CATIE
CENTRO AGRONOMICO TROPICAL DE INVESTIGACION Y ENSEÑANZA
Annual Crops Program

LIMITING FACTOR ECONOMIC EVALUATION

OF CROPPING SYSTEMS

T. David Johnston

Turrialba, Costa Rica
1978

SUMMARY

Economic analysis is only one of several important evaluative criteria used to compare cropping systems, but it is an important criterion, because many small farmers want and need improved cropping systems which will increase their family's income. Cropping systems researchers have responded to this need by designing systems which provide higher incomes/ha than the farmer's current systems, but in many cases small farmers have been reluctant to adopt these new systems.

Many people have attempted to explain this reluctance by attributing it to: (1) a preference for subsistence vs market oriented cropping systems; (2) an unwillingness, or an inability, to bear risks associated with improved cropping systems; or (3) the belief that small farmers give income maximization activities a very low priority, because their cultural and social values emphasize attainment of other more important goals. All these explanations are probably valid in many cases, but there is another explanation which is often overlooked -- cropping systems with higher incomes/ha do not always provide the highest family income. When land is the small farmer's limiting factor, the system with the highest income/ha also provides the highest family income per cropping season, but land is not always the farmer's limiting factor. Labor, working capital, irrigation water, transportation facilities, tractor time or fertilizer might be more limiting than land on a particular small farm. Consequently, if cropping systems researchers wish to design systems which have the greatest impact on family income, they need to know which resource is most limiting. This information can only be attained

by making a through study of the farmer's resources, cropping systems, and farming systems. In addition, the researcher must obtain information on social, cultural, agro-climatic, marketing and other constraints which make certain types of cropping systems unacceptable (or mandatory) for a particular group of small farmers.

The key words here are "a particular group", because small farmers are not all alike. Different types of small farmers need different kinds of farming and cropping systems. The decision to adopt a particular cropping system is an individual decision which is strongly influenced by the system's compatibility with the entire set of activities included in the farming system and with the farmer's goals. Systems which are relatively more effective at utilizing existing resources to achieve the farmer's goals will be chosen for inclusion in the farming system.

Cropping systems researchers cannot, of course, develop individual cropping systems for every small farmer, but they can be aware of the need to design different types of cropping systems for different groups of small farmers, and they can recognize the importance of differences in farmer's goals, farming systems, resource mixes, agro-climatic characteristics, etc. Researchers who are aware of these differences have a better understanding of the constraints affecting adoption of improved cropping systems, and are able to design improved systems which make more efficient use of each group's most limiting resource. In this way the researcher can concentrate his efforts on developing systems which are useful and appropriate for each different group of small farmers he works with, and his "improved" systems will have a much better chance of being adopted.

RESUMEN

La evaluación ecónomica es sólo uno de varios criterios importantes que los pequeños agricultores usan para comparar sistemas de cultivos alternativos. Es, sin embargo, un criterio importante porque muchos de los pequeños agricultores quieren y necesitan sistemas de cultivos mejorados que les permitan incrementar los ingresos familiares. Los investigadores de sistemas de cultivos respondieron a esta necesidad, diseñando sistemas con ingresos/ha más altos que los sistemas corrientes, pero en muchos casos, los pequeños agricultores no querían adoptar estos sistemas mejorados.

Muchas personas han tratado de explicar esta actitud la cual atribuyen a: (1) una preferencia de los pequeños agricultores por sistemas de subsistencia en lugar de sistemas comerciales; (2) poca tolerancia a riesgos asociados con la adopción de sistemas de cultivos mejorados; o (3) la creencia de que los pequeños agricultores dan poca prioridad al mayor ingreso ya que sus valores sociales y culturales ponen más énfasis en otras metas de mayor importancia para ellos. Todas estas explicaciones deben ser válidas para ciertos casos, pero hay también otra explicación -- los sistemas de cultivos con mayores ingresos por hectárea no siempre dan mayores ingresos familiares. Cuando el terreno es el factor limitante, los sistemas con mayores ingresos/ha también dan el mayor ingreso familiar por ciclo de cultivos, pero el terreno no es siempre el factor limitante. La mano de obra, capital de trabajo, agua para riego, transporte, horas disponibles de un chapulín o tractor, o los fertilizantes pueden ser más limitantes que el terreno en cierta finca

