McCown, R.L., Jones, R.K., and Peake, D.C.I. (1985) Evaluation of no-till tropical legume ley farming strategy. In: Muchow, R.C. (ed) *Agro-Research for the Semi-Arid Tropics: North-West Australia*. pp. 227-269. (University of Queensland Press: St Lucia.)

ABSTRACT

Most of tropical Australia's land is utilised only for extensive grazing of beef cattle. Technology now exists for improving the productivity of these lands many-fold by oversowing with legumes, but it is generally not profitable. Dryland cropping appears to hold considerable commercial promise when appropriate technology is used, but costs are high and prices low relative to southern Australia. This paper reports on the evaluation of a farming strategy in which net benefits are enhanced by synergies gained by integrating beef production and cropping. This strategy is stated as a hypothetical system with the following features:

- Self-regenerating legume ley pastures of 1-3 years duration are grown in rotation with maize or sorghum;
- Cattle graze native grass pastures during the green season and leguminous pastures and crop residues in the dry season;
- Crops are planted directly into the pasture, which is chemically killed at, or shortly before, planting;
- The pasture legume sward, which volunteers from hard seed, is allowed to form an understory in the main crop.

The research program uses a systems approach in evaluating the biological feasibility of this system for this climatic zone. In this preliminary stage of evaluation it is important that results not be location-specific: emphasis is placed on explaining the dependance on climatic and edaphic variables. Important findings include:

- One year of legume ley generally has provided a succeeding crop with the equivalent of 50-75 kg fertiliser N. Longer leys have had greater effects and a longer residual impact.
- Mulch retention due to no-tillage generally has resulted in increases in maize grain yield of over 20 per cent.
- Herbicide and planting technologies have been developed to allow on-farm evaluation to proceed.
- Cattle have gained weight during the dry season when grazing legume leys and maize standover material.

22.1 Introduction

To a great many people from early settlers to today's farmers and agricultural scientists, the true agricultural potential of Australia's semi-arid tropics (SAT) was, and remains, an enigma. Research has shown that in many growing seasons impressive crop yields can be achieved. However, this apparent productive capacity has never been reflected as sustained profitability in any of

the several attempts at commercial dryland cropping, and the original low-input cattle grazing system continues to be the only economically successful use of this land.

Past unsuccessful attempts at commercial cropping made little effort to tailor imported technology to the special problems of this frontier region. Today, as a new effort to develop agriculture is being considered, we face a crucial question. Is the key to a profitable, permanent industry the development of farming systems much better suited to this environment, or, under current economic and political conditions, will the inherent limitations imposed by climate and soil, together with geographic isolation, prevent *any* capital-intensive farming system from succeeding? This paper describes research aimed at (1) deriving an optimum farming strategy for this region and (2) making a preliminary assessment as to whether it is good enough.

Of the vast areas of undeveloped land in this region only a small fraction is proving to be potentially arable (Williams et al., chapter 3, this volume). This land tends not to be found in large, contiguous areas, but rather interspersed with large areas of land suitable only for grazing (see Williams et al., chapter 3, this volume). One possible pathway towards a more efficient utilisation of these heterogenous land resources is the *integration* of cattle grazing and cropping. The concept of legume ley-farming, so important in the integration of wheat and sheep production in Australia's mediterranean climates, would appear to offer much in the SAT, but to date there has been no substantial evaluation of the strategy anywhere in this climatic zone.

This paper reports on a research program that seeks to answer the question: "Will the concept of legume ley-farming work in the tropics?" We first describe the reasoning behind a version of this farming strategy that addresses several of the major economic and ecological problems of cattle and crop production. Then we describe the research goals and our approach to setting research priorities in the evaluation of this hypothetical system. Finally we summarise progress to date.

22.2 Some Problems of Agricultural Production in the SAT

A major constraint to cattle production in this region is the poor nutritive value of grass pasture in the dry season. As a result of research, technology is available for overcoming this problem, i.e. by oversowing native pastures with legumes and fertilising with superphosphate. Implementation of this technology generally has not been economic to date due to high prices of the inputs relative to the average price of beef in this region (Winter et al., chapter 19, this volume). Fluctuations in demand, as well as in prices, add a further disincentive to pasture improvement, especially using borrowed capital.

Major constraints to crop production include low soil fertility and high risks of climatic adversity. Research has shown the need for high inputs of fertiliser, particularly nitrogen and phosphorus (Jones et al., chapter 18, this volume).

One climatic risk is that of too-short a period between earliest ploughing or planting rains and the time the land becomes untrafficably wet; capitalisation in large machinery to prepare large areas of land quickly has been a heavy financial burden in past cropping ventures. Another serious risk is that of unfavourable water and temperature conditions during crop establishment. Rapid drying of the bare soil surface results in high soil temperatures and/or strong seals that seriously reduce emergence of crop seedlings (Arndt 1965; McCown et al. 1980). However, the most serious climatic risk is that of soil erosion, a major problem in past cropping schemes in this region of normally high rainfall intensities (Richards 1978).

North-West (NW) Australia differs very greatly from most of the SAT sociologically and economically, but the important ecological problems are common throughout this zone. For example, Jones and Wild (1975), in their comprehensive review of the constraints to agricultural production in West Africa, focus on these same problems under the headings of (1) control of water, (2) maintenance of soil fertility, and (3) maintenance of favourable soil physical properties. Traditional practices for conserving and restoring soil productivity, which are dependent on abundant land, are falling victim to rapidly increasing rural population pressure. In general, these methods are not being replaced by the modern agricultural inputs necessary to sustain productivity. Without radical change in this trend, it is difficult to envisage the future of agriculture in sub-Saharan Africa as other than a continuing decline in land and labour productivity (McCown et al. 1979).

