'ecological climate diagram' (see Walter, 1979:25-30). Such diagrams are particularly useful in identifying homoclimes, and thus aid in the selection of potential agroforestry species.

It is not possible to describe here the detail required for the other components. However, the general form of the survey is shown in Appendix 5, and the reader is referred to Young (1985) for a detailed explanation. Suffice to say that the ICRAF 'agroforestry data base' provides a useful form of primary survey, which is a necessary background for the more detailed farm-scale analysis as facilitated by land evaluation. Conceptually, the latter provides the 'level 3' detail required for design (Young, 1985). However, at this early stage in the design process the aim should be to provide the designer with a broad understanding of biophysical conditions, which, together with the aforementioned socioeconomic information, should resolve the design context to the extent where the refinement of design goals becomes possible.

5.3.3 Design Goals

A statement of goals needs to be provided at the beginning of the design process. These are framed with reference to biophysical and socioeconomic conditions, and, as more information becomes available during the research-analysis-synthesis sequence some refinements may be necessary. The statement of design goals aids in the resolution of the design context and contributes to the development of evaluatory criteria (see Fig. 2).

As indicated in Chapter 3, agroforestry systems are potentialy suitable for a wide range of biophysical and socioeconomic conditions. Therefore, in the context of this thesis, design goals can be stated in general form only. Nonetheless, this will serve to illustrate the various aspects which more specific goal statements would need to address.

It is suggested that general design goals should include social value, productivity, stability, sustainability, equitability, and adoptability. Increased social value is a primary goal of all agroecosystems[8] (Conway, 1987), and is coherent with the concept of agroforestry as a form of social forestry. It is achieved by combining different levels of productivity, stability, sustainability and equitability (see Conway, 1987), and thus, these may also be considered as design goals which need to be attained to promote increased social value. To these, 'adoptability' (see Raintree, 1984) should also be added, since unless the design proposal is adopted by the farmers in question its' impact on social value is zero.

Thus, increased social value can be considered as the main goal of agroforestry design. It is attained through a number of 'secondary goals', which include productivity, stability, sustainability, equitability, and adoptability. Each is examined in more detail in the following:

8. Agroecosystems are ecological systems modified by human beings to produce food, fibre or other agricultural products (Conway, 1987:95); agroforestry, although also concerned with forest products (eg. timber), can be regarded as a particular type of agroecosystem.

(i) Social value; this, as Conway (1987:100) notes, 'is a function of the amount of goods and services produced by the agroecosystem, their relationship to human needs and their allocation among the human population'. Clearly, 'social value' requires considerable specification to be of much practical value as a design goal. In the first instance, it needs to be considered in relation to an identified sub-set of the rural population-at-large[9], distinctions drawn between 'needs' and 'wants' of that population (see Smith 1977:27-31), and judgements made as to an appropriate distribution of goods and services. As pointed out previously, design goals are framed and progressively refined in the light of biophysical and socioeconomic conditions. In regard to the latter, the determination of 'level of living' (see Sec. 5.3.1) will be of considerable aid in refining the 'social value' goal, since the various components of basic needs such as nutrition, shelter and health, will have been identified (see Knox, 1975:26; Smith, 1977:36). Similarly, the initial biophysical survey will contribute to specifying social value. For example, it may be that environmental degradation is of such severity that an increase in human nutritional levels through increased food production is simply unrealistic.

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9. In the context of farm-scale agroforestry design, 'social value' must be considered primarily in relation to the landowner, dependents, and on-farm workers. However, it is not unreasonable to expect that increases in social value would produce benefits for other sectors of the rural population, for example, those engaged in seasonal work or supporting rural services.

(ii) Productivity; this is regarded as one of the criteria of good agroforestry design (Raintree, 1984), and for agroecosystems in general, is a key system property which contributes directly to the goal of social value (Conway, 1987). Productivity can be defined as the output of valued product per unit of resource input (Conway, 1987). The latter include land, labour, capital, technology and energy. As for social value, productivity goals can be specified more closely, for example, in terms of yield or income per hectare, as information becomes available from the initial surveys and subsequent research and analysis.

(iii) Stability; this refers to 'constancy of productivity in the face of small disturbing forces arising from the normal fluctuations and cycles in the surrounding environment' (Conway, 1987), and like (ii) above relates directly to 'social value'. Over time, productivity may remain static, rise or fall. The system can be regarded as stable if rises counterbalance falls. As a design goal, stability can be engendered by diversification in production; since fluctuations are commonly a result of climatic variability and/or changes in market demand, a range of products, each with slightly different environmental requirements (within the limitations imposed by the overall ecological situation) and consumer demand potential, creates a situation where 'constancy of productivity' is more likely than with a single product system.

(iv) Sustainability; like 'productivity,' Raintree (1984) regards 'sustainability' as a major aim of agroforestry design. It is defined by Conway (1987:101) as 'the ability of an agroecosystem to maintain productivity when subject to a major disturbing force'. The latter may include soil salinity and erosion, declining market demand, rare prolonged drought, major floods, or a sudden rise in oil prices. Design for sustainable production is best approached by conservative land use practices aimed at maintaining soil fertility and water quality and quantity. This will promote sustainable land use, and thus contribute to long-term sustainable production. However, as pointed out in Sec. 3.4, sustainability can ultimately only be achieved by relying on renewable resources, even then, low frequency-high magnitude environmental perturbations are likely to influence the sustainability of land use systems of whatever kind. Thus, as a design goal, sustainability is more usefully defined as the 'continuing use of land without severe and/or permanent deterioration in the qualities of the land' (see Sec. 5.2).

(iv) Equitability; this is defined as 'the evenness of distribution of the productivity of the agroecosystem among the human beneficiaries' (Conway, 1987:102). The latter may be a farm household, a village community, or a national population, and ideally, 'evenness of distribution' is judged according to need. This is less useful than the aforementioned as a design goal. Although it clearly has direct bearing on the primary goal of increased social value, it is difficult to envisage how design could influence 'equitability', other than through increasing productivity, and thus, providing the basis for its' attainment. Nonetheless, it is included here because if design is set with an overall landscape planning framework, distributional problems will become an issue for the 'decision-making' component, and at the larger-than-farm scale (eg. the catchment) may determine design priorities.

(v) Adoptability; this means that the design proposal is able to be implemented, given biophysical and socioeconomic conditions. This goal can be achieved by the designer(s) acquiring a close familiarity with the design context, and framing the design proposal within its' constraints and potentials. As pointed out previously a thorough understanding of socioeconomic factors is essential, but is often overlooked in design procedures which emphasise biophysical possibilities (see Chap.4).

5.3.4 Research-Analysis-Synthesis: The Role of Land Evaluation

The definition of the design context involves research, analysis and synthesis of biophysical and socioeconomic data and information (see Fig. 2). The form of a primary survey has already been suggested in the preceding sections. However, beyond this, there is a need to provide more detailed information to bring the design context into sharper focus. Two problems are immediately apparent. The first concerns the selection of site-specific data relevant to agroforestry at the farm-scale, and the second, the means by which a useful synthesis is to be achieved. In regard to the first, it is clearly necessary to have some guidelines to direct data collection in a time-efficient manner towards clarifying the design context. This is particularly important where resources are available for the collection of primary data. Clearly, it is possible to place severe limitations on the time available for production of the design proposal by collecting too much detail in the research and analysis phase. In practice, the solution to this kind of problem is usually provided, *de facto* , by the work schedule. Simply stated, there comes a time where research and analysis must stop and the job of synthesis and design begin. Reiteration is of course possible as data deficiencies are revealed during the process of producing the design proposal. However, such deficiencies may not become apparent until the evaluation stage (see Fig. 2). While it is unrealistic to suggest that this can always be avoided, it is possible to minimize the time spent in reiteration by carefully considering the relevance of the data and information to be collected.

Once the relevant information is selected and analysed a clear resolution of the design context is largely dependent on the method of synthesis. The latter essentially involves producing a composite picture of the total farm environment. In practice this means compiling a map or series of maps from which the design proposal can be developed. Clearly, it is possible to lose much detail in an attempt to condense diverse information into a mappable form.

Thus, in view of the above, there is clear need for a systematic and comprehensive method for selecting and synthesising information relevant to farm-scale agroforestry. Such a method should first, be adaptable to farm-scale agroforestry, second, incorporate both biophysical and socioeconomic data, third, provide a synthesis of relevant information in a mappable form, and fourth, indicate land use options and thereby provide a starting point for the generation of design alternatives. It is suggested here that 'land evaluation' satisfies these requirements and is therefore outlined in detail in the following.

(a) Fundamentals of land evaluation

Mabbutt (1968:11) suggests that the term 'land' denotes 'a complex of surface and near-surface attributes significant to man', and that these attributes 'vary individually and in relation to each other to give local character'. Identifying, recording and establishing the extent of such character is 'land classification', which when applied in the context of land use planning is commonly termed 'land evaluation' (eg. Vink, 1983). Laughlin, Basinski and Cocks (1981) state that land evaluation aims to help answer three basic questions. These are first, what is the 'best' use for a particular land portion, second, what is the 'best' land portion for a particular use, and third, what is the 'best' management for both land and land use. Land evaluation, by 'assessing the consequences of using land with given physical and biological characteristics for a particular purpose or purposes' (Laughlin *et al.*, 1981:1), addresses these questions and thereby aids in the rational determination of land use. In practice, this generally involves the production of some kind of land suitability classification.

Various methods have been devised to evaluate landscape with respect to proposed uses for the purpose of suitability classification (see Weddle, 1973; Laughlin *et al*, 1981). Perhaps the best known of these is the so-called 'land suitability assessment' developed by McHarg (1969). Other well-known methods, often utilized in design work, include 'sieve mapping' and the 'land unit approach' (Lyle, 1985a). The latter, which involves dividing the landscape into a number of roughly homogeneous portions and then assessing each with respect to the proposed uses, has in recent years become more-or-less synonomous with 'land evaluation'.

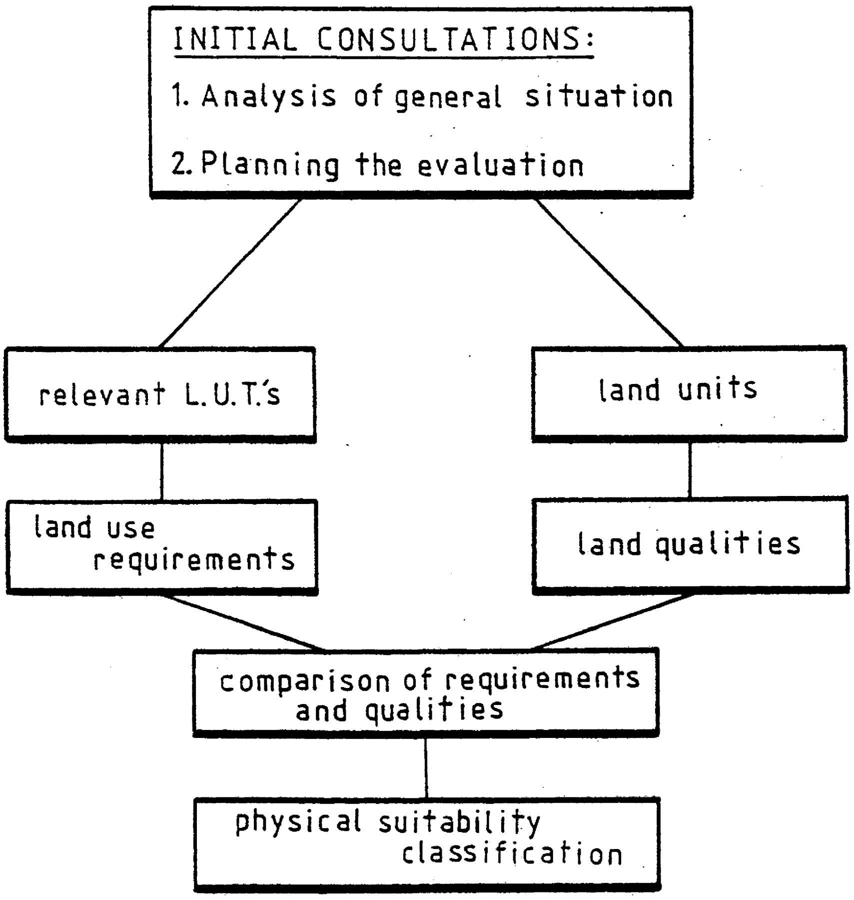
Gelens (1984) suggests that land evaluation, as a 'land unit approach', can be applied at three levels of detail. These are, (i) the reconnaissance level, (ii) the semi-detailed level, and (iii) the detailed level. At the reconnaissance level, and to a lesser extent at the semi-detailed level, major kinds of land use (eg. forestry and agriculture) are assessed with respect to broadly defined landscape units. At the detailed level, the land portions studied show a relatively greater degree of homogeneity, and land use is more narrowly defined, for example, in terms of different kinds of forestation (timber production, fuelwood production, protective forestation etc.). This is the appropriate level of detail for farm-scale agroforestry.

