IIL #7784050 PN-AAS-274 39009

Agricultural Systems 11 (1983) 95–103

The Evaluation of Preliminary Farming Systems Technologies: Zero-tillage Systems in West Africa

H. C. Knipscheer

Winrock International, Bogor, Indonesia

K. M. Menz

Bureau of Agricultural Economics, Canberra, Australia

&

I. Verinumbe

Lake Chad Research Institute, Maiduguri, Nigeria

SUMMARY

The appropriate form of evaluation of new farming systems depends on the stage of development of the technology. At each stage of technology development new systems are screened and the most promising ones selected for further research. Linear programming is a cost-effective tool for the evaluation of preliminary technologies as it allows interaction between the production parameters, quantifies the impact of limiting factors by shadow prices and can also be used for simulation. The screening of potential zero-tillage systems for West Africa is a concrete example.

INTRODUCTION

Farming systems research attempts to improve existing farming systems by means of technology (USDA, 1981). (A general perspective of farming systems research from the viewpoint of the international agricultural research centres can be found in TAC (1978). This perspective has been

Agricultural Systems 0308-521X/83/0011-0095/$03·00 © Applied Science Publishers Ltd, England, 1983. Printed in Great Britain

updated and broadened to include rational and sub-rational programmes by Shaner *et al.* (1982)). Such research has been described as a multidisciplinary approach to small farm analysis, with the social scientist participating in the *ex ante* evaluation of new farming systems or new technologies (Norman, 1978). The development of a new technology (or system) is a continuous process of design, evaluation and redesign, which can be conceptualised as passing through stages. These stages have been labelled 'notional', 'preliminary' and 'developed' (Anderson & Hardaker, 1979). The early (notional/preliminary) stages correspond to so-called 'upstream' farming systems research, while later (developed) stages correspond to 'downstream' research. (Gilbert *et al.* (1980) provide a detailed discussion of the 'upstream'/'downstream' dichotomy. We prefer to regard technology development as a process over time and, consequently, we think that the notional/preliminary/developed conceptualisation of technology design is more appropriate.) In farming systems research, evaluation is usually done with reference to the appropriateness of a technology for some particular target group of farmers. (Indeed, this is the one, and perhaps only, common characteristic of almost all farming systems research.)

The appropriate form of evaluation is, among other things, a function of the stage of development of the technology (Menz & Knipscheer, 1981). As technologies are developed (fine-tuned) to the needs of a particular target group, they must be evaluated more specifically from the viewpoint of that group. Consequently, farming systems research tends to become more expensive as the technology develops because of: (a) the direct cash costs of evaluating a system at the farm level (for example, by on-farm trials) and (b) the opportunity cost, which is a result of the location specificity of farming systems research and which can be regarded as the cost of ignoring farmers on whom the new system is expected to have no impact. Since preliminary technologies (by definition) are not fine-tuned for implementation directly by a specific group of farmers, evaluation is necessarily of a more general nature (for example, intuition, research station experiments). However, if the evaluation becomes too general, the relevance of the technology to farmers may be obscured. What is needed is an evaluation methodology for preliminary technologies which retains the essence of the farming systems approach whilst avoiding the expenses associated with location specificity.

The purpose of this paper is to propose linear programming (LP) as an

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appropriate design/evaluation tool for a preliminary farming systems technology. An example case study is presented whereby LP is applied to a preliminary farming system of potentially great importance to tropical Africa.

ZERO-TILLAGE IN HUMID WEST AFRICA—AN EXAMPLE OF A PRELIMINARY FARMING SYSTEMS TECHNOLOGY

The major land management system in the humid zone of West Africa is bush-fallow. Following a period of cultivation, land is left to bush-fallow in order to restore soil fertility. However, with increases in population pressure, the ratio of fallow period to cultivation period has declined, causing a corresponding decline in soil fertility (Ruthenberg, 1976). Over the last decade, much attention has been devoted to the development of new land management systems that allow longer cultivation periods and a shorter fallow, while maintaining soil fertility levels. Zero-tillage is one such system (Hartmans, 1981). Zero-tillage or no-till farming is basically farming without ploughing. Seeds are planted in a narrow slit or trench opened in the previously killed sod or crop residue. Weeds and other competing vegetation are controlled by chemical herbicides and/or by physical management of previous crop residue.