22.3 A Strategy for an Improved Farming System

Not only in NW Australia, where much land is still undeveloped, but in other SAT regions where the intensity of land utilisation still allows at least short-duration vegetated fallows, there is the possibility that integration of cropping and livestock production using legume ley-pastures in rotation with nitrophilous crops could greatly improve the ecology and economics of agriculture. The economics of improving pastures for better dry season animal nutrition improve markedly when the same pastures produce the N required for a succeeding crop. Ley pastures grown in strip-cropping patterns contribute to improved water and soil conservation of crop lands. By adopting no-tillage technology as well, pasture herbage (killed) can be retained on the soil surface in currently cropped areas with benefits to (a) water and soil conservation, (b) crop yields, and (c) timeliness of planting and with savings in machinery and fuel costs.

In Australia's wheat-sheep zone, the development of leguminous ley systems in the 1930s and 1940s greatly retarded the deterioration of cereal lands and increased production both of wheat and animal products (Donald 1982). Jones and Wild (1975) concluded their review of agriculture in West Africa with: "The Australian example points to a very promising field of co-operative research between agronomists, soil scientists and animal husbandry specialists, with a highly productive mixed farming system for savanna conditions as the ultimate goal". However, Ruthenberg (1980) concludes that the probability of successful implementation of sown ley systems in the tropics is low. "A ley system must show itself to be better than a tumbledown grassland or other fallow system in (1) haying a better fertility-restoring capacity, (2) supporting more livestock production, and (3) allowing a more efficient use of the farm labour. The combined effect must be higher by a substantial margin than the costs of establishing a full ley-farming system. These conditions rarely exist." (Ruthenberg 1980, p. 123.)

We accept Ruthenberg's criteria for success of such a system. However, it is our judgement that pasture legumes that have been domesticated only in the last decade or so provide a much better prospect of satisfying criteria (1) and (2) than pasture plants previously available for the SAT. The promise of this new resource provides the main justification for a serious test of the concept of legume ley-farming in this climatic zone.

Our research is based at Katherine, N.T. in the wet semi-arid or monsoonal tropics (see Williams et al., chapter 3, this volume, for comparison of Katherine's climate to other SAT regions). Agricultural research was begun here in 1946 by CSIRO's Land Research and Regional Survey Division. Work until the late 1960s methodically covered a wide range of crop and pasture production issues, including aspects of integration of the two enterprises (Norman 1966; Norman and Begg 1973). Our work, which began in 1978, builds on this foundation as well as that provided by work from the Northern Territory Administration.

Our hypothetical system combines the concepts of legume ley-farming and no-tillage with the existing native pasture grazing system. The key feature (No. 1, below) is the rotation of a self-regenerating legume pasture and a crop of maize or sorghum, with the legume supplying all or most of the nitrogen fertiliser requirement of the crop. A number of legumes have been introduced accidently or deliberately to Australia and have proved to be well adapted to the pasture environments of the SAT. Since these have been selected for persistence in permanent pastures, it is not surprising that many have attributes that make them less suitable as a ley pasture plant. However, there are a number of non-woody, prolific-seeding types that warrant evaluation more specifically for a ley-pasture role.

Features of the hypothetical farming system are:

1. self-regenerating legume ley-pastures of 1-3 years duration are grown in rotation with maize or sorghum
2. cattle graze native grass pastures during the green season and leguminous pastures and crop residues in the dry season
3. crops are planted directly into the pasture, which is chemically killed at or shortly before planting
4. the legume sward which volunteers from hard seed after the pasture is killed is allowed to form an understorey ("live mulch") in the main crop.

Chief among the criteria for evaluation is the ability to replenish soil nitrogen in a cropping system. In ten studies conducted in the Top End of the

N.T. during the 1950s and 1960s, the average range of N fixed by pure swards of one of the legumes, the annual *Stylosanthes humilis* (Townsville stylo) was 75-130 kg N ha^{-1} a^{-1} with individual values as high as 195 kg N ha^{-1} a^{-1} (Vallis and Gardener 1984, Table 1). The success of a ley system depends very greatly on what proportion of this nitrogen finds its way into the succeeding crop(s). Although little is known about the magnitudes of various N losses, especially under grazing, in these environments, the amount of N fixed is sufficiently large that even if losses are substantial, much of the crop's N requirements usually could be met.

The second feature concerns the integration of cropping with the existing native pasture grazing system. The strategy of having cattle on native grass pastures during the green season, when these pastures are at their best, and on sown leguminous pastures in the dry season, was developed by Norman (1968*a*). Cattle grazing dry standing hay of the annual legume Townsville stylo, normally gained weight during the dry season (Norman 1968*a*; Norman 1970; Woods 1970). Although even modest amounts of rain on dry legume can cause spoilage and a marked reduction in acceptance by cattle (Norman 1968*b*; McCown et al. 1981) the expected frequency of this at Katherine of 1 in 10 years (R.L. McCown, unpublished data) makes this an attractive dry-season nutrition strategy. However, the test of this strategy in the late 1960s and early 1970s failed due to Townsville stylo's poor ability to compete with invading annual grasses and, ultimately, to its susceptibility to anthracnose. It is mainly the availability of several "new" legumes with superior competitive ability and resistance to anthracnose that makes a new attempt at implementing this strategy feasible. Growing a nitrophilous crop every 1-3 years should further contribute to maintaining legume dominance by (a) regularly depleting soil N, and (b) providing an opportunity for economic use of an herbicide selective for grass weeds.