pequeña. Consecuentemente, si los investigadores en sistemas de cultivos quieren diseñar sistemas con la mayor contribución al ingreso familiar, es necesario saber cual es el factor limitante. Para eso se debe hacer un estudio de los recursos con que cuenta el agricultor, sus sistemas de cultivos y su sistema de finca. También, el investigador debe obtener información sobre restricciones sociales, culturales, agro-climáticos, de mercadeo u otras restricciones que exigen (o que prohiben) ciertos tipos de sistemas para un grupo específico de pequeños agricultores.

Las palabras claves aquí son "para un grupo específico", porque no todos los pequeños agricultores son iguales. Distintos tipos de pequeños agricultores necesitan diferentes tipos de sistemas de fincas y sistemas de cultivos. La decisión de adoptar cierto sistema de cultivos es una decisión individual, la cual es influenciada principalmente por como calza este sistema con los otros sistemas que están incluídos en el sistema de finca, y como contribuye el mismo con las metas del agricultor. Los sistemas que son relativamente más eficaces en utilizar recursos existentes y en lograr las metas del agricultor serán escogidos para incluirlos en dicho sistema de finca.

Claro que los investigadores de sistemas de cultivos no pueden desarrollar sistemas de cultivos individuales para cada agricultor, pero pueden darse cuenta de la necesidad de diseñar distintos tipos de éstos para diferentes clases de pequeños agricultores. También deben reconocer la importancia de diferencias en las metas, sistemas de fincas, cantidades y mezclas de recursos, características económicas y otras diferencias entre distintos grupos de pequeños agricultores. Los investigadores que notan estas diferencias tienen un mejor entendimiento de las restricciones que afectan la adopción de sistemas de cultivos mejorados y así pueden diseñar sistemas de cultivos mejorados que son más eficientes en el uso del factor(es) limitante(s) para cada grupo de pequeños agricultores. Así el investigador puede concentrar sus esfuerzos en desarrollar sistemas que son útiles y apropiados para cada grupo de pequeños agricultores con quienes se trabaja, y consecuentemente, sus sistemas "mejorados" tienen mayor posibilidad de ser adoptados.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIMITING FACTOR ECONOMIC EVALUATION OF CROPPING SYSTEMS

T. David Johnston*

IMPORTANT EVALUATIVE CRITERIA FOR CROPPING SYSTEMS

Evaluation of cropping systems is a complex, many faceted task. A complete evaluation must take into account: climatic conditions; soils; cultural characteristics; marketing; transportation facilities; ecological considerations; risk; socio-economic analysis; land, labor and capital availability; and the personality and preferences of the individual farmer. All these criteria are potentially important when one evaluates cropping systems, but some will be more important than others in a given situation, because the relative importance of each evaluative criterion is determined by the objectives of the evaluator. If a cropping systems researcher's objective is to design improved systems which small farmers will adopt, then he must view these criteria as the small farmer would view them and give each criterion the same relative importance the small farmer would give it.

Small Farmer's Adoption Criteria

Economic potential has often been used as a key criterion in making cropping systems recommendations for small farmers. This has been done because cropping systems that provide higher incomes give farmers resources needed to satisfy (or partially satisfy) goals such as: an

---

* Ph.D. Especialista en Mercadeo, CATIE

appetizing and nutritionally balanced diet, leisure, security, prestige, an adequate standard of living, etc. Economic potential is not, however, the only criterion small farmer use in selecting cropping systems. Figure 1 suggest a conceptual framework for describing the process whereby the farmer narrows the set of all possible cropping systems by systematically excluding systems which are infeasible due to agronomic, social, cultural, managerial, marketing, or other constraints. This leaves him with a subset of economically feasible systems, from which he selects a smaller subset that will be included in the farming system. Figure 1 highlights the fact that economic viability plays a key role in the selection process by using feedback arrows to indicate that systems which are economically viable may become more viable over time if resources earned by these systems are used to overcome existing agronomic, social, cultural, managerial, or marketing restrictions. Similarly, if a cropping system is not economically viable at present, but appears to be potentially viable, resources may be invested in projects designed to resolve or alleviate