The advantages of zero-tillage systems include the prevention of run-off nutrient losses and soil erosion. Consequently, a higher level of production can be maintained for a longer period than would be the case under conventional methods of seedbed preparation and weed control (Lal, 1979). Presently, the International Institute of Tropical Agriculture (IITA) is conducting research on zero-tillage systems that are potentially suitable for the humid zone of Africa. Here we restrict our analysis to the transitional forest zone of West Africa, which is a large agroclimatic zone characterised by a bi-modal rainfall distribution (distinct dry periods between two rainy seasons). The land has a rolling-to-undulating topography, with slopes up to 12%, so that soil erosion is a major factor preventing long-term cropping without fallow.

The zero-till system being researched at IITA includes a maize crop during the first rainy season (April–July). Only maize provides enough mulch material for the system to be successful, and first season maize is regarded as an integral part of the system. However, a number of alternative cropping systems are possible during the second rainy season.

It is also possible to combine a tree or shrub alley-cropping system with zero-tillage maize by planting maize between rows of planted permanent woody shrubs or trees. Fallow and cultivation essentially occur simultaneously and by pruning the shrubs while maize is growing, competition between maize and the shrub is minimised. Periodic pruning not only prevents shading but also provides green manure for the food crop. During the rest of the year the fallow species replenishes the soil with nutrients, protects it from erosion and helps to control weeds by shading (reducing the need for herbicide).

ALTERNATIVE ZERO-TILLAGE TECHNOLOGIES

The following are various zero-tillage cropping systems ranked according to increasing labour requirements: (1) maize–stylo (first season maize followed by second season *Stylosanthes guyanesis*, a forage legume); (2) maize–maize/stylo; (3) maize–maize; (4) maize/leuceana–maize/leuceana (two seasons maize cropping between rows of *Leuceana leucocephala*, a leguminous shrub). These systems are selected in view of their different input requirements. The maize–maize system is most thoroughly investigated and reported. It serves as a yardstick with which the other zero-tillage cropping systems can be compared. The maize/leuceana zero-tillage, alley-cropping system is the most labour intensive, because of the necessity to prune. However, it saves cash as the application rate for herbicide can be reduced and no fertiliser needs to be purchased. Maize–stylo is the least labour intensive system since the stylo

TABLE 1
Input Requirements and Returns Per Hectare for Small-scale Zero-tillage Farming Systems Which Include First Season Maize

System	*Labour* (*h*)	*Cash* (₦)*	*Net returns* (₦)*
Maize–stylo	227	196	742
Maize–maize/stylo	278	196	760
Maize–maize	274	196	659
Maize/leuceana–maize/leuceana	320	152	734

* One naira (₦) = $1·80.

4

functions only as a cover crop. The maize–maize/stylo mixture represents a compromise system which combines some of the advantages of the other systems. The labour and cash requirements and the values of output for the four systems are shown in Table 1.

LINEAR PROGRAMMING AS THE EVALUATIVE TOOL

The zero-tillage farming systems technology can be regarded as being in the preliminary stage of development, in relation to its applicability to tropical African conditions. Sufficient research has been conducted to indicate its promise. However, any attempt to make a final farm-level evaluation is premature, as the system has not yet been 'fine-tuned' to the needs of a specific group. LP appears to be a particularly suitable evaluative tool, given the preliminary nature of the technology. It explicitly takes into account some farmer circumstances (prices, resources), without incurring the expense of on-farm testing. (And without getting 'bogged down' in an attempt to model all relevant aspects of the farm household. The latter is prevented by inadequacies of theory, quantitative methods and data (Crawford, 1981), to say nothing of cost.) Using shadow prices, LP can provide a rigorous and economically meaningful definition of 'constraints' or 'limiting factors'. In the authors' opinion, the loose definition of a limiting factor as anything limiting yield (e.g. Byerlee *et al.*, 1980) has detracted significantly from its usefulness as an operational concept in farming systems research. (Yet the identification of constraints remains the cornerstone of most farming systems research.)

LP facilitates the determination of opportunity costs of resources used in alternative farming systems and, by tracing important interactions in a system, it can provide useful guidance for further research and development (redesign) of a system. LP allows speedy and cheap evaluation under a range of alternative assumptions about prices and resource availabilities (Dillon & Hardaker, 1980). This is especially important with *preliminary* technologies, which should potentially be suitable for a wide range of conditions.

The zero-tillage LP model used published and unpublished information obtained from farming systems (and other) scientists at IITA, combined with survey results of farmers' resource endowments and prices paid and received. The details are available elsewhere (Knipscheer, 1980; Verinumbe *et al.*, 1981).