The third feature of this hypothetical farming system is that of the retention of surface mulch by use of no-tillage planting technology. Although experience in the tropics is as yet limited, there are indications that the potential benefit is greater here than at higher latitudes. In temperate regions, where decades of research on reduced tillage led to optimistic forecasts of adoption, rates of adoption have been slow and there are still uncertainties about the potential of this practice (Cannell 1981). In those areas of North America where improved conservation of water and soil is important, retention of surface residues is practised widely. In other environments, e.g. in Britain, problems of excessive straw and wetness can be dominant, and it is recommended that residues be burned. In temperate climates, surface mulch exacerbates any problem of low soil temperature or excessive wetness at planting (Baeumer and Bakermans 1973). In contrast, in the tropics, the need for improved soil conservation in cropping is universal and the benefits of mulch retention are very great (Lal 1975; Obi 1982; Hayward et al. 1981). Similarly, the effect of mulch in retarding evaporation losses and the consequent rise in soil temperature is beneficial to young crops in the tropics generally (Lal, chapter 13, this volume; Hayward et al. 1981) because the

potential evaporation is generally so high and rainfall so unreliable in this season. Thus surface mulch affects the water and temperature regimes in a similar way in temperate and tropical zones, but in the former the effect is often detrimental and in the latter, virtually always beneficial.

Those herbaceous pasture legumes that are well adapted to this climate invariably produce a proportion of seed which is still "hard" when the pasture re-establishes during the storm rain period of October–December. When killed with a herbicide at planting time, this pasture produces the mulch so important to establishment and early growth of the crop. With subsequent rain, newly germinable seed from the hard seed pool produces a new stand of legume (No. 4, above). Although this can be prevented by use of a pre-emergent herbicide, this intercrop (*live mulch*), offers several potential benefits:

- it provides a more long-lasting protective cover for the soil than the dead mulch;
- it provides high protein forage to complement the low protein stover grazed in the following dry season; and
- it provides an additional source of seed for pasture re-establishment.

The main potential detriment is that the presence of the understorey may suppress crop yield.

The implications of competition are especially important in this particular type of intercropping, where economic success is very much dependent on achieving most of a full yield of the main crop and some yield of a second crop (Willey 1979). This reflects the much lesser monetary value of the forage intercrop; however, since there are no capital or labour costs in establishing the intercrop, any yield of forage or seed is a bonus. The degree to which water shortages during the growing season jeopardise the success of this forage intercropping strategy in the SAT is unknown. Recent results from the West African humid tropics have shown that yields of crops sown into legume swards killed only on the row zones can compare favourably with those of crops without the live mulch (Akobundu 1982).

An attempt is made in Fig. 22.1 to depict the inter-relationships of the important components in this system as a flow diagram, showing (a) physical entities as boxes and (b) processes as ovals. Recognition of a number of internal cycles aid understanding. On the left, cattle from native pasture enter a ley-pasture cycle during the dry season (indicated by shading) where they graze crop residues and dry legume herbage. At the end of the dry season, cattle return to native pastures. If the pasture area is cropped in the wet season, the pasture phase contributes mulch and soil nitrogen, as well as legume seed for the volunteer legume understorey. The latter is depicted as part of a life-cycle (centre), which produces seed either for re-establishment of the pasture or for mulch and the legume understorey in a successive crop. From the crop phase emerge the edible residues, and the cycle is thus completed.