Two main approaches to land evaluation can be identified, namely, general-purpose land evaluation and specific-purpose evaluation (Gelens, 1984). The first evaluates land with respect to a generally defined use (eg. land suitability classification; see Sec. 4.2.3). The kind of land use is not directly questioned and alternative land uses are not considered. Furthermore, socioeconomic factors are neglected. In contrast, specific-purpose evaluation considers land use options (and thus socioeconomic factors) as well as the land itself. Thus, this second approach is an appropriate way to define the agroforestry design context since both biophysical and socioeconomic factors are considered.

(b) F.A.O. land evaluation procedure

The land evaluation procedure as presented by the F.A.O. (1976) can be applied at the detailed level appropriate to farm-scale agroforestry. Furthermore, it is a form of specific-purpose evaluation. This is made clear in the following definition: 'land evaluation is the process of assessment of land performance when used for specified purposes, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation' (F.A.O., 1976:1). The procedure is shown diagrammatically in Fig. 3. Essentially it involves a comparison of alternative land uses with the properties of the land in order to answer two basic questions. First, for a specified land use, which portion of the landscape is most suitable, and second, for a given area of land, what

fig 3



Land evaluation procedure.

(adapted from Gelens, 1984.)

is the most suitable use (Young, 1984b; 1987). Beyond this, the approach recognizes that while a particular use may not be optimum it may nonetheless show some degree of suitability (see F.A.O., 1976; 1984). Thus, an element of restrained choice is introduced to the way in which land uses can be aportioned within the landscape.

A fundamental feature which distinguishes it from other methods such as 'land capability classification' and the 'site index method' (see Young, 1984a), is that land uses are given as much attention as the surveys of the land itself. The other methods tend to detail land resources, but consider land use in a highly generalized way. Another important feature, not mentioned in the literature but important in the context of this thesis, is its' ability to assess the landscapes' 'design potential' (see Weddle, 1973). This is achievable since the procedure indicates potential for change by systematically comparing proposed land uses to the biophysical attributes of land, ranking them on a suitability scale, and then showing the results as a series of suitability maps (see F.A.O., 1976). A landscape which shows a high suitability for a large number of land uses has a high potential for change. Thus, 'design potential' is concomitantly high. This is simply because the arrangement of elements in relation to the landscape and each other is initially dependent on how land uses are arranged. Elements can be arranged differently (design alternatives) if land uses are rearranged. However, the design alternatives can only be realistic if the land use is well-matched to the land. Hence, the initial land evaluation is of fundamental importance.

In view of the foregoing, it is clear that the F.A.O. land evaluation framework is potentially suitable for use in agroforestry design. In particular, it appears to represent a systematic and comprehensive way of accomplishing the research-analysis-synthesis sequence required to resolve the design context. This is because the procedure is first, applicable to the farm-scale, second, is able to utilize both socioeconomic and biophysical information, and third, can generate design alternatives by indicating a variety of land use options. The latter are shown in a graphical form, that is, as land suitability maps, which as well as showing the landscapes' 'design potential' represent a base map on which the design proposal can be developed. Moreover, since such maps result from a matching of land use with land, they have incorporated and synthesized both socioeconomic and biophysical information. Thus, land suitability maps represent a functional summary of the design context. It should also be noted that 'suitability' in the context of the F.A.O. land evaluation refers to use on a sustained basis, that is, the use must not result in severe or progressive degradation (Young, 1978). Clearly, this is appropriate to the concept of agroforestry land use which places a high priority on sustainability and conservation.

(c) Land evaluation in the context of agroforestry

In the following, the land evaluation procedure as outlined by the F.A.O. (1976) is described with particular reference to agroforestry. Although specific guidelines have been established for rainfed agriculture (F.A.O., 1983) and forestry (F.A.O., 1984) there are, as yet, none available for agroforestry. However, Young (1984a; 1984b; 1986; 1987) has indicated the major features of agroforestry land evaluation within the framework of the F.A.O. procedure.

While evaluation of this kind can be a complex and highly sophisticated assessment procedure, it can nonetheless be simplified and still retain the fundamental concept of matching land with land use. A simplified land evaluation procedure for agroforestry design is outlined in the following. For the purposes of illustration, comments apply mainly to the common situation where agroforestry would involve tree establishment in an already functioning agricultural system.

(i) Initial survey aimed at providing an analysis of the general farm situation; the form of this initial or 'primary' survey has already been suggested (see Sec. 5.3.1 and 5.3.2). The main outputs would include a list of potentially marketable agroforestry products, an assessment of resources (capital and labour) available for plantation establishment and management, a list of potential tree species as indicated by climatic type and general impression of site quality, some statement of general objectives, and an identification of general constraints. The latter refers to areas on which the landowner wishes to maintain the present use unaltered. Such areas can therefore be excluded from evaluation. However, it is desirable that the entire farm is evaluated so that land use options can be at least presented for consideration.

(ii) Selection of relevant land utilization types (L.U.T.'s); a 'land utilization type' is 'a kind of land use described in a degree of detail greater than that of a major kind of land use' (F.A.O., 1976). Essentially, they consist of a set of technical specifications framed with reference to socioeconomic conditions. L.U.T.s need to be refined as more information becomes available. However, the initial statement should note the proposed species and its' intended function, as well as giving some indication of the resources available for establishment and management. For example, a L.U.T. may be initially described as 'silvopastoral system (trees, pasture and livestock) comprising plantation of *Gleditsia triacanthos*, primarily for fodder production, with secondary use as stock shelter in summer and for soil protection; established and managed by landowner (maximum labour force of two), using mechanical site preparation, labour intensive establishment, thereafter management inputs low in terms of both capital and labour'.

(iii) Determination of land use requirements for L.U.T.s; these can be divided into three groups, namely, requirements for growth, requirements for management, and requirements for conservation. The first refers to species specific requirements for survival and growth, and include temperature range, moisture regime, drainage conditions, soil nutrient status, and tolerance to environmental conditions of salinity, flooding, strong winds etc. The second, management requirements, refers to the 'conditions of land necessary for successful management of the plantation, under the conditions specified in the L.U.T.' (Young, 1984a). For example, mechanized site preparation requires the absence of rock outcrops and steep slopes, minimal soil erosion hazard, and good internal site access. On the other hand, if site preparation and management are to be labour-intensive, distance from the farm residence may be a limiting 'condition' of the land. Finally, conservation requirements need to be considered. For example, if soil protection is required, dense canopied, deep-rooted evergreen trees are ideal. However, if the L.U.T. specifies an open crowned deciduous tree (as in the foregoing example) it should be noted that on sites with high erosion hazard the species is unlikely to fulfil its proposed function for a number of years (until such time as the leaf fall is sufficient to provide a protective litter cover).

(iv) Delineation of land units; a 'land unit' is defined as 'an area of land possessing specified land qualities and land characteristics, which can be demarcated on a map and which is employed as a basis in land evaluation' (F.A.O., 1984). In principle, such units should be homogeneous, however, various degrees of internal variation will occur depending on the scale of the survey. The term 'land quality', as used in the above definition, refers to 'a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the suitability of land for a specified kind of use' (F.A.O., 1984). Land quality is a synthesis of a number of 'land characteristics', which are single attributes of land which can be measured or estimated, and are used to describe land qualities or distinguish between land units of differing suitabilities. Although Young (1984b) suggests that the term 'land unit' does not refer to a particular type of mapping unit, it is desirable that they are delineated from environmental attributes which are likely to approximate the range of more specific factors which have a direct effect on plant growth. In this regard, the landform attributes of aspect of topographic position are particularly significant (see Geiger, 1950; Kellman, 1975; Marsh, 1983). For example, aspect influences degree of insolation, air and soil temperatures, wind exposure, and air humidity (through influence on local precipitation and fog incidence); topographic position may approximate soil nutrients via such intermediaries as water table depth and its' potential influence on soil pH, and soil moisture tension through soil depth (see Kellman, 1975:31). The importance of landform attributes is underscored by Bailey (1987:317): 'Landform is an important criterion for recognizing smaller divisions within macroclimatic units.

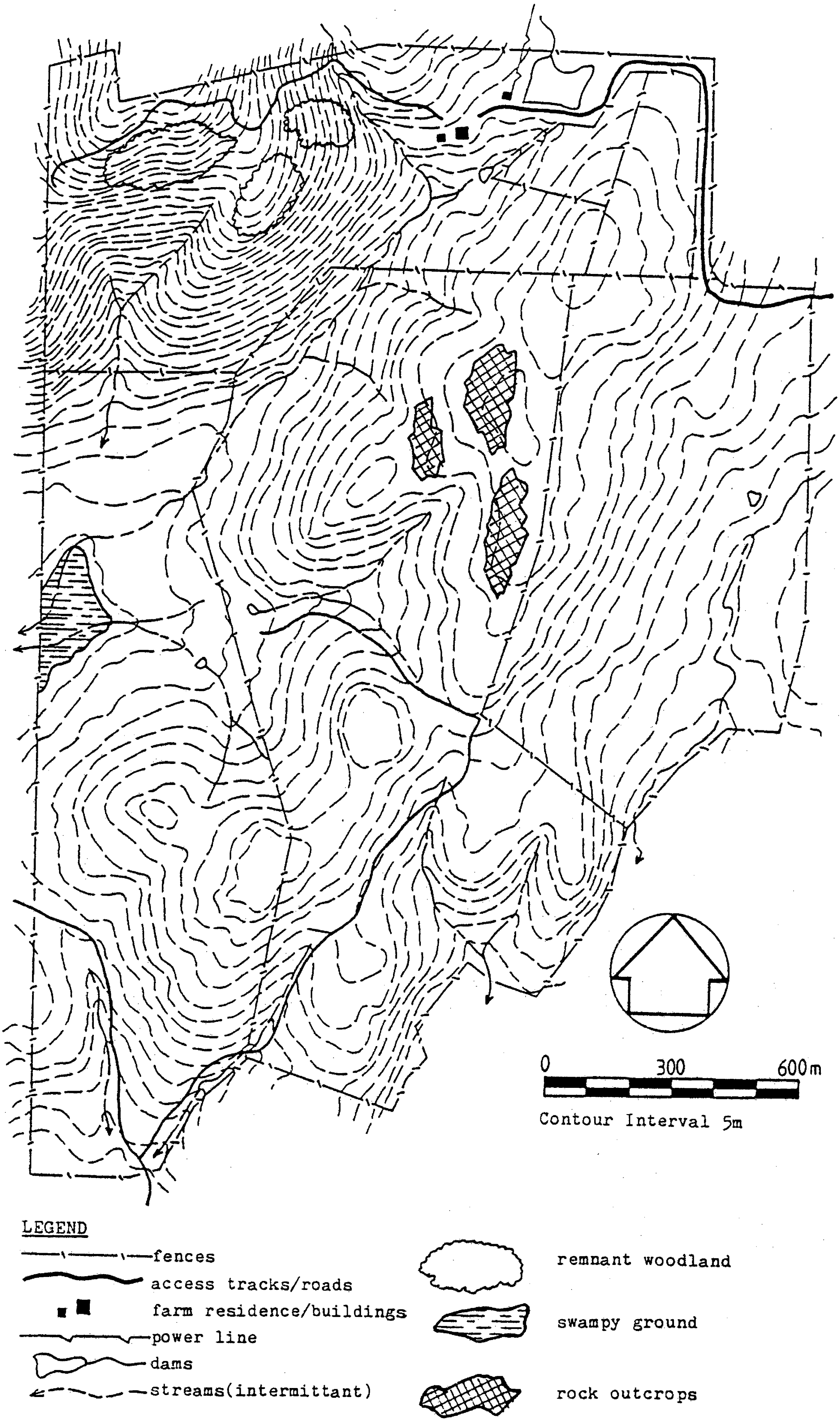
Landform modifies the climatic regime at all scales within macroclimatic zones; it is the cause of the modification of macroclimate to local climate. Thus, landform provides the best means of identifying local ecosystems. At the mesoscale, the landform and landform pattern form a natural ecological unit. At the microscale, such patterns can be divided topographically into slope and aspect units that are relatively consistent as to soil moisture regime, soil temperature regime and plant association, i.e. the homogeneous site'.

Thus, in view of the above, it is clear that land units based on landform attributes of aspect and topographic position (which includes slope) will ensure some degree of homogeneity in environmental conditions relevant to plant growth. This would seem appropriate in the context of land evaluation for agroforestry. Hence, in Fig. 4 an example of a farm landscape is shown and includes typical features easily identifiable at the scale of survey (in this instance approximately 1:15000). From this base map land units have been derived using topographic position (components identified include crests, slopes, flats and depressions; see Speight, 1984) and aspect (slope predominantly north or south facing). Further subdivisions are made on the basis of the presence of swamps, remnant woodland, and rock outcrops, all of which are land characteristics relevant to agroforestry (Young, 1984b). The resulting land units are shown in Fig. 5 (in practice it is useful to present these as a transparent overlay on the base map).

(v) Identification of land qualities; the term 'land quality' has been explained in the foregoing. These are subdivided into three groups to match the previously determined land use requirements.

fig 4

Base map of farm landscape.



LAND UNIT MAP (Fig. 5)

AND KEY OVER PAGE.