RESULTS

The maximum profit LP solution showed the combined zero-tillage, alley-cropping (maize/leuceana) system to be clearly superior to the other zero-tillage systems (Table 2).* To test the validity of the results under a wide range of conditions, various assumptions were made about labour availability and cost, cash availability and maize yield. The maize/leuceana system remained the most profitable farming system under a

TABLE 2
Maximum Profit Plan for Zero-Tillage Systems (Standard Model)*

Description	*Amount*
Optimum farm plan	
1. Maize–leuceana (95%)	1·35 ha
2. Maize–stylo (5%)	0·07 ha
Hired labour (August)	161 man-hours
Hired labour (April)	0 man-hours
Net profit	979 ₦
Surplus resources	
Land	4·58 ha
Shadow prices non-selected systems**	
1. Maize–maize/stylo	₦66·68
2. Maize–maize	₦168·24

* For resource constraints of standard model, see footnote to Table 3.

** Alternative systems with sole pigeon pea and a mixture of maize/pigeon pea as second season crops were also evaluated. Shadow prices of these systems were between ₦100 and ₦200.

wide range of conditions, but was occasionally slightly less profitable than maize–stylo system (Table 3). Maize–maize and maize–maize/stylo were constantly ranked behind the other two systems.

In general, the model gives strong support to the idea of incorporating a legume (leuceana or stylo) into the zero-tillage system. Until now research attention has focused upon the maize–maize system. For resource-poor African farmers, zero-tillage using legumes as a nitrogen source is preferable both to not using nitrogen fertiliser and to purchase of

* The optimal solution also included a minute area of maize–stylo. There was surprisingly little mixing of cropping systems in the optimal solutions.

TABLE 3
Ranking of Alternative No-till Systems According to Profitability Under Different Assumptions*

	Maize–stylo	*Maize–maize/stylo*	*Maize–maize*	*Maize–leuceana*	*Net farm profit (₦) of optimal plan*
Additional farm labour unit (August)	1	3	4	2	1 212
Labour wage ₦0·25/h	2	3	4	1	1 119
Labour wage ₦0·50/h	2	3	4	1	979
Labour wage ₦1·00/h	1	3	4	2	867
Cash ₦200	2	3	4	1	736
Cash ₦300	2	3	4	1	979
Cash ₦400	1	3	4	2	1 211
Cash ₦500	1	3	4	3	1 142
First season yield 100%	2	3	4	1	979
First season yield 75%	2	3	4	1	740
First season yield 50%	2	3	4	1	499

* Standard assumptions: 144 man-hours per month labour availability. 300 ₦ cash. Labour wages = ₦0·50/h.

artificial nitrogen inorganic nitrogen fertiliser (except when offered with extremely heavy subsidies). The alley-cropping, zero-tillage system provides additional advantages which gives it the edge in profitability over maize–stylo in most situations.

CONCLUDING COMMENTS

The practical example given here has resulted in important implications for future work in zero-tillage farming systems in tropical Africa. In particular, the potential value of legumes, especially leuceana, in the system has been demonstrated.

The value of LP as a tool for the evaluation of technologies has long been recognised. However, there is little record of its use in guiding technological design at an earlier stage in the development process.

Although the technologies studied by Goodwin *et al.* (1980) and Barlow *et al.* (1979) were *ex ante* in the sense of being not yet adopted by

farmers, it appears that they were at the 'developed' stage in the sense of being ready for adoption by a well-defined group. The only study which we were able to find in the literature which had used linear programming to evaluate what might be regarded as a 'preliminary' technology was that of Klein & Kehrberg (1981).

There are features of LP which make it attractive for farming systems research, particularly as a design/evaluative tool for what we have called preliminary farming systems technologies. The location specificity problem in farming systems research has resulted in the recognition of the need for cost-effective methodologies which retain the spirit of the farming systems approach. LP is one such tool.

No attempt was made here to compare the profitability of the preliminary zero-tillage systems with the traditional bush-fallow system. Lack of data (on the farm-level performance of bush-fallow; on the length of fallow required under a zero-tillage system) is one reason for this. But there is another important reason as well: in its present state of (under)development, farm level (final) evaluations of the zero-tillage system are not yet meaningful. Such final evaluations are outside the scope of this paper which had the objective of providing information relevant to future research and development of zero-tillage farming systems for tropical Africa. It is premature to attempt a judgement on the present suitability of such systems for African conditions, not only because further technological improvements remain to be made in these systems, but also because the presently used bush fallow system will become less attractive as population pressure continues to build up.

ACKNOWLEDGEMENT

The authors wish to thank Dr A. J. DeBoer for his helpful suggestions during the preparation of this paper.

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8

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9