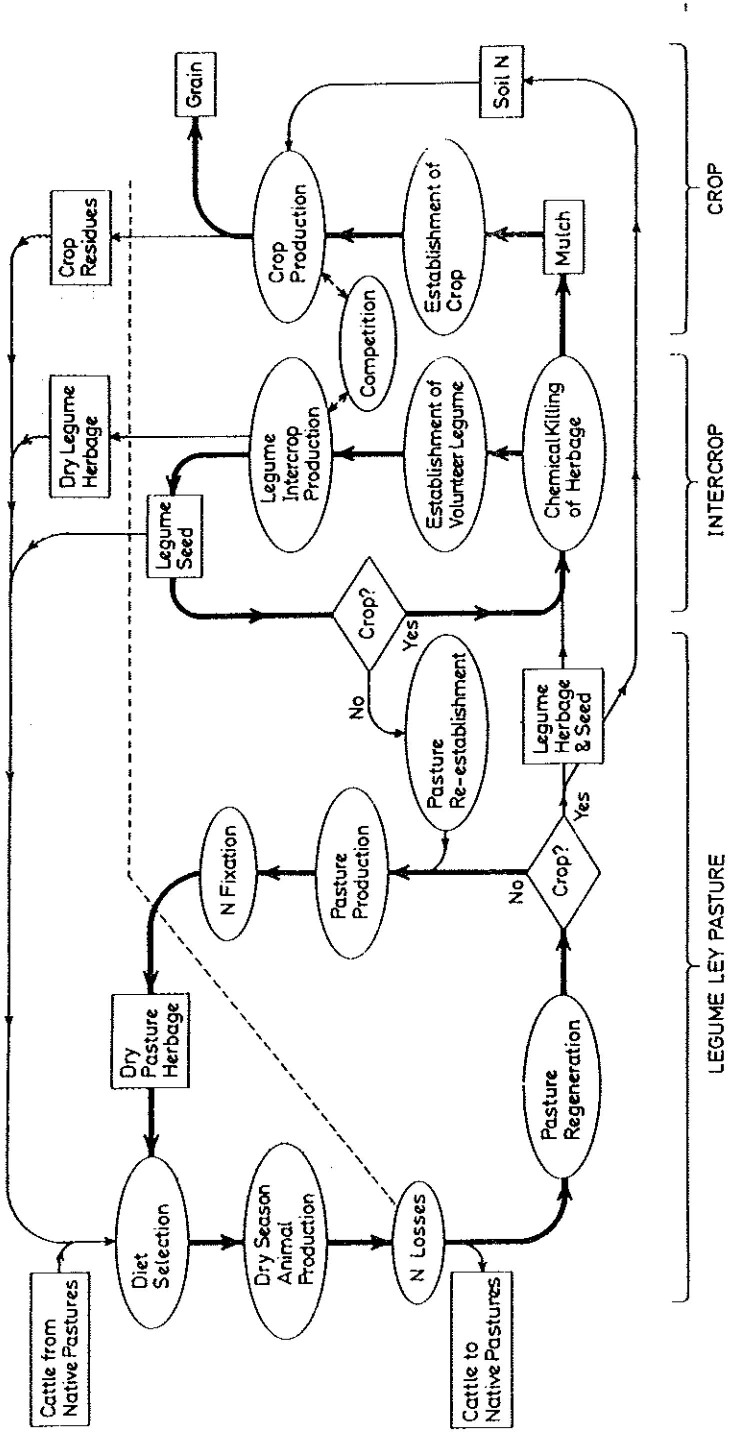

Figure 22.1 The hypothetical farming system being evaluated at Katherine showing flow of inputs and outputs among sub-systems (boxes) and important processes being researched (ovals).

22.4 Research Goals and Approach

How do we go about answering the question "will it work in the tropics?" Although we want an answer generally applicable in the SAT, our first goal is to test the feasibility of the strategy at Katherine (hereafter referred to as Goal I). This is, in part, a response to an urgent need for an improved approach to farming in this region. However, even a single-minded effort to obtain a general answer to the question "will it work in the SAT?" would still probably require research resources to be concentrated at a single location. This is because adequate evaluation of the strategy necessitates operations at physical and temporal scales large enough to avoid serious ecological and economic anomalies. The high costs of research at such scales limit severely the number of sites at which it is conducted. Katherine Research Station, with its good crop and animal research facilities, together with a climate and soils whose important attributes are shared with large areas of the tropics, provides our high-investment research location.

Goal II is to provide the most general evaluation of this farming strategy for the SAT in spite of being constrained to work in one district. The extent to which this is achieved will depend on the degree of understanding of the processes within the system and their control by climatic and soil factors. Such understanding enables predictions to be made about the implications of altering system configuration and about performance in other physical conditions in NW Australia, or elsewhere in the SAT.

Potentially enormous research resources are required to understand all of the important processes at the level of detail that they are often studied. Our problem at the outset was to identify a procedure for studying this complex subject in such a way that achieves our goals, but with a small team, a modest budget, and within a ten-year period.

We have found two concepts especially helpful in allocating our relatively small research resources to a relatively major task. Firstly, within systems, sub-systems can be identified that "possess an integrity of their own, such that when studied in relative isolation the resulting increased knowledge about them can be fitted back into the whole system from which they were derived and contribute to our knowledge of the latter" (Spedding 1975).

We have identified four major sub-systems in which the interactions among component variables are considered to be much more important than the interactions among the four sub-systems. These have become research areas that have been manageable entities, i.e. they have been initiated over time; they have been individual subjects for special funding; and some can be studied readily at multiple sites. These sub-systems are:

1. the effect of legume ley-crop rotation on crop production
2. the effect of no-tillage technology on crop production
3. the effect of competition between the crop and the forage legume intercrop
4. the effect of cattle ley-pasture relations on animal and crop production.

Secondly, the concept of hierarchy in systems enables questions to be answered in each major sub-system hierarchically and thus provides the basis for identifying research priorities within sub-systems. To illustrate this, a hierarchical ordering of selected questions in the *legume ley-crop rotation* sub-system is shown in Fig. 22.2. Initial experiments were designed to answer questions at the highest level, and where expedient to do so, to answer important questions at the two lower levels as well.

1.	How much of the soil N requirements of a coarse grain crop can be supplied by a tropical legume ley in rotation?
1.1	How much do legumes differ in N-contributing ability?
1.1.1	What proportion of legume N is available to succeeding crops?
1.1.1.1	How much N of legume "origin" is leached beyond crop root zone?
1.1.1.1.1	What is the rate of mineralisation of N from dead legume roots?

Figure 22.2 An example of a partial hierarchy of research questions, in this case pertaining to the *legume ley crop rotation* sub-system.

There is no doubt about the convenience provided by a study of major sub-systems separately. Nevertheless, there are benefits to be gained by studying the whole system as an entity. Not only is it a check on the assumptions used in isolating sub-systems, but it serves as a superior form of demonstration to those best placed to evaluate further this farming strategy at more tactical levels, e.g. on state government agricultural department field stations, pilot farms, etc.