LAND UNIT KEY:

1. Hillcrest.
2. Hillcrest with rock outcrop.
3. Upper slope.
4. Upper slope; east facing.
5. Upper slope; west facing.
6. Upper slope; west facing with rock outcrops.
7. Mid-slope; east facing.
8. Mid-slope; south facing.
9. Mid-slope; south facing with remnant woodland.
10. Mid-slope; west facing.
11. Mid-slope; north facing.
12. Lower-slope; east facing.
13. Lower slope; south facing.
14. Lower slope; west facing.
15. Lower slope; north facing.
16. Flat.
17. Flat with standing water.
18. Depression (stream gullies and major drainage lines).

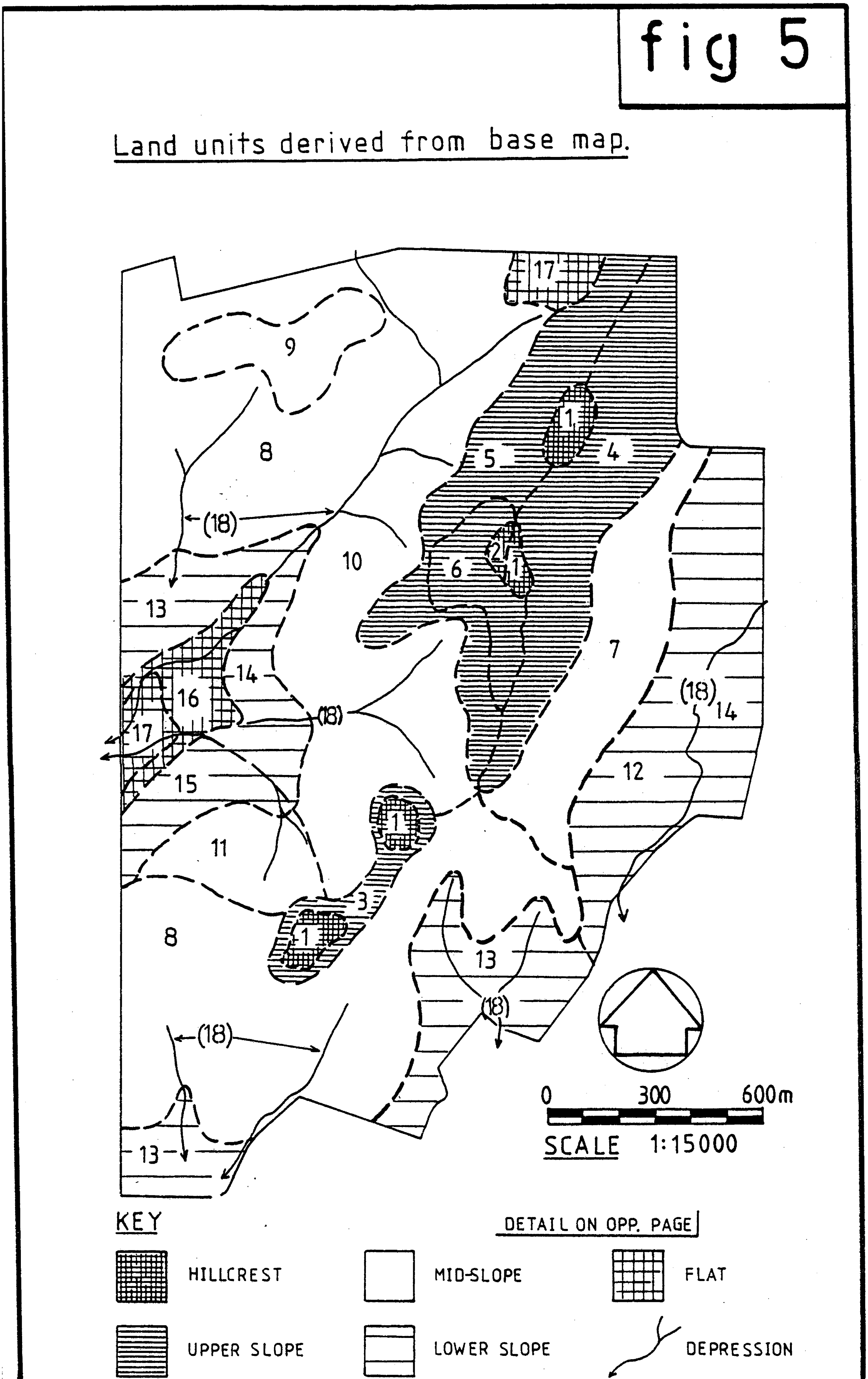


fig 5
Land units derived from base map.
17
9
1
8
5
4
(18)
2
1
10
6
13
7
14
16
(18)
(18)
14
17
12
15
1
11
3
8
1
13
(18)
(18)
0
300
600m
SCALE 1:15000
13
KEY
DETAIL ON OPP. PAGE
HILLCREST
MID-SLOPE
FLAT
UPPER SLOPE
LOWER SLOPE
DEPRESSION

First, there are qualities affecting growth, second, qualities affecting management, and third, qualities affecting conservation. For each land unit the qualities can be described using the land characteristics shown in Table 3 (see Appendix 6 for more detail).

Once these five steps are complete it is then possible to match land use requirements with land quality, and thereby ascertain the suitability of the particular land units and L.U.T.s. Land suitability can be ranked as highly suitable (a perfect match), moderately suitable, marginally suitable, currently not suitable, or permanently not suitable. Thus, for each L.U.T. there will be a map showing its relative suitability for each farm land unit. Areas of land use conflict, for example, the same land unit indicated as highly suitable for two or more L.U.T.s are readily identified, and a decision made as to which is to be allocated a moderately or marginally suitable land unit (this problem is discussed in Sec. 5.6).

In conclusion, the land evaluation procedure described in the foregoing incorporates socioeconomic and/or biophysical information in the formulation of L.U.T.s, determination of land use requirements, delineation of land units, and identification of land qualities. Furthermore, an effective synthesis is accomplished by the production of land suitability maps, which, moreover, represent the landscapes design potential.

5.4 Visual, Functional and Ecological Appropriateness

The specification of the form of agroforestry elements should be visually, functionally and ecologically appropriate within the design context (see Chap. 2). Each of these aspects is discussed in the following.

5.4.1 Visual Aspects

The need to consider visual/aesthetic aspects in agroforestry has been emphasises by Schmidt (1979), but in general they are either ignored

TABLE 3. Summary of land qualities and characteristics relevant to Agroforestry

A. Qualities affecting growth	1. Based mainly on climate; radiation, temperature, moisture. 2. Based mainly on soil; drainage, rooting, nutrients. 3. Special aspects; establishment, maturing. 4. Limitations; hazards, salts, toxicities, biological (pest,weeds).
B. Direct estimate of growth	production
C. Qualities affecting management	1. Management operations; conditions affecting mechanization, soil workability, land preparation, storage and processing, timing of production. 2. Location and access; location, size of management units, internal accessibility.
D. Qualities affecting conservation	soil degradation, hydrological and biological degradation, loss of amenity.

Source: Young (1984b)

or treated superficially (eg. Reid and Wilson, 1985). However, if agroforestry land use is adopted on a wide-scale its visual impact on the landscape will become clearly apparent to the general public, and low visual quality is likely to become a reason for controversy. In recent years, this situation has arisen in regard to government owned production forests. In order to avoid such conflicts in agroforestry developments, visual aspects need to be carefully considered in the intial design.

It has been suggested that the form of landscape elements needs to be 'visually appropriate' within the design context (see Sec. 2.4). In essence, this means that form should be aesthetically pleasing. Judgements relating to aesthetic quality result from the perception of landscape, itself a function of complex interactions between humans and the landscape. As Zube, Sell and Taylor (1982: 3) note, the human component 'encompasses past experiences, knowledge, expectations and socio-cultural context of individuals and groups. The landscape component includes both individual elements and landscapes as entities.' The interaction between these components produces a variety of outcomes (eg. satisfaction, well-being, stimulation), which in turn affects subsequent human-landscape interactions (see Zube *et al.*,1982:24). The end-result of this 'landscape perception process' is an 'aesthetic response', which is exhibited in preference or like-dislike affects (Ulrich, 1986).

Given the nature of the components which make up the perception process, it is hardly surprising to find that aesthetic responses to particular landscapes or landscape attributes are often mixed. For example, in regard to single crop commercial forests, Robinson, Laurie, Wagner and Traill (1976:303) have found that the 'simplicity of these landscapes makes them appealing to some. Others find them sombre and monotonous and would accord them low visual quality .....', and for agricultural landscapes, 'Many find their simplicity and neatness constitute a landscape of at least average quality while others find them unattractive'. It would appear to be extremely difficult to arrive at a consensus as to what constitutes an aesthetically pleasing landscape, despite considerable research in the area of landscape preference (eg. Buhyoff, Wellman, Harvey and Fraser, 1978; Wellman and Buhyoff, 1980; Purcell and Lamb, 1984; Gimblett, Itami and Fitzgibbons, 1985; Brown, Keane and Kaplan, 1986), and attempts to provide a theoretical framework for landscape aesthetics (see Sancar, 1985),

Nonetheless, a recent review of research in the area of forest aesthetics (Ulrich, 1986), indicates that there is some agreement in regard to the visual/aesthetic aspects of forest management and the composition of individual forest stands. Ulrich (1986:35) states that 'preferences tend to be significantly higher for managed forest stands than for non-manipulated settings', and, 'observers prefer park-like settings, characterized by openness, uniform ground covers, and ordered complexity associated with large-diameter trees and only small amounts of slash and downed wood.' These findings suggest that typical agroforestry developments, such as tree/pasture systems, should produce a favourable aesthetic response, whereas areas of natural regeneration, which may well be part of farm conservation strategy within the overall agroforestry design, could elicit unfavourable responses since high-density shrub understories 'have powerful negative effects on preference' (Ulrich, 1986 :35). However, such areas could be used to provide a pleasant contrast to the even-aged plantations which tend to be characteristic of agroforestry. Moreover, since in most situations areas of regeneration will be restricted in scale, their visual impact on the total farm landscape is likely to be minimal.

Beyond this, there are a number of general points which can be made in regard to the visual aspects of agroforestry. These are listed below, and relate to the farm landscape as a whole, rather than to the composition of individual elements, and, given the aforementioned difficulties in determining what is 'aesthetically pleasing', must be regarded as largely subjective. The following is drawn from Anstey, Thompson and Nichols (1982), Lucas (1984), and Patrick (1985), and the reader is referred to their work for more detail (the first two references include photographs and sketches illustrating the visual aspects of design noted here).

(i) Integration; the integration of new and existing landscape elements ensures visual unity, and is achieved by attention to shape, scale, and colour. In regard to shape, stands of trees without straight, sharp edges, and informally linked to a framework of planting which outlines waterways, valleys, spurs and ridges, and hence the general landform shape, augment the broad landscape better than individual specimens or isolated geometric plantations. The scale of elements is also an important integrative factor, and an attempt should be made to follow the scale of the landform pattern. This applies particularly to the abovementioned 'framework', which in broad expansive landscapes should be bold and simple, whereas in areas with complex topography the framework should exhibit more subtlety concomitant with the landform variation. In regard to colour, it is generally best to avoid golds, purples, and variegated foliage, and rely instead on variations in summer-greens.

(ii) Variety; this is achieved mainly by defining spaces of various size and shape (within the restrictions imposed by function and with due regard to integration), thereby establishing an overall spatial pattern in the farm landscape, which, from a distance, may take on the appearance of a mosaic of 'cells of land'. For the observer, these may be experienced on the base-plane as a series of linked spaces exhibiting varying degrees of enclosure which may range, for example, from the closed and intimate space of a shaded woodlot, to the open and broad space associated with pasture and shelterbelts.

(iii) Transitions; changes in land use, landform, or vegetation, create areas of 'tension' to which the eye is drawn. In general, the aim in treating such areas should be to create harmonious relationships between elements by avoiding straight, abrupt edges, including those resulting from ornamental plantings along plantation edges, and instead, creating large groups of trees which drift informally along gullies, swales and ridges, and merge into the main crop. Other situations may call for a gradual transition from dense woodland to grassland. This can be facilitated by a gradual increase in tree spacing towards the open grassland. The transition between land and sky is often particularly prominent, hence skyline plantings should avoid imposing a discordant additional transition. Thus, ridges and crests may be better left unplanted, or, at least, plantations requiring short-rotations and clear-felling avoided in preference to those orientated toward long-term selective logging.

(iv) Local character; this is provided by natural and/or man-made features which give the landscape a sense of local identity. The aim should be to display such features rather than close visual access with plantings, structures etc. As Seddon (1979:67) puts it, designers should attempt to 'individuate by understanding and clarifying the locally distinctive ...' This is important in agroforestry, particularly if adopted on a broad scale, since the potential exists for large tracts of the landscape to be 'homogenised' by uniform plantings of species such as Pinus radiata.

5.4.2 Functional Aspects

In the context of agroforestry, function can be noted in the L.U.T. specifications (see Sec. 5.3.4) as production and/or protection. A 'functionally appropriate' form of landscape elements is that which allows the L.U.T. to fulfil its' intended function, within the constraints and potentials imposed by the design context. For example, in an agrisilvicultural L.U.T., soil protection could be achieved by a variety of spatial arrangements, including zonal strip planting (eg. alley cropping), zonal boundary planting (windbreaks and shelterbelts), or scattered plantings of multipurpose trees (see Nair, 1985). The arrangement which is most appropriate is dependant on the biophysical and socioeconomic aspects of the design context. In particular, the extent and type of existing soil degradation, and the expertise and skills of the landowner.