Figure 22.3 summarises our research approach. Horizontal strata represent

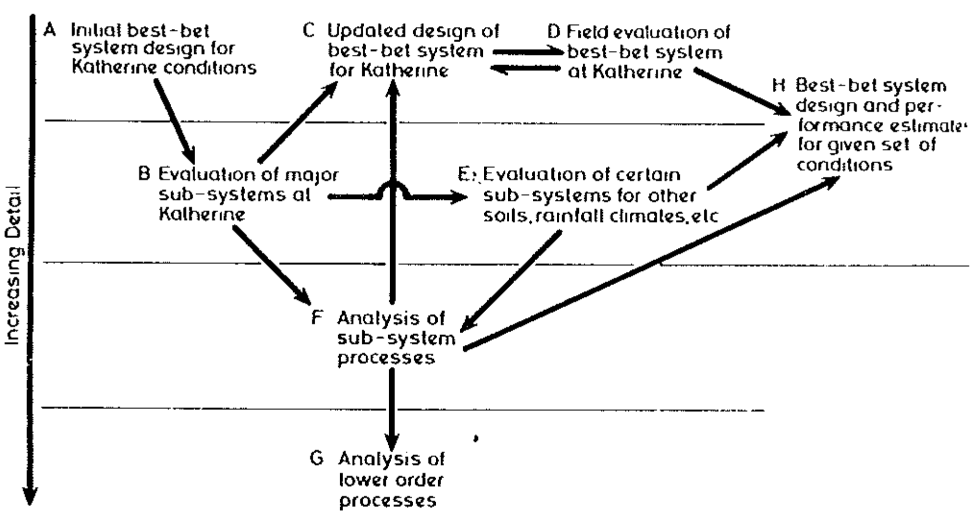

Figure 22.3 A framework to aid research planning in preliminary evaluation of farming systems.

levels of organisation or detail. The system configuration that emerges from the design process is the best-bet conceptual system at the outset (A). From this, the priority aspects to be evaluated within major sub-systems (B) can be identified. Results from this evaluation serve to update the best-bet conceptual system for Katherine (C). At the earliest stage of reasonable certainty that current best-bet species and technology would provide a fair test of the proposed farming strategy, a "whole system" study was initiated (D). Results from this serve to update our local best-bet system (C), thus serving Goal I, that of efficient progress toward a system that performs well at Katherine.

From an evaluation of major sub-systems (B), progress toward Goal II (H), requires sub-systems to be evaluated under a range of levels of those variables known to drive key processes (E). In certain cases duplication of studies on contrasting soils is most informative. Where rainfall is the variable, the temporal dimension cannot be dealt with, practically, without the aid of computer simulation using models of crop and pasture production and historical weather records. Another approach is to physically simulate other conditions, e.g. utilise an automatic rain shelter and/or irrigation.

Another activity that stems from evaluation of sub-systems, i.e. "B" and "E", is the analysis of sub-system processes (F), and in more detail at "G". These decisions regarding allocation of resources to more detailed studies of function have proved to be the most difficult; the benefits of further understanding that might expedite progress toward our goals is weighed against the opportunity costs of retarded activity at higher levels.

These decisions regarding level of detail are complicated by considerations not shown in Fig. 22.3. On any geographic frontier of agricultural research, at the point of having answered a relevant high-order question, further analysis at lower levels in the hierarchy generally is very enticing. For some of us it is an institutional reality that the next step is the most rewarding, career-wise. Not to do so invites the charge of being "unscientific". However, in the context of "research-for-development" it is a potential waste of precious resources, not the least of which may be time. Here is where the criterion of "Does it serve either of our goals sufficiently directly?" must be applied ruthlessly. In a case where the further understanding of a process is clearly important in predicting significant adaptations of the system in 'C' or 'H', (Fig. 22.3) and the probability of rapid progress is high, then proceeding to that lower level is sound research-for-development.

In Fig. 22.3, what emerges from the flow of activities is a best-bet system design at a strategic level. In relation to Goal I (C and D), once evolution of the conceptual system and the field implementation are well advanced, further progress depends on adoption by local farmers and/or further research of a more tactical, or adaptive, nature. Once this happens the next stage of evolution probably would be the development of a diversity of variations on our theme, the differentiation taking place in response to the varied environmental and economic conditions, skills, and preferences in the farming community. In cases where there is interest in adopting the system at other locations in the SAT, the understanding resulting from Goal II (H) can be drawn upon for designing a best-bet system, or for concluding that the prospects are too poor to warrant further adaptive research.

The application of general systems theory to agricultural systems has taken two distinct paths. The first (the "systems approach") is characterised by the use of methods of systems analysis and simulation. Research is aimed generally at developing mathematical models of the biological or bio-economic functioning of production systems (see Spedding, 1975). The second branch has developed in response to the urgent need for improving small-holder farming systems in developing countries. In this case a farming system is analysed conceptually to identify needs for research, and most of the research is conducted on farms with farmers. This methodology has come to be referred to as FSR (farming systems research) (Shaner, 1982; Dillon and Virmani, chapter 25, this volume).

In research-for-development, where there is a need for substantial changes in technology (e.g. the "System Replacement" case of Dillon and Virmani, chapter 25, this volume), there is a need to combine the methods of these two branches of systems research. While FSR identifies the need for research, it is best conducted initially on research stations, where there are the advantages of research facilities, logistics, and control. Our research approach is an attempt to adopt appropriate concepts of the "systems approach", to enhance the efficiency of research conducted in an FSR framework.

22.5 Research Progress

Sub-system 1 — The effect of legume ley-crop rotation on crop production

The high-order objectives in the study of this sub-system concern quantification of the N contribution to a nitrophilous crop by a legume-ley as influenced by length of ley and species of legume. Substantial losses of N under grazing are expected, and explanation of the relative importance of losses from litter, urine and dung are objectives of a lower order and priority. It is to be expected that soil type will influence strongly N transfer processes, so study of this sub-system is conducted both on a heavy textured red earth (Tippera or Tindall loam or clay loam) and a sandy red earth (Blain sand).

A very direct experimental approach is used to estimate the N contribution by legumes, in which a crop of maize or sorghum is used in a bio-assay. Rates of fertiliser N are superimposed on the crop so that its response to N, additional to that supplied by the preceding legume and grass (control) swards, can be measured and compared. Supporting measurements include soil N prior to cropping, and the yield and chemical composition both of the ley and the crop.

Salient results from six experiments that are still in progress include:

(a) On the loamy soil, maize grain yield without N fertiliser following one-year leys of various pasture legumes was equal to that of maize receiving 50-75 kg N ha^{-1} following one year of grass. (Fig. 22.4 shows data from one experiment.) Legume leys of longer duration had greater effects in the first crop and a greater residual effect on a second crop.

(b) For a given level of legume-ley dry matter production, the apparent N contribution from a one-year ley of Caribbean stylo was much less on the sandy soil than on loam.

(c) Legume species did not differ greatly in N contribution after one-year leys, but large differences occurred following four-year leys.

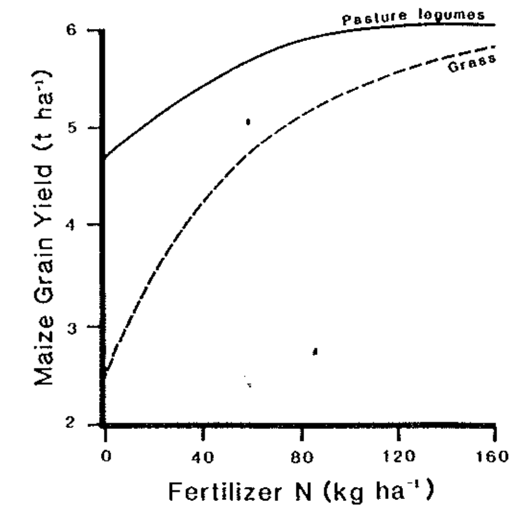

Figure 22.4 Maize grain yield responses to N fertiliser in the first crop following one year of legume or grass leys on a loamy red earth soil.

A study of N loss from urine has been conducted on the loamy soil. Of the ^{15}N applied mid-dry season in urine, 60 per cent was found in the soil five weeks later. Since no rain fell and 94 per cent of ^{15}N in urine applied 15 cm beneath the soil surface was recovered, it seems likely that loss was as ammonia (I. Vallis and R.K. Jones, unpublished data).

Sub-system 2 — The effect of no-tillage technology on crop production

The priority objective here is to quantify the advantages or disadvantages of no-till planting in relation to conventional tillage. The compelling reason for inclusion of this practice is that, wherever comparisons have been made, the inherent benefit of no-tillage in conserving soil has been demonstrated. A less certain implication of this new technology concerns short-term effects on crop yields.

Our first experiment was designed to test whether high soil temperatures could explain very poor maize growth on the sandy red earth (Blain sand). In the absence of mulch, there was high mortality of seedlings at emergence and survivors showed thermal injury lesions and slow growth.

The results from a subsequent experiment demonstrated how important mulch is to this soil. In order to have control over water, the study was conducted using irrigation in November, just before the onset of storm rains. A single layer of hessian was used as a convenient form of experimental mulch. Results are shown in Fig. 22.5. By the time seedlings were emerging daily maximum soil temperatures at 1 cm were well above 60°C. Under this mulch temperatures were reduced by only about 4°C, but with dramatic benefit both to maize and sorghum. Although conditions in this study were extreme our overall experience is that it is not feasible to grow maize in this climate on sandy soil without a substantial mulch.

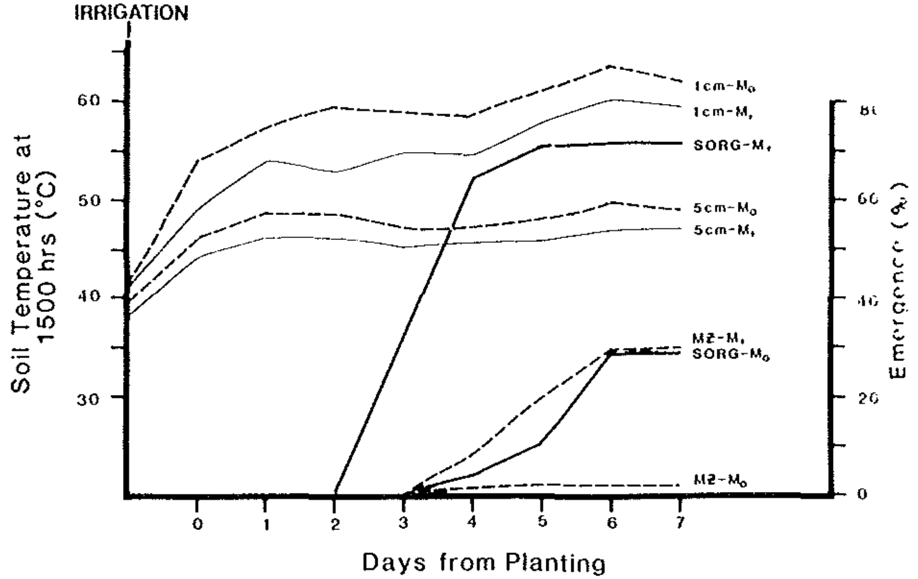

Figure 22.5 The effect of mulch on soil temperature at 1 cm and 5 cm and on seedling emergence of maize (Mz) and sorghum (Sorg). (M_0 no mulch; M_1 one layer of hessian)

In other studies on this soil, no-till and mulch retention have resulted in an average increase in maize yield of 35 per cent in two maize crops, whereas there was no benefit to sorghum yields in four crops.

On the loamy red earth, injurious soil temperatures are less frequent than on the sand, although without mulch, temperatures are still too high for optimum seedling growth. However, upon drying, this massive soil tends to form strong seals that impede seedling emergence (Arndt 1965). In four crops, mulch retention resulted in an average yield advantage of 18 per cent in maize, but had no effect on sorghum.

Having confirmed that local physical conditions virtually ensured that mulch retention by no-tillage would not be detrimental to crop yields, and often beneficial, priorities shifted to:

(a) what constitutes a minimum effective mulch;
(b) how to get an effective mulch economically; and
(c) how to plant into the mulch efficiently.