The other aspect of form, that is, shape, is also important in regard to function. For agroforestry, boundary shape, may be the most relevant design aspect. Three general points, derived from the so-called 'form-function principle' (see Forman and Godron, 1986:177) are worth considering. First, rounded or compact shapes with minimal appendages (ie. low perimeter-to-area ratio) are characteristic of systems where it is important to conserve energy, materials, or organisims, second, convoluted boundaries with a high perimeter-to-area ratio characterise systems where considerable interchanges (energy, materials, or organisms) occur with the surroundings, and third, dendritic shapes are associated with energy and material flows, and the movement of organisms. As for spatial arrangement, 'appropriate' shapes are those which facilitate function, but at the same time are practical within the constraints imposed by the design context. Both aspects are discussed further in Sec. 5.5.

5.4.3 Ecological Aspects

Ecological aspects relate primarily to the notion of sustainability. As noted in earlier sections, this is an important aspect of agroforestry, and should be stated as a design goal. Form which promotes sustained land use can be regarded as generally 'appropriate' in all agroforestry design contexts, and will depend to a large extent on a spatial arrangement of elements which promote soil and water conservation, and, moreover, is feasible given the socioeconomic circumstances of the farmer. Other ecological aspects of form become apparent through shape. These are noted in Sec. 5.5.2.

5.5 Specification of Form

Form is expressed in the spatial arrangement and shape of landscape elements. In the context of farm-scale agroforestry the latter include windbreaks, shelterbelts, hedgerows, pasture (plus livestock), cropping areas, productive plantations, access roads/tracks, firebreaks, dams, farm buildings, and fences. Form is specified in the design proposal (see Fig. 2), which will initially be represented by a 'master plan' showing a general schematic layout of the proposed agroforestry developments. Such plans are not detailed, rather, they indicate 'the essential principles to be followed in the development and the broad lines of the design' (Crowe, 1979:15). Detailed plans, showing the exact form elements, are then produced from the master plan to facilitate implementation. These may need to show sections of the farm at a scale larger than that of the master plan. For example, on a 1:5000 plan it is possible to show detail of about 15m x 15m in area (3mm x 3mm plan scale).

In the following, some comments are made regarding the two major aspects of form in the context of agroforestry. This is intended to illustrate the kind of considerations which should be fundamental to agroforestry design.

5.5.1 Spatial Arrangement

Two points need to be considered, first, the location of elements in relation to the landscape, and second, their location in relation to each other. In general terms, the first is achieved by examining the constraints and potentials of the landscape to find the optimal location for each element. The fundamental aim should be to match, as near as possible, the proposed spatial arrangement of elements with the existing pattern of landscape suitability. Various suitability models, appropriate to landscape design in general, have been developed to facilitate this (see Lyle, 1985:241-259). For agroforestry design, an appropriate model is 'land evaluation' as outlined by the F.A.O. (1976). This has been discussed in detail in Sec. 5.3.5.

Some design elements, such as farm buildings will in most instances already be established and not able to be relocated easily. Similarly, fences can be regarded as more-or-less fixed, although there will be room for some modification as incompatibilities between their present alignment and the new arrangement of elements becomes clear. These, and other existing man-made elements, are considered along with 'natural features' in the analysis of the landscapes' constraints and potentials.

The second spatial aspect, namely, the relative location of elements, involves a consideration of 'places' and 'paths'. Both are fundamental to spatial design in any context (McCluskey, 1985). Place is a centre of activity and point of arrival and departure, and is represented by the farm residence and associated buildings. The rest of the farm landscape is structured into domains, or 'spheres of influence', by a network of generally ill-defined paths (roads, access tracks etc). Thus, the outcome of the 'specification of form' is a restructuring of domains as paths are reorientated to accord with the new spatial arrangement of elements and the existing centre of activity (place). The relative location of elements within domains is then important in engendering the economic and ecological interactions, which by definition, are a characteristic of agroforestry (see Sec. 3.3). In particular, relative location which engenders beneficial interactions between the woody (trees) and non-woody (crops, pasture, livestock) elements is central to agroforestry design. The juxtaposition of windbreak, pasture and woodlot to create well-sheltered lambing havens is a typical example (see Reid and Wilson, 1985: 148-149). A central question is whether tree and crop elements should be arranged in a 'mixed cropping' or 'zonal' pattern (see Huxley, 1985b). An answer to this kind of question requires an understanding of the ecological interactions at the tree/crop interface. Generally, positive interactions suggest mixed cropping, and negative interactions some form of zonal cropping (Huxley, 1985b).

Also important is the location of elements relative to the centre of activity. Thus, a plantation requiring intensive management is ideally located close to the farm residence so that frequent visits to such sites will incur relatively low economic and ecological costs. Economic costs are both direct and indirect. The former include the cost of petrol and vehicle maintenance, and the latter, the cost involved in having labour engaged in travel rather than on-ground work. Ecological costs relate to the use of non-renewable resources (petrol) and its consequence for sustainability (see Sec. 3.4).

In view of the above, it is clear that much of agroforestry design will revolve around attempting to reconcile the location of elements in regard to the landscape with their location in relation to each other. In many instances, optimal landscape location may not be optimal for interaction between elements. Thus, a number of possible sites, even though they may be less than optimal, should be indicated for each element in the initial analysis. This can be achieved by the previously described land evaluation procedure (since some degree of choice is provided in the way L.U.T.s are arranged, it follows that there will also be some choice in locating sites for the associated elements).

5.5.2 Shape

Shape is important in regard to the visual/aesthetic qualities of the farm landscape (see Sec. 5.4.2). However, it also needs consideration in relation to function. For example, in regard to windbreaks, the shape of the cross-sectional profile is important in determining effectiveness (see Brown and Hall, 1968; Breckwoldt, 1983:94-95), and in plan-view, rounded, rather than square ends, facilitates stock movement and avoids pitting and subsequent soil erosion at windbreak corners (Marriot,1987,Potter Farmland Foundation; pers comm.). In some instances, the usual long rectangular shaped windbreak (plan-view) may be impractical due to rough and steep terrain. Nonetheless, effective stock shelter can be provided by adopting windbreak shapes to suit paddock corners (see Reimer, 1986:65). The usual shape of woodlots is either square or rectangular, but a hexagonal shape over the same area enables 12% more trees to be established without altering inter-plant distance (Oates and Clarke, 1987). Thus, a more efficient use of resources is achieved, and at the same time, it is suggested that straighter growth will be encouraged and less tension wood formed as a result of a more even distribution of trees (Oates and Clarke, 1987:96).

A further example of the shape-function relationship can be seen in the design of farm dams. In situations where the dam is to function as both a water storage and waterbird habitat, the shape should be as irregular as possible to allow for the creation of areas of shallow water (N.P.W.S., 1982; Breckwoldt, 1983). The latter provides a habitat for the various grasses, reeds, algae and insects, which in turn act as food sources for numerous bird species (see Breckwoldt, 1983:127).

Shape also takes on an ecological significance in relation to the 'edge effect' (Forman and Godron, 1981; Forman, 1982). The latter refers to the observed differences in the composition and abundance of species at the interface of two ecosystems (eg. pasture and woodland). Different shapes exhibit variation in the interior-to-edge ratio, for example, a large isodiametric shape is mostly interior, while a rectangular shape of the same area has proportionally less interior and more edge, and a narrow strip of equal area may be all edge (see Forman, 1982:37). Thus, to a large extent, shape determines the length of edge. The manipulation of shape is therefore a means of either maximixing or minimising 'edge effects'.

The importance of the 'edge effect' in farm wildlife conservation has been noted by Breckwoldt (1983). However, its application to agroforestry needs closer consideration. Increased wildlife may conflict with production objectives since the fauna are likely to feed off pasture and crops, and in some instances, damage trees by browsing bark and leaves. Nonetheless, in relation to the tree and crop components alone, Huxley (1985b:264) points out '.... if the overall biological effect at the tree/crop interface is generally positive then the amount of interface can be maximised.' This can be achieved by mixed cropping (alternating narrow strips of trees with crops), or, by creating shapes which maximise edge in instances where elements are more spatially discrete (eg. a zonal arrangement). For rectangular shapes, the favourable interior-to-edge ratio can be further improved by creating irregularities along the perimeter. For example, a woodlot with an undulating perimeter will have comparatively greater edge with adjacent pasture or crops than a strictly rectangular woodlot of the same area.

Shape has to be considered within the constraints of the cost and difficulty of protective fencing where livestock are a part of the system, or in the many instances where vermin are a problem. Nonetheless, the connection between shape and ecology is through the 'edge effect'. If the latter is beneficial in particular agroforestry situations the extra cost and time involved in fencing may be worthwhile. Clearly, this is an area which needs further research before firm design guidelines can be produced. The first step is to determine the interaction at the tree/crop interface (see Huxley, 1985b), and thus indicate which edges should be maximised or minimised. The determination of the shape of elements could then proceed in the light of these findings. At present, it can be said that a farm landscape in which edge is maximised will certainly be more visually interesting, is likely to be beneficial for wildlife conservation, and in some instances, will result in an increase in production levels.

5.6 Outline of Proposed Agroforestry Design Procedure

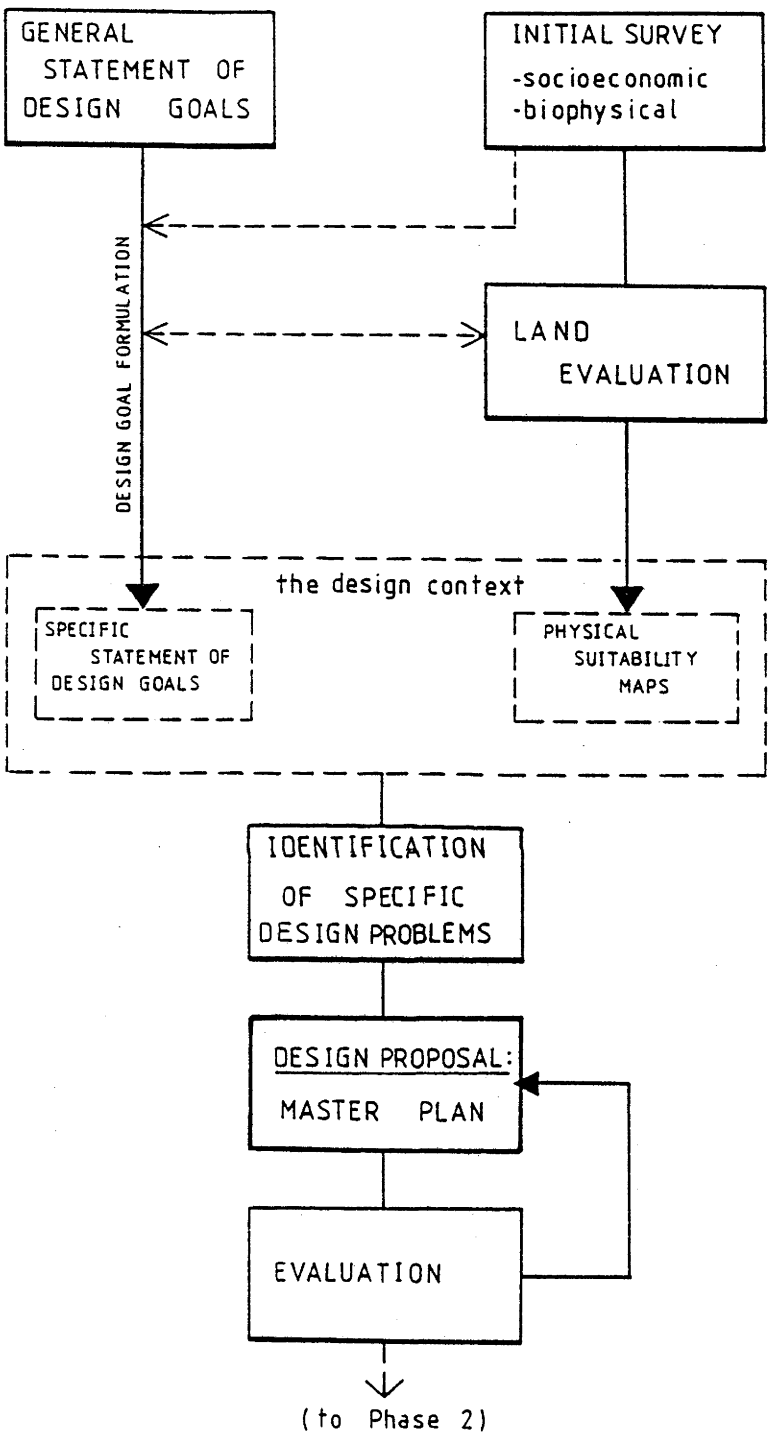
In the foregoing Sections, the major components of the design process, as shown in Fig. 2, have been discussed with particular reference to agroforestry. It is now possible to outline a design procedure for agroforestry. This is presented in three phases, the first culminating in the production of a master plan for the whole farm (Fig. 6), and the second, a detailed plan for each land unit (Fig. 7); the master plan is subject to evaluation before proceeding to phase 2, and similarly, the detailed land unit plan is evaluated before implementation begins (Figs. 6 and 7 respectively). The production of working specifications at the very beginning of the implementation stage marks the end of the design process (see Chap. 2), and represents the third and final phase of the agroforestry design procedure.

In the following, the major stages in phase 1 and 2 are detailed and a number of points are made in relation to phase 3.

5.6.1 Phase 1: Farm Master Plan

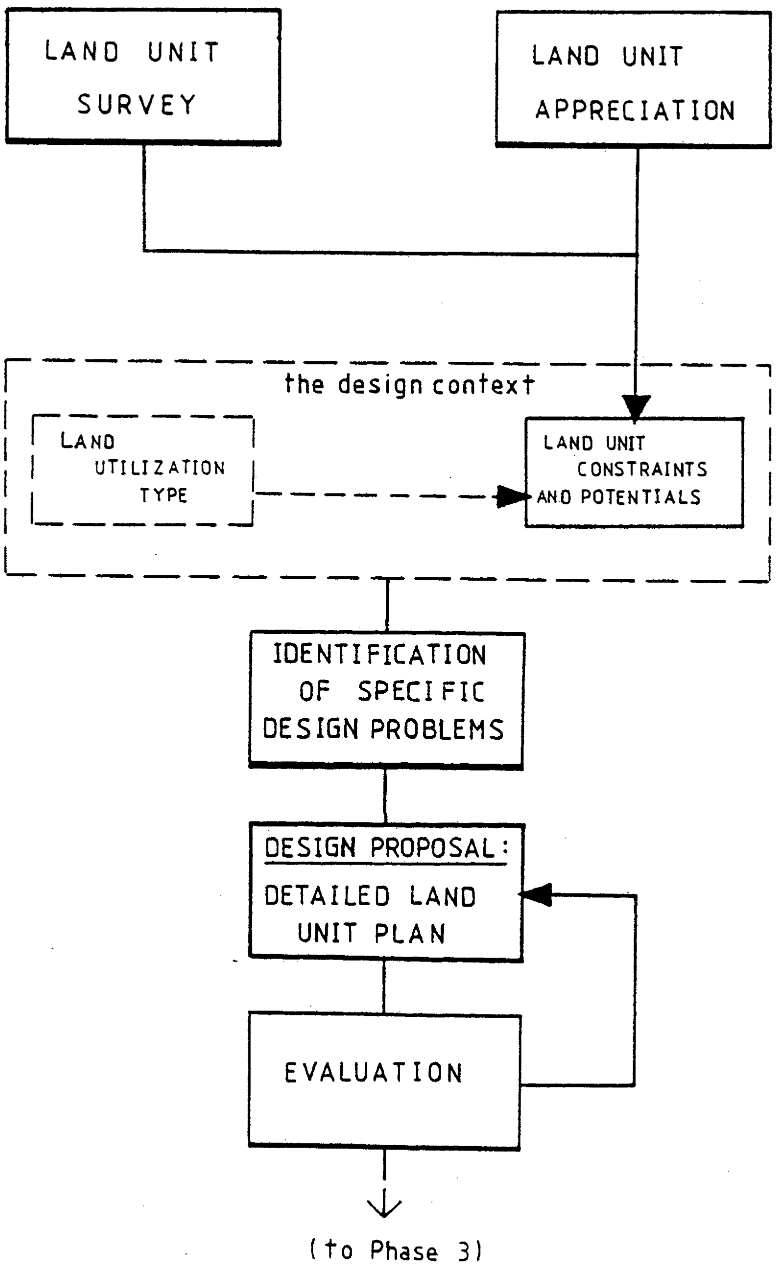
(i) Initial Survey and Statement of Design Goals; the design process begins with two parallel sets of activities. These are (a) an initial survey of the socioeconomic and biophysical conditions pertaining to the farm in question, and (b) a general statement of design goals (Fig. 6). The form of the initial socioeconomic and biophysical survey has already been suggested (Secs. 5.3.1 and 5.3.2 respectively). For the biophysical survey, the 'environmental data base for agroforestry' (Young, 1985) provides guidelines, and is

fig 6



Phase 1 design: farm master plan.

fig 7



Phase 2 design: detailed land unit plan.

summarized in Table 4 (for more information see Appendix 5 and Young 1984a; 1985); environmental components have been grouped in order of importance to agroforestry as suggested by Young (1985:7), and the summary includes the detail required to 'level 2'. These initial surveys led directly to the land evaluation stage (Fig. 6), and so represent an 'analysis of the general situation' which is required at the outset of the land evaluation procedure (see Fig. 3). Design goals can be stated in general form as increased social value, productivity, stability, sustainability, equitability, and adoptability (see Sec. 5.3.3). The last five represent 'secondary goals', which are likely to aid in the attainment of the primary goal of increased social value. As indicated in Sec. 5.3.3, the information derived from the initial surveys will help in the formulation of more specific goal statements.

(ii) Land Evaluation; the role of land evaluation in the design process has been discussed and the procedure outlined in Sec. 5.3.4. As noted in Fig. 6, land evaluation contributes to the refinement of design goals (by specifying in detail what is possible within the constraints of biophysical and socioeconomic conditions), and in turn, the design goals should to some extent guide the formulation of 'land utilization types'; for example, 'sustainability' would be reflected in an L.U.T. which specifies conservation as well as production (as in the example given in Sec. 5.3.4). The major output from land evaluation are physical suitability maps, which together with a specific statement of design goals, represent the design context (Fig. 6).

(iii) Identification of Specific Design Problems; once the design context has been resolved specific design problems will become clear

TABLE 4. Summary of initial biophysical survey

Location	country; direction and distance from major population centre(s); latitude and longitude; altitude.
Climate	classification; general description; detail on rainfall, temperature, frost incidence, evaporation, humidity and growing period.
Soils	classification; general description; detail on texture, reaction, drainage, limiting horizons, degradation.
Landform	classification (based primarily on slope); general description; detail on slope shape and position.
Hydrology	classification (based on degree of surface water-logging); general description of groundwater conditions; detail on groundwater, river regime, degradation, flooding.
Vegetation	classification; physiognomic description and level of degradation.
Fauna and Disease	fauna, pests and disease affecting plants or animals.
Geology	classification; general description; detail on grain size, age, formation, lithology.
Land Use	classification; general description.

Adapted from Young (1985).

(Fig. 6). These will take the following general form. First, in instances where a particular land unit is given the same suitability ranking for two or more L.U.T.s, a decision has to be made as to which L.U.T. is most appropriate. Problems of this kind can be resolved by reference to design goals, that is, by ascertaining which L.U.T. is most likely to attain the specified design goals given the conditions of the particular land unit. If no logical decision can be arrived at, there may be no option but to proceed to the design proposal (stage iv; see below), produce more than one master plan, and subject each to evaluation. The second major problem concerns the basic spatial aspects of design, namely, a consideration of 'places' and 'paths' (see Sec. 5.5.1). Although land evaluation considers these in part by reference to 'access', ascertained in terms of such land characteristics as slope (see Appendix 6), they are not directly considered as a constraint. Thus, it is at this stage that places (i.e. 'focal points' or 'centres of development) and paths (access tracks, roads) should be taken into account. These will already have been shown on the farm base map (eg. Fig. 4), over which a transparent overlay of the suitability map can be superimposed. The problem may then arise as to whether land suitability should be reassigned in the light of existing places and paths, or alternatively, should the latter be relocated to accord with suitability? As noted in Sec. 5.5.1, the major 'place' or 'focal point' is the farm residence and associated buildings, which in most instances will already have been established. Thus, land suitability may have to be reconsidered. For example, a L.U.T. involving intensive management and ranked as highly suitable for a land unit which is distant from the major focal point requires reassessment. Similarly, if capital is unavailable for the construction of new access tracks (this will have been indicated in the initial surveys), land unit suitability will again need reassessment. Otherwise, new circulation routes can be shown in the design proposal in accordance with the location of the existing focal point, the requirements of the particular L.U.T., and the physical constraints of the land (eg. slope). The resolution of these kind of problems may, in some instances, help in solving the first mentioned problem, namely, the conflict arising from land units having been ascribed the same suitability rating for two or more L.U.T.s. The third major problem concerns fences. These will have been indicated on the farm base map (see Fig. 4), and again, the 'suitability overlay' will show where problems are likely to occur in terms of the present fence alignment and the proposed land use arrangement. The extent to which fence alterations are possible is largely dependent on the availability of capital (indicated in the initial surveys). If alterations are possible, they are shown in the design proposal, otherwise, land suitability may need to be reconsidered. For example, should a land unit ranked highly suitable for a particular L.U.T. still be considered so if the existing fences subdivide the area? As for the 'places and paths' problem mentioned above, the resolution of this problem may aid in solving the first mentioned 'suitability conflicts'. Thus, the order in which the major design problems are noted here is not intended to indicate the order in which they should be approached. As in most design problems, frequent iteration is necessary to find a solution which will lead to a realistic design proposal.

(iv) Design Proposal: Master Plan; this is the first attempt at the 'specification of form'. The master plan will show a general schematic layout of proposed developments, and represents an attempt to solve the kind of problems mentioned above within the constraints and potentials of the design context. The spatial arrangements of L.U.T.s, existing and proposed focal points, access roads and tracks, and fences are shown. Since the location of L.U.T.s in relation to the landscape and each other has been determined, it follows that the approximate positioning of associated elements (stock fodder plantations, protective plantings, pasture etc.) has also been indicated. The exact location of each within particular land units must await the more detailed design proposals developed in Phase 2 (see below). It is during this second phase that the other important aspect of form, that is 'shape', is considered.

5.6.2 Phase 2: Detailed Land Unit Plan

(i) Land Unit Survey and Appreciation; the development of a detailed design proposal begins with a survey of the land units' biophysical attributes, and an 'appreciation' of its' visual qualities (Fig. 7). The survey is directed toward providing the information necessary for the compilation of a large-scale base plan. Although much biophysical information will have been obtained from the Phase 1 land evaluation, it has been conducted on the assumption of relative homogeneity within the land unit so as to provide a generalised summary for the purpose of matching land with land use. The Phase 2 survey recognizes that the land unit comprises a mosaic of more-or-less favourable sites for the location of particular elements, and thus aims to reveal landscape variations. There are likely to be many relevant landscape features which have so far been precluded from consideration due mainly to their restricted spatial extent relative to the size of the land unit. Hence, landscape features such as minor gullies and drainage depressions, small rock outcrops, microtopographic variations, frost pockets, and particularly well sheltered areas are shown on a base plan. The scale of mapping will depend to a large extent on the size of the land unit and the degree of landscape variation, nonetheless, scales of between 1:2000 and 1:10000 could be expected to be adequate in most situations.[10] The second activity, namely, land unit appreciation, is concerned with visual/aesthetic aspects. Thus, views, into and out of the land unit, judgements as to their visual quality, and recommendations for screening or the maintenance of the vista are noted on the base plan. Also, spaces with distant local character, and transitions (see Sec. 5.4.1) which require careful treatment are recorded. Photos and sketches may be required to supplement the base plan representations. An example of survey and appreciation is shown in Figs. 8 and 9 respectively (see also Weddle, 1979). The area shown is land unit 4 (see Fig. 5).

(ii) <u>Identification of Land Unit Constraints and Potentials</u>; at this stage, the constraints and potentials in regard to the proposed L.U.T. are identified in the light of survey and appreciation (Fig. 7). The L.U.T. specifications to some extent determine the severity of the constraints. For example, the area of poor drainage at the foot of the road embankment, and the surficial gravel deposits mid-slope (Fig. 8), could be expected to exercise constraints on tree establishment in general. However, whether or not such areas are to be excluded from planting is dependent on the environmental requirements of the particular species noted in the L.U.T. On the

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10. At these scales it is possible to map a variety of landscape elements which may be relevant to design (see Speight, 1984).

fig 8

Land unit survey.

(land unit 4: see fig. 5)

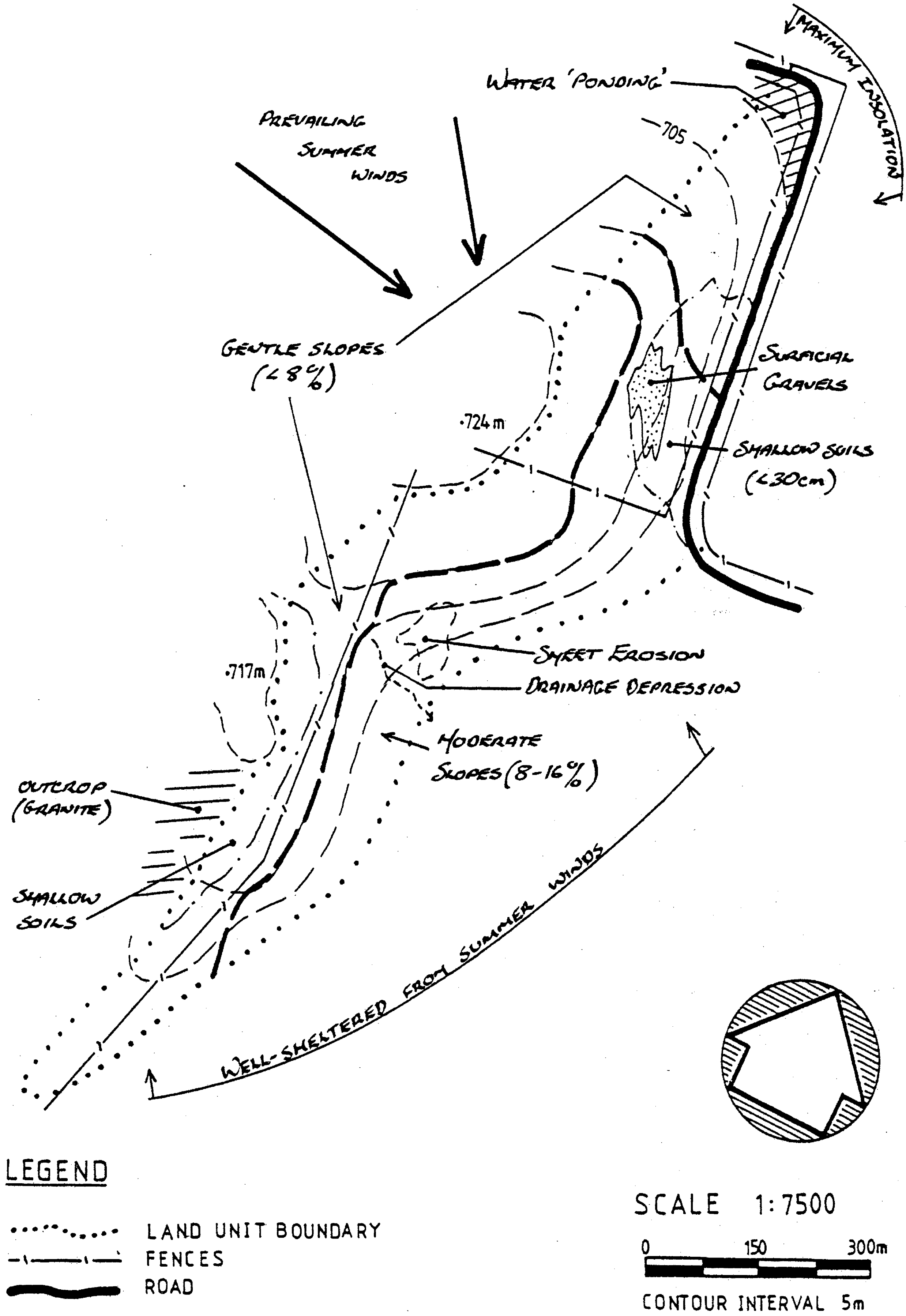
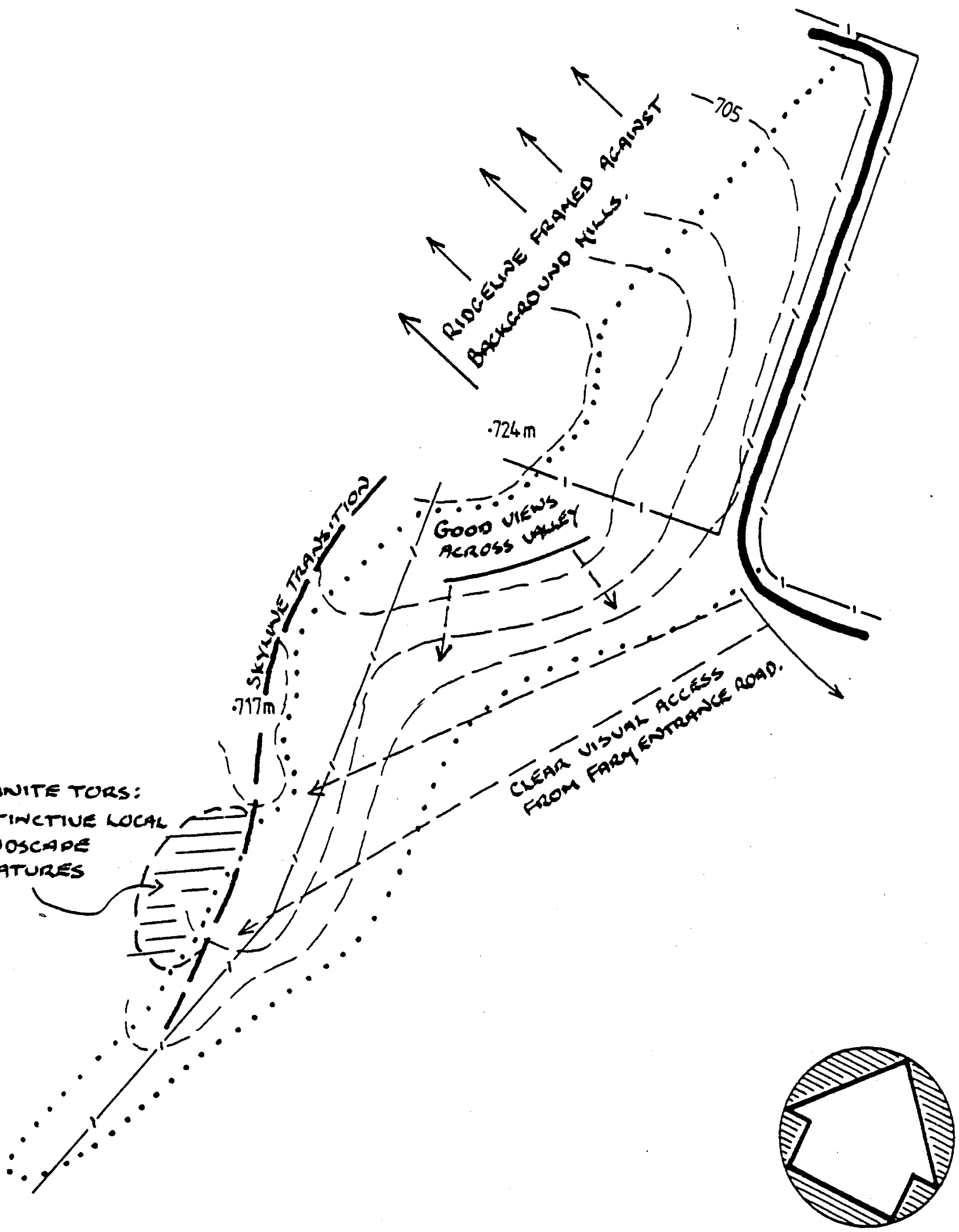


fig 9

Land unit appreciation.

(land unit 4: see fig. 5)



LEGEND

LAND UNIT BOUNDARY
FENCES
ROAD

SCALE 1:7500

0 150 300m

CONTOUR INTERVAL 5m

other hand, some constraints will operate irrespective of species. For example, in the land unit appreciation (Fig. 9) the granite tors are suggested to be an area of distinct local character, and thus, visual access recommendations may act as a constraint on tree planting of any kind on some portions of the land unit (Fig. 9). The delineation of areas showing constraints or potentials for the proposed L.U.T. can be indicated on a clear plastic overlay. This, together with the L.U.T. specifications, represents the Phase 2 design context (Fig. 7).

(iii) Identification of Specific Design Problems; as in Phase 1, specific design problems become clear once the design context is clarified (Fig. 7). The shape of elements, and their location relative to each other is the central issue at this stage. Shape is determined primarily by function (see 5.5.2), which will have been noted in the L.U.T. specification. However, it also needs to be specified within the context of the previously determined constraints and potentials. For example, an 'L' shaped windbreak may be functionally appropriate, however, landscape constraints may make implementation difficult. This situation can occur where one leg of the windbreak traverses across slope, and the other up-slope. The up-slope plantings, in some instances, show retarded growth due to shallower soils towards the ridge top and less moisture, whereas those across slope fare much better as a result of relatively deeper soils and run-off interception (pers. obs.; Bega Valley, N.S.W.). The end result is a windbreak of uneven height and density, and consequent 'wind funnelling' along the more advanced plantings when wind direction shifts to the less developed up-slope side. Conversely, it is not uncommon to find windbreak shape determined by landscape potential, rather than function. A common example is windbreaks, which in plan-view faithfully reflect paddock shape, rather than the prevailing wind direction. The main reason is that the existing fences are seen as a potential, in that they reduce new fencing requirements to one, rather than two, windbreak edges. The second aspect, namely, the location of elements in relation to each other, can be partially resolved by 'functional analysis' (see Sec. 4.2.2). This requires a clear recognition of function, and a consideration of inputs and outputs and their integration in order to find the 'ideal' spatial arrangement of elements. However, as for shape, relative location will to a large extent depend on landscape constraints and potentials. For example, topographic variation, size of catchment area and soil-type, will determine the practicability of siting water storage up-slope of tree and/or crop elements for the purposes of 'gravity-fed' irrigation. In general, the aim at this stage is identify where the 'ideal' shape and spatial arrangement of elements is discordant with the land units' constraints and potentials.

(iv) <u>Design Proposal: Detailed Land Unit Plan</u>; this represents an attempt to specify form (shape and spatial arrangement) which is likely to engender beneficial interactions between elements, but at the same time is realistic given the landscape constraints and potentials. The location and shape of elements is shown in plan view, along with relevant existing features (topographic variation, fences, access tracks etc.). Elements such as dams may need to be shown on a separate larger scale plan to accurately specify form. The land unit plans will need to be supplemented by section and elevation drawings to provide a more complete picture of proposed developments.

5.6.3 Phase 3: Working Specifications

In some instances, accurate large-scale plans showing the dimensions and precise location of elements may be required. Examples include earth-works such as road embankments, dams and drainage diversions. Also, plantations with shapes derived from landform, or the more complex regular shapes (eg. hexagonal), would require additional specification to that provided in the land unit plan. Working specifications are particularly important where the designer (or representative) is not involved in implementation. Even relatively simple operations, such as fencing-off a farm wildlife refuge, can be done wrongly if left entirely in the hands of a contractor unfamiliar with the design concept (R. Breckwoldt, 1987; pers. comm.).

5.7 Conclusion

A framework for farm-scale agroforestry design has been established by first clarifying the nature of agroforestry design, and, in the light of this, presenting a systematic design procedure. As a result, the latter clearly reflects the general design implications drawn from the concept and practice of agroforestry (Sec. 5.2), and is coherent with the explanation of (a) the design context (b) visual, functional, and ecological 'appropriateness', and (c) the specification of form (Secs. 5.3, 5.4 and 5.5 respectively).

First, the procedure recognizes that since agroforestry is an integration of forestry and agriculture, information from both disciplines is required to produce a design proposal. Moreover, the concept of a 'design context' requires that such information encompass both socioeconomic and biophysical information. This is made explicit in the broad ranging data requirements of the initial survey and subsequent land evaluation stage. Undoubtedly, other disciplines besides forestry and agriculture will provide important inputs, nonetheless, the main point is that the design procedure presented here is capable of accommodating such diverse inputs. Indeed, the latter are required to resolve the design context to the extent where the production of physical suitability maps and a specific statement of design goals are possible (see Fig. 6).

The second implication is that an agroforestry design procedure must give attention to socioeconomic conditions; this follows from a consideration of agroforestry as a form of social forestry. The way in which the design procedure accommodates socioeconomic factors has been noted in the above. In addition, it is clear that the primary design goal of 'social value', and the secondary goal of 'adoptability', provide further impetus for a close examination of socioeconomic conditions.

The third implication for agroforestry design follows from the observation that agroforestry encompasses a diversity of land use practices, and is potentially suitable for a broad range of socioeconomic and biophysical conditions. Thus, an 'agroforestry design procedure' must be presented in a form which is applicable to a wide variety of situations. Clearly, the proposed procedure, although representing a considerable elaboration on the general model of the landscape design process, retains sufficient generality to ensure wide applicability. This stems largely from the fact that the procedure is built around several fundamental concepts which are applicable to design in any situation. These concepts are (a) design is the specification of form (b) form is the shape and spatial arrangement of landscape elements, and (c) form must be expressed within a design context which is set by biophysical and socioeconomic conditions, and specified design goals. On the other hand, a degree of specifity is provided in the detailed outline of the procedure. For example, the description of the land evaluation stage clearly places the procedure within the context of agroforesty.

The fourth implication is that agroforestry design must be concerned to create beneficial interaction between elements; this follows from the definition of agroforestry as a land use system which has ecological and economic interactions between the woody and non-woody elements. In the first instance, 'beneficial interactions' can be considered as those which enable the system to fulfil its' proposed function. The latter may be of an ecological (protective) or economic (productive) nature, and are recognized in the notion of 'functional appropriateness'. Furthermore, 'beneficial interactions' are extended to include those which (a) create an aesthetically pleasing landscape (ie. are 'visually appropriate'), and (b) promote sustainability (ie. are 'ecologically appropriate'). All these aspects are recognised at a fundamental level, that is, the understanding of a design proposal as a specification of form which is visually, functionally, and ecologically appropriate, and the notion that beneficial interactions are engendered by particular shapes and spatial arrangements.

The fifth, and final implication for design, concerns agroforestry as a conservative and sustainable land use. This aspect is recognized first, by specifying 'sustainability' as a design goal, and second, by noting 'ecological appropriateness' (a specification of form which engenders sustainability) as a basic requirement of the design proposal.

Thus, the proposed agroforestry design procedure and the concepts which underly it are concordant with the concept and practice of agroforestry as presented in this thesis. Nonetheless, the procedure must be regarded as an initial statement on agroforestry design, which will require modification and refinement in the light of field experience. As it stands, the procedure redresses the failure of existing design approaches to satisfactorily resolve the design context as a result of insufficient attention to socioeconomic conditions. Furthermore, it recognizes (a) the need for a systematic method of land assessment in the early stages of design, and (b) the importance of providing a synthesis of biophysical and socioeconomic aspects in order to resolve the design context.

Finally, the procedure recognizes that at the farm-scale the specification of form requires a three-phase approach. The first gives an approximate positioning of elements by determining the spatial arrangement of land utilization types, which, along with focal points, fences, access roads and tracks, are shown on the farm master plan. The second phase results in an accurate specification of the shape and spatial arrangement of elements on the subdivisions of the farm landscape (ie. land units). The design context and specific design problems are identified during phase one, and again in phase two. This is recognition of the fact that the landscape rarely shows the uniformity assumed in the delineation of land units. The small-scale variations within land units offer constraints and opportunities which may be crucial to the production of a realistic design proposal. The third, and final phase, involves the production of working specifications. These communicate the designers' intentions to the landowner/contractor, and mark the end of the agroforestry design procedure.

CHAPTER SIX

Discussion and Conclusion

6.1 Discussion

Agroforestry is a rural land use which has the potential to provide social benefits through the sustainable production of food and raw materials and the conservation of natural resources. In order to fully realise this potential careful design is clearly necessary. However, as a design subject, agroforestry has so far received little attention. Margules' (1970:34) observation that 'Foresters and other single discipline trained professionals, continue to make the mistake of neglecting the aspect of design' is nowhere more apparent than in the field of agroforestry. The few works which consider design (eg. Oates and Clarke, 1987; Reid and Wilson; 1985) do so in a superficial manner, and show little understanding of the precedences which have been set in the established field of landscape design. This thesis has attempted to redress this situation by presenting a systematic procedure for the design of agroforestry systems, based on the rational problem-solving approach common in contemporary landscape design.

The proposed procedure has been developed against a background which has the following major components:

(i) an understanding of design as 'the specification of the form of landscape elements which are visually, ecologically and functionally appropriate within the context of particular landscapes, socioeconomic conditions and design goals'.

(ii) a normative model of the landscape design process, which in its' basic form can be expressed as RESEARCH - ANALYSIS - SYNTHESIS - DESIGN - EVALUATION.

(iii) an understanding of agroforestry as 'a collective name for land-use systems and technologies where woody perennials are deliberately used on the same land management unit as agricultural crops and/or animals, in either a spatial arrangement or a temporal sequence, there being both ecological and economic interactions between the different components'.

(iv) a review of existing design approaches applicable to agroforestry.

The resulting three-phase design approach, and the explanation of associated concepts, must be regarded as an initial statement on agroforestry design which will need modification and refinement in the light of field experience. Nonetheless, the previously ill-defined area of agroforestry design has been clarified, and a framework established to facilitate further developments. The latter must include (a) a consideration of the conceptual and methodological design problems associated with the temporal aspects of agroforestry, (b) the establishment of more specific design statements applicable to particular agroforestry systems and landscapes, and (c) the establishment of a framework for design at other landscape scales (eg. the catchment).

In its' present form the procedure has the following strengths:

(i) it is logically defensible

(ii) it has a capacity to incorporate information from the diversity of sources relevant to agroforestry

(iii) requires close attention to socioeconomic conditions

(iv) provides a systematic approach to the problem of agroforestry land assessment

(v) provides a comprehensive synthesis of biophysical and socio-economic conditions

(iv) recognizes that a farm landscape requires land unit subdivision to facilitate the production of a design proposal which first, accurately reflects the conditions of the landscape, and second, is useful for the purpose of on-ground implementation.

6.2 Conclusion

The successful establishment and functioning of agroforestry systems will depend to a large extent on design procedures which reflect a clear understanding of the basic concepts of design and an appreciation of the complexities of agroforestry land use. Both aspects have been addressed in this thesis in order to provide a framework for agroforestry design. The central feature of this framework is a three-phase design procedure, which although more complex than existing 'agroforestry design approaches', is nonetheless realistic given the complexities inherent in a land use which must be both sustainable and productive, and moreover, adaptable to a wide range of biophysical and socioeconomic conditions.

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APPENDIX ONE

Temporal and Spatial Arrangement of Elements in Some Common Agroforestry Systems.

System	Sub-systems/ practices	Primary role of woody perennials	Arrangement of elements in space(s) and time (t)	Nature of major type of interactio[n] between elements
Agrisilvicultural	Hedgerow intercropping (Alley cropping)	Protective (soil productivity)	s: Zonal (strip) t: Concomitant	Spatial
	Improved fallow	Protective (soil productivity) and productive	t: Sequential (time-dominant)	Temporal
	Multistorey crop combination	Productive	s: Mixed, dense t: Coincident	Spatial and temporal
	Multipurpose trees on farmlands	Productive	s: Mixed, sparse t: Interpolated	Spatial
	Shade trees for commercial plantation crops	Protective and productive	s: Mixed (scattered) or Zonal; t: Coincident	Spatial and temporal
	AF fuelwood production	Productive	s: Zonal (strip/boundary) t: Coincident	Temporal and spatial
	Shelterbelts and windbreaks	Protective	s: Zonal (boundary) t: Coincident/ Interpolated	Spatial
Silvopastoral	Protein bank	Productive (and protective)	s: Zonal t: Coincident/ Interpolated	Temporal
	Living fence	Protective	s: Zonal/boundary t: Coincident	Spatial
	Trees over pastures	Productive (and protective)	s: Mixed, sparse t: Coincident	Spatial
Agrosilvopastoral	Woody hedgerows for browse, mulch, green manure and soil conservation	Productive and protective	s: Mixed or zonal (strip) t: Coincident	Temporal and spatial
	Tree-crop-livestock mix around homesteads	Productive and protective	s: Mixed t: Coincident/ Intermittent	Spatial and temporal
	Agrisilvicultural to silvopastoral	Productive	s: Mixed t: Overlapping to separate	Temporal and spatial

Source: Nair (1985)

APPENDIX TWO

Classification of Agroforestry Systems.

Sub-system/Practice (indicating the arrangement of components)	Major output/function	Country/ Region	Socio-economic scale of production	Some of the woody species involved
I.A. Agrisilvicultural systems – Humid lowlands				
Improved 'Fallow' (in shifting cultivation areas)	Food and wood production; Soil fertility improvement	Indonesia	Subsistence	*Aleurites molucana* *Erythrina* spp. *Styrax* spp.
Woody species planted and left to grow during the 'fallow phase'		Nigeria	Subsistence	*Acioa barterii* *Anthonotha macrophylla*
Multispecies mixes (Tree gardens) Multilayer, multi-species, dense plant associations with no organized planting arrangement	Production of food, fodder and wood products for home consumption and sale for cash	Nigeria	Subsistence	*Daniellia oliveri* *Gliricidia sepium* *Parkia clappertoniana* *Pterocarpus africana*
		Pacific Islands	Subsistence	*Inocarpus edulis* *Morus nigra* *Spondias dulce*
		India Sri Lanka	Subsistence, Intermediate	*Areca catechu* *Artocarpus* spp. *Cocos nucifera* *Mangifera india*
		Paraguay	Subsistence, Intermediate	*Melia azedarach* *Leucaena leucocephala*
		S.E. Asia	Subsistence Intermediate	*Albizia falcataria* *Artocarpus* spp.
I.B. Agrisilvicultural systems – Tropical highlands				
Multipurpose trees and shrubs on farm-lands	Food production; Soil conservatin	India	Subsistence	*Alibizia* spp. *Bauhinia variegata* *Dalbergia sissoo*
		Kenya	Subsistence	*Ceiba petandra* *Eriobotrya japonica* *Grevillae robusta*
		Nepal	Subsistence	*Bauhinia* spp. *Erythrina* spp. *Ficus* spp *Litsea polyntha*
		Paraguay	Subsistence	*Melia azedarach*
		Tanzania	Subsistence	*Albizia* spp. *Cordia africana* *Croton macrostachys* *Trema guineensis*
II.B. Silvopastoral systems – Tropical highlands				
Protein bank	Production of fodder/ animals and fuelwood; Soil conservation	Indian sub-continent	Mostly subsistence	*Albizia stipulata* *Bauhinia* spp. *Ficus* spp. *Grewia oppositifolia* *Morus alba*
III. Agrosilvopastoral systems				
Woody hedgerows for browse, mulch, green manure and soil conservation	Production of food/fodder/ fuelwood; Soil conser-vation	Indian sub-continent (Humid lowlands), S.E. Asia	Mostly subsistence	*Erythrina* spp. *Leucaena leucocephala* *Sesbania* spp.
Tree-crop-livestock mix around homestead (known as Home Gardens, these dense associations are found in almost all ecological regions and several countries; only some examples are gicen)	Production of food/fodder/ fuelwood, etc. for home consumption; and, sometimes, for sale (cash)	Sourh and SE Asia (Humid lowlands)	Subsistence o intermediate	
		Nigeria (Humid lowlands)	Mostly subsistence	
		Latin American countries	Mostly subsistence	
		Tanzania (Highlands)	Subsistence to intermediate	

Examples of agroforestry systems classified according to structural, functional, socio-economic, and ecological criteria (from Nair, 1985).

APPENDIX THREE

Survey Form: Forest Farming.

PART I - ECOLOGY

(a) Site:

(b) Natural Vegetation:

	Trees	Shrubs	Grasses	Other types	Barren
Species & genus					

Present vegetation (if changed by developments)

Life forms (note if drought-resistant, conventional, or other types)

(c) Habitat factors:

(i) Climatic;

rainfall (monthly average)

humidity

saturation deficit

wind (prevailing and intensity)

temperature (monthly average, maximum & minimum)

light (average hours for each month)

other influences

(ii) Physiographic;

elevation above sea-level

slope

erosion

denudation

cold-air drainage

waterlogging

salinity

other influences

(iii) Edaphic;

soil type

soil mineral matter

mechanical composition

organic matter

humus & organisms
solution acidity (pH)
soil water (hygroscopic, capillary, gravitational, pF)
soil atmosphere and drainage
soil temperatures
other influences

(iv) Biotic;
human activities
animals (grazing, trampling, etc.)
plants (preferences, light and shade or microclimate, competition, spread and other relevant matters)
pests and diseases already in evidence

(d) General:

(Enter any further comments including likely effects, adverse or favourable, of developments upon the local and adjacent habitats).

PART II - ECONOMICS

(a) Economic Factors:

(Mention markets and costs)

(b) Situation:

(Transport facilities, and other important details)

PART III - SILVICULTURE/PASTURAGE/LIVESTOCK

(a) Cultural facilities afforded: (State briefly the conditions offered to crops as deduced from Part I.)
Trees and shrubs
Grasses and herbage
Livestock (types)

(b) Special requirements:

Protection
Environmental limits (heat, cold, aridity, salinity, etc.)
Conservation
Controls
Buildings and equipment
Other needs

(Any further factors)

Form of survey for the collection of information about a locality and its usefulness for the growing of tree crops. (from Douglas and Hart, 1978)

APPENDIX FOUR

Diagnosis and Design Methodology: Factors to Consider in the Four-Stage Design Procedure.

Prediagnostic stage

1. Environmental description of study area;

   (a) biophysical factors,

   (b) socioeconomic factors,

   (c) structure and function of the human ecosystem of the area.

2. Differentiation of land use systems within the study area;

   (a) land units (possessing a similar set of biophysical characteristics),

   (b) management units (with similar production objectives and resources),

   (c) land use systems (distinctive combinations of land units and management units).

3. Preliminary description of selected land use system(s);

   (a) structure and function of supply subsystems at the management unit level,

   (b) additional descriptive information on production activities (agricultural, forestry, livestock and agroforestry practices).

Diagnostic stage

4. Diagnostic survey;

   (a) problems and potential at the ecosystem level,

   (b) problems and potentials at the management level (supply problems and their casual factors, present constraints and problem-causing syndromes, future sustainability problems),

   (c) farmers' strategies for coping with identified problems.

5. Diagnostic analysis;

   (a) present problems and potentials at the ecosystem level,

(b) present problems and potentials at the management unit level,

(c) sustainability problems.

6. Derivation of specifications for appropriate technology;

(a) general development strategy for the system,

(b) functional potentials for problem-solving interventions,

(c) potentials for improving resource utilization,

(d) possible constraints on candidate technologies.

Technology design stage

7. Technology appraisal;

(a) main criteria are given in preceeding step (design specifications),

(b) state of the art with respect to the various candidate technologies (both agroforestry and non-agroforestry).

8. Technology design;

(a) design specification,

(b) candidate technologies,

(c) function and location of components within the system, component species, number of components, spatial arrangement and management of component combinations,

(d) overall productivity, sustainability and adoptability of the design.

9. Design evaluation;

(a) productivity,

(b) sustainability,

(c) adoptability.

Follow-up planning

10. Topics requiring further D&D attention;

    (a) requirements for additional diagnostic information and analysis,

    (b) requirements for more complete information on candidate technologies needed to refine the initial design,

    (c) requirements for in-depth economic, ecological and social evaluation of the proposed design.

11. Research needs;

    (a) state of the technology art and the suitability of different classes of technology (notional, preliminary, validated) for different types of research (on-station, on-farm),

    (b) whether the envisaged follow-up to the D&D exercise is essentially research-orientated or development/dissemination-oriented,

    (c) farmers' and research/extension officers' attitudes towards on-farm experimentation;

    (d) riskiness of the proposed technologies,

    (e) need for candidate technologies to be exposed to a wider or more realistic set of environmental and farming system conditions (than would be available on research stations).

12. Project implementation plan;

    (a) topics needing further D&D attention during the course of the project,

    (b) research needs,

    (c) feedback from farm trials (including farmers' evaluation and suggestions) and on-station experimental work in the course of the project (suggesting modifications and refinements in the technologies and the plan of work).

Source: Raintree (1984)

APPENDIX FIVE

Form of Survey: Biophysical Conditions
(ICRAF's Environmental Data Base).

1. LOCATION:

Country
Direction and distance from major popn. centre(s)
Latitude and longitude
Altitude

2. GEOLOGY:

Summary level

Class; crystalline, sedimentary or surficial deposits. The first group is subdivided into basic and felsic rocks, the second, into siliceous and calcareous, and the last covers river alluviums, aeolian sands etc.

Level 1 detail

General description of rock type; sandstones, quartzites etc.

Level 2 detail

Specific description; grain size, age, formation, lithology.

3. LANDFORMS:

Summary level

Class; classification based on slope (steep > 17°, moderate 17° to 5°, gentle < 5°). Depositional landforms (alluvium, coastal plains) separated from gently-sloping landforms of erosional origin, with a further class of 'swamps').

Level 1 detail

General description of landform; e.g. 'gently undulating plain with broad concave valley floors', plus numerical value of slope or slope range, and relative relief.

Level 2 detail

Specific description; slope shape and position on slope.

4. CLIMATE:

Summary level

Class; according to Koppen system.

Level 1 detail

General description of climate; altitudinal zone, rainfall regime, annual temperature, annual rainfall, number of dry months.

Level 2 detail

Specific description; mean monthly rainfalls, temperature of hottest and coldest months, rainfall for driest month, frost incidence, mean annual E_0, humidity index, growing period.

5. HYDROLOGY:

Summary level

Class; based on degree of surface water logging i.e. wet permanently, seasonally, or not at all.

Level 1 detail

Groundwater conditions; fresh or saline, and mean depth for year.

Level 2 detail

Groundwater; lowest and highest values for depth.

River regime; perennial, intermittent, seasonal or none.

Degradation; effects on flow regime through deforestation, siltation etc. noted as absent, present or severe.

Flooding; noted as never, rare, common or absent.

6. SOILS:

Summary level

Class; any or all of a generalized classification (e.g. desert, saline, alluvial etc.), F.A.O. soil class, or national or local classification.

Level 1 detail

General description of soil; any other classification, texture, reaction, drainage, other features.

Level 2 detail

Specific description; texture class (topsoil and subsoil), reaction (topsoil and subsoil), drainage, limiting horizon (depth and material), degradation (severity and type).

7. VEGETATION:

Summary level

Class; given for area and site in general terms e.g. rainforest, or, if cultural vegetation recorded as 'planted'.

Level 1 detail

Physiognomic description and notes on dominant and other species.

Level 2 detail

Degradation; severity and type.

8. FAUNA AND DISEASE:

(no summary level or Level 2 data)

Level 1 detail

Record significant fauna, pests or diseases affecting plants (trees or crops) or animals.

9. LAND USE:

Summary level

Class; record classes of land use (e.g. irrigated agriculture, livestock production, forestry, recreation, wildlife conservation etc.) in order of area covered.

Level 1 detail

General description of land use practices.

(no Level 2 detail)

10. OTHER INFORMATION

Notes on distinctive features of the environment, additonal data not already recorded, sources of information etc.

Adapted from Young (1985).

APPENDIX SIX

Check List of Land Qualities for Agroforestry

Land quality/ Land use requirement or limitation		Subdivision of land quality	Land characteristics (examples)
A. <u>QUALITIES AFFECTING GROWTH</u>			
1. Radiation regime/ Radiation requirements	1	For growth	Total radiation. Net radiation. Sunshine hours, annual. Sunshine hours, growing season.
	2	Photoperiodism	Day length/season. (Latitude)
2. Temperature regime/ Temperature requirements	1	For growth	Mean annual temp. Mean growing season. Altitude. Mean, hottest month. Mean, coldest month. (Climatic type) (Latitude)
	2	Heat tolerance	Mean max. hottest month. Extreme max.
	3	Cold tolerance	Mean min. coldest month. Absolute min. temp. Frost frequency.
3. Moisture availability/ Moisture requirements	1	For growth	Growing period. Mean annual rainfall. Rainfall, growing season. Rel. E_T Deficit. Confidence limits for four above. Rainfall/Eo. Rainfall regime. (Climatic type)
	2	Critical periods	Rainfall critical period. Rainfall driest month. Rel. ET deficit crit.per. Groundwater depth, lowest.
	3	Drought hazard	Dry season, length. Probability significance, drought.
	4	For animals	Distance to source. Water quality, salts.

Land quality/ Land use requirement or limitation		Subdivision of land quality	Land characteristics (examples)
4. Soil drainage/ Aeration (oxygen) requirements	1	-	Soil drainage class. Groundwater depth, mean. Groundwater depth, highest. Period waterlogging.
5. Rooting conditions/ Rooting requirements	1	-	Soil effective depth. Stones and gravel. Outcrops and boulders. Soil structure. (Soil texture)
6. Nutrient availability/ Nutrient requirements	1	Total/general	Class.
	2	Availability	(pH)
	3	Retention	CEC OM % Clay%
	4	N	Total
	5	P	Available. Reserve/total.
	6	K	Exchangeable. Reserve/total.
	7	Other nutrients	Various
7. Conditions for germination and establishment/ Requirements for same	1	-	Surface sealing/crusting. (Soil texture) Measures of climatic reliability/season.
8. Conditions for ripening, maturing/ Requirements for same	1	-	Dry season, length. Humidity/season.
9. Climatic and physiographic hazards/Suscepti-bility to same	1	Flood	Flood frequency. Period of inundation.
	2	Landslide	Obs. freq./estim. hazard.
	3	Wind, storm	High wind frequency. Exposure (indices).
	4	Fire	Length dry season. Obs. freq./estim. hazard.
	5	Hardship for animals	High temperatures. Low temperatures, frost, snow
10. Salts/ Tolerance of salts	1	Salinity	ECE TSS (Soil type)
	2	Sodicity	ESP SAR (pH, alkaline) (Soil type)

Land quality/ Land use requirement or limitation		Subdivision of land quality	Land characteristics (examples)
11. Soil toxicities/ Tolerance of same	1	Aluminium/acidity	pH Exchangeable Al
	2	Carbonates	$CaCO_3$ % Depth to calcrete.
	3	Acid sulphate	Presence. Estimated hazard.
	4	Micronutrients	Presence fo toxicities.
12. Biological hazards/ Susceptibility to same	1	Weeds	Observed/estimated.
	2	Pests	Animals, predators. Birds. Insects.
	3	Diseases	Plant diseases, obs./est. Animal diseases, obs./est.
B. <u>DIRECT ESTIMATES OF GROWTH</u>			
13. Direct observatons or estimates of yield or production	1	Existing resources	E.g. by forest inventory, pasture survey.
	2	Predicted yield	E.g. by crop yield modelling forest site index.
	3	Survival	Observed or estimated.
	4	Genetic potential	Measures of biological diversity, presence of species.
C. <u>QUALITIES AFFECTING MANAGEMENT</u>			
14. Conditions affecting mechanization/ Requirements for mechanization	1	For operations before and during growth	Slope angle. Outcrops, boulders. Terrain class.
	2	For harvesting	Slope angle. Outcrops, boulders. Terrain class.
15. Soil workability/ Requirements for soil workability	1	-	Class. Soil structure. (Soil texture)
16. Conditions affecting land preparation/ Requirements for land preparation	1	Movement of earth, rock	Slope. Microrelief. Outcrops, boulders.
	2	Vegetation clearance	Vegetation cover.

Land quality/ Land use requirement or limitation		Subdivision of land quality	Land characteristics (examples)
17. Conditions affecting storage and processing/ Requirements for same	1	Storage	E.g. humidity.
	2	Processing	E.g. humidity.
18. Timing of production/ Requirements for location	1	-	E.g. harvest dates.
19. Location/ Requirements for location	1	-	E.g. distance to markets, to road.
20. Size and internal accessibility/ Requirements for same	1	Size of potential management units	Hectares.
	2	Internal access (by man)	E.g. slope.
	3	Internal access by animals	E.g. Swamps, dense vegetation
	4	Conditions affecting fencing, hedging	E.g. availability of materials.
D. QUALITIES AFFECTING CONSERVATION AND ENVIRONMENTAL IMPACT			
21. Soil degradation hazard/Soil degradation susceptibility	1	Water erosion	Modelled or estimates soil loss, bare ground. Modelled or estimated soil loss under land use. Slope angle.
	2	Wind erosion	Modelled or estimated soil loss, bared ground. Modelled or estimated soil loss under land use. Wind severity/frequency.
	3	Soil physical degradation	(Soil texture) Organic matter %.
	4	Salinization	Present soil salinity. Groundwater level. Groundwater salt content. (Soil type)
	5	Soil chemical degradation	(pH)
	6	Biological degradation	Organic matter %

Land quality/ Land use requirement or limitation		Subdivision of land quality	Land characteristics (examples)
22. Degradation of hydrological regime/Requirements for preservation	1	River flow	-
	2	River water quality	-
	3	Groundwater level	-
23. Biological degradation/ Requirements for preservation	1	Vegetation degradation	Present veg. status.
	2	Species preservation, plant	Presence of rare species.
	3	Species preservation, animal	Presence of rare species.
	4	Effects on disease	-
24. Loss of amenity, recreation/ Requirements for preservation	1	-	Existing use for recreation, amenity.

E. <u>LAND CHARACTERISTICS AFFECTING MULTIPLE LAND QUALITIES</u>

	Land characteristics	Land qualities or subdivisions affected
1	Latitude	Photoperiodism, temperature for growth.
2	Climatic type	Radiation for growth, temperature for growth, moisture for growth/critical periods/drought hazard.
3	Slope angle	Landslide hazard, mechanization, land preparation, internal access, soil erosion hazard.
4	Soil type	Drainage, rooting, nutrients, salts, toxicities.
5	Soil texture	Rooting, nutrients, mechanization, workability.
6	Soil reaction (pH)	Nutrient availability, salts, Al-toxicity.
7	Vegetation type	Synthesis of growth requirements and direct estimate of vegetation resources.

Source: Young, 1984b.

ADDENDUM

The Role of Research in Agroforestry Design

As pointed out in Chapter 2, 'the formulation of proposals involving landscape change for agroforestry is the province of rural landscape planning', and, the three major components of the latter, namely, design, technical and decision-making activities (see Fig. 1), 'will direct the course towards the creation of an agroforestry system' (p.14). Furthermore, the success or failure of the system will be largely dependent on a thorough consideration of each planning component (p.14). Thus, at the outset, explicit recognition is given to technical-research activities (along with 'decision-making') as complementary and indispensible companions to the process of agroforestry design. In other words, while research on technical matters (eg. specification of 'beneficial' plant interactions, ecological aspects of shape, investigations into economics and marketing of unusual products) is excluded from design per se, it is nonetheless seen as integral the overall planning process in which design is set (see Fig 1).

Clearly, lack of technical knowledge will hinder the development of firm design guidelines, and may result in the production of unrealistic design proposals. However, this does not detract from the validity of the design framework as presented in this thesis. From a practical viewpoint, design must often proceed despite lack of technical knowledge. Indeed, many of the environmental problems which agroforestry has the potential to redress (see pp. 22-29) require urgent action through design based on currently available knowledge. It may not be possible, in some situations, to await the results of long-term research. In view of this, the agroforestry design framework is directed towards direct implementation rather than research (p. 73). However, where urgent action is not required, the design procedure is compatible with the comprehensive planning approach represented by the 'Diagnosis and Design" methodology (pp. 72 to 75), being a detailed statement of what is required at step 8 (see Appendix 4). This situation had already been conceptualised by placing design in the context of landscape planning (see Sec. 2.2).

Even if the agroforestry design procedure is considered in isolation, the framework will direct the designer/s to consider technical research beyond that indicated in the research stage of design (see Sec. 5.3.4). For example, the ecological aspects of shape (pp. 116-119) require consideration even if the designer/s subjective views are that aesthetic criteria (see Sec. 5.4.1) have been met. This will occur because the basic tenet of agroforestry design is that form must be ecologically, as well as, visually appropriate (see Sec. 2.5). It may be that ecological data is simply not available, in which case the designer must request assistance from the technical component of the planning process (see Fig. 1). If such assistance is not forthcoming (for whatever reason) the exigencies of the situation may necessitate that design proceed on the basis of the best available current knowledge. The design framework as presented in this thesis facilitates this.

In summary, technical research is regarded as an important input in the design process. However, substantial research results may, in some instances, take many years to accumulate. It is considered preferable for the formal landscape design and planning process to proceed at all times on the clear understanding that design has to be based on current available knowledge. The degraded state of many environments suggests that such a pragmatic approach is desirable in the agroforestry field.