Work to date has been on the loamy soil and has shown the following:

(a) As little as 700 kg ha^{-1} of dead standing Caribbean stylo reduced soil temperature substantially (Fig. 22.6).
(b) Analysis of the radiation balance has shown that mulch retards the rise in soil temperature (Fig. 22.6) and soil strength by slowing drying. This is due primarily to the interception of radiation by mulch.
(c) Pasture mulch is efficient in radiation interception, when compared with mulches such as stover; 1900 kg ha^{-1} of dead standing Caribbean stylo intercepted 80 per cent and 700 kg ha^{-1} 55 per cent of direct beam radiation.
(d) Tropical grasses, in general, are killed by dosages of glyphosate similar to those used in temperate regions (1.5-2.0l ha^{-1}).
(e) The most successful planter, in terms of seedling emergence over a wide range of conditions, has been a narrow tyne, preceded by a rolling coulter to cut surface mulch and followed by a narrow in-furrow press wheel.

Research has recently commenced on planting in the sandy soils. Indications are that there are fewer technical problems here than on the loam. Generally, it seems that no-tillage technology for this farming system is feasi-

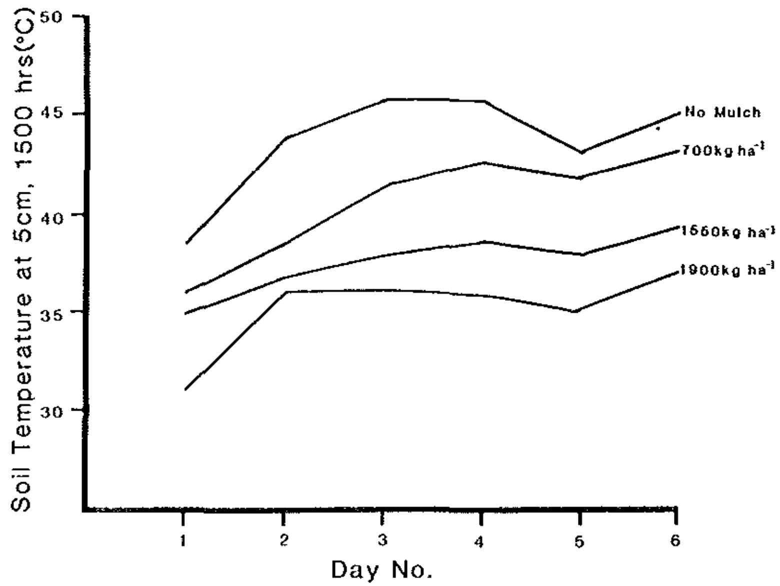

Figure 22.6 The effect of various amounts of mulch (dead stylo) on soil daily temperature trends.

ble in all major respects, and further significant progress most likely will be made by R and D efforts in conjunction with farmers.

Sub-system 3 — The effects of competition between the crop and the forage legume intercrop

The objectives of this research are:

(a) to assess the effect of a pasture legume intercrop on a maize or sorghum main crop yield;
(b) to explain the nature of the interaction between the legume intercrop and the main crop;
(c) to evaluate various successful pasture legumes for their suitability as an intercrop; and
(d) to learn how to control grass weeds in this system.

Two studies have been conducted to assess the effect of Caribbean stylo, *Alysicarpus vaginalis* and *Centrosema pascuorum* intercrops on maize yield. In one, intercropped maize outyielded sole maize by 15 per cent. In the second, sole maize yielded 6.3 t ha^{-1} and intercropped maize only 4.3 t ha^{-1}. These differences are not explained adequately by data collected on yield, chemical composition and weather. It is evident that evaluation of the merits of this sub-system will be served better by analysis of the effect of supply of the two resources most likely to be deficient in this system (i.e. water and nitrogen) than by more comparisons of sole versus intercropped maize production. Intensive study of competition for water and nitrogen has begun recently. The necessary control of water is provided by an automatic rain shelter. ^{15}N labelled fertiliser is providing an efficient means of quantifying the partitioning of an N supply.

Comparison of the suitability of the three legumes (above) indicate that:

(a) all are capable of producing about the same amount of herbage (1.5-2.5 t ha^{-1}) prior to maize maturity, but the late flowering *C. pascuorum* can produce more than the others following maize maturity;
(b) Caribbean stylo produces very little seed as an intercrop due to its failure to flower in the shade of a full maize canopy (50 000 plants ha^{-1}, 75 cm rows);
(c) *A. vaginalis* produces 2000-4000 seeds m^{-2}, an amount sufficient to establish a dense pasture the following season; and
(d) the large seeded *C. pascuorum* establishes much less readily than the other species.

Research into the control of grass weeds in the legume plus graminaceous crop mixture has yet to commence, but a number of promising herbicides have been identified.

Sub-system 4 — The effect of cattle-ley pasture relations on animal and crop production

Study of this sub-system is conducted within our whole system experiment.

The objectives of the system experiment are:

(a) to quantify the N contribution to a crop by various legumes under realistic dry season grazing management;
(b) to compare liveweight performance in the legume-ley system (see Section 22.3) with that on continuously grazed native pasture and on permanently improved pastures;
(c) to document the ecological stability of pastures of Caribbean stylo, *A. vaginalis* and *C. pascuorum*, which were virtually pure legume at the outset, particularly in relation to their self-sown re-establishment and ability to resist invasion by annual grasses;
(d) to document the trends in weed abundance, both in crops and pastures, and to identify possible weed management strategies; and
(e) to quantify costs and yields of maize production under more realistic operational conditions with respect to planting and harvesting.

The cropland component of this study consists of three paddocks in which the legume-ley is Caribbean stylo, *A. vaginalis* or *C. pascuorum*. Within each paddock, there are three areas of equal size. This allows a 1-year maize: 2-year legume-ley rotation, with a maize crop every year. Adjacent, on one side, is a large area of unimproved native woodland pasture, and on another side, an ongoing experiment on improved pasture (cleared, large amounts of superphosphate over ten years, sown legumes and sown grasses).

The native pasture area is stocked during the green season at an appropriate density (0.2 beast ha^{-1}) with equal numbers of weaners and yearling steers. Following crop harvest, three groups of four (2 weaners + 2 yearlings) are moved into the cropland paddocks. An equal number remain on the native pasture. At the end of the dry season, yearlings are turned off and weaners return to native pasture; the latter return in the following year to their respective legume paddocks for finishing.

Maize is direct-planted after spraying with glyphosate. In one half of the crop area, the legume understorey is allowed to develop; in the other half this is prevented by a pre-emergent herbicide. A range of N rates is superimposed on the maize crop to assess response above that contributed by the two-year leys.

Botanical composition of ley pastures is measured annually near the end of the green season. Pasture on offer, leaf/stem/seed composition, and chemical composition, are measured periodically through the dry season in conjunction with diet sampling with oesophageally-fistulated cattle.

Because this experiment was planted as recently as January 1982, results of time trends, as influenced by legume-ley-crop rotation are not yet available. Animal production, however, is not as dependent on crop ley sequences, and results from the first dry season should be no less informative than those to come. No rain fell until 8 November. The liveweight gain on legume-ley/stover, averaged over legume species, was nearly 80 kg $head^{-1}$ greater than on native pasture for the four-month period. In the cropland, during the first seven weeks, 10-20 per cent of time spent grazing was in the stover, and after that virtually all grazing was on legume. There was virtually no effect of legume species on liveweight performance.

Caribbean stylo and *A. vaginalis* re-established in the second year at very high densities. Density of *C. pascuorum*, however, was disappointingly low in spite of abundant seed. This adds to other evidence that re-establishment without disturbance may be a serious deficiency in this large-seeded annual, which is so promising as a ley plant in other respects.

22.6 Conclusion

To attempt an appraisal as to how far we have advanced in resolving the enigma of the agricultural potential of Australia's seasonally dry tropics would be presumptuous. It is somewhat less presumptuous to say that we have resumed a process that has the potential to produce efficient farming systems optimally adjusted to conditions in this region. Our contribution to this farming systems research process is primarily at the strategic level, that is, the "notional" and "preliminary" stages of technology design and evaluation (Menz and Knipscheen 1981).

In the NW Australian institutional context, accomplishment of the final "developed" stage depends largely on the efforts of regional research and extension organisations, agricultural development authorities and farmers. The continuity between stages, including feedback loops, so important in FSR (Dillon and Virmani chapter 25, this volume), must depend on close co-operation between parties with major responsibilities in different stages of the process. When should strategies being evaluated in the preliminary stage move into the development environment such as that described by Cameron and Hooper (chapter 24, this volume)? If, in the preliminary stage, the perception of the problems of existing agriculture is accurate, the logic of the proposed "solutions" (Section 22.3) is sound, and the results of the early evaluation are promising, then it could be argued that trial implementation should not wait for completion of the research. In the present case, although our current best-bet system may be inferior to our eventual one, it seems less probable that cropping, as a sole enterprise using conventional tillage, can do what is needed.

Our results indicate a need for an accelerated research effort in three areas. Firstly, a much better understanding is needed of differences in the performance of the legume-ley-crop rotation sub-system on soils of contrasting texture. This will require assessment of nitrogen and water balances. Such work will need to be at the analytical level of (F) in Figure 22.3 and is necessary to allow generalisation to other conditions in terms of (H) in Figure 22.3.

Secondly, in this system where the legume supplies "free" N, P supply becomes the major fertiliser cost. Explanation of the quantitative dependence of N produced on P supply is a necessary basis for assessing P fertiliser requirements. This N–P relationship is especially important in determining the realistic potential of a legume-ley strategy for agriculture in countries where P fertiliser costs are an even greater constraint than in northern Australia.

Thirdly, there is an urgent need to quantify the hydrological implications of this farming system. Local pilot farms, presently practising conventional tillage and continuous cropping, are relying on conventional earth structures to control surface water. At the intensity estimated to be necessary to adequately control soil erosion, this approach is proving to be too costly and less than effective. To what extent can a no-till ley-rotation system reduce the need for structures? Can grain legumes be substituted for legume-leys without serious sacrifice in soil surface protection? To provide answers that can be applied generally, the research must relate readily-measured attributes both of soil and vegetation to hydrological processes, particularly the partitioning of rainfall into infiltration and runoff.

Acknowledgments

Because of the summary nature of the research progress report, the important contributions by the following scientists have not been made evident: N.S. Gould, (no-till planter evaluation); A. Somervaille (glyphosate studies); P.J. Ross and J. Williams (radiation balance of mulches); R.J. Chamberlin and R.C. Muchow (crop/intercrop competition); W.H. Winter and J.B. Liang (animal production); M.H. Andrew (pasture ecology).

We wish to thank the following for financial support: N.T. Department of Primary Production (no-till planter evaluation); N.T. Agricultural Development and Marketing Authority; and Rural Credits Development Fund (crop–intercrop competition).

Finally, we gratefully acknowledge the competent technical contributions made by N.P. Dalgleish and W.A. Beyer and their extraordinary dedication in initiating the field program under difficult circumstances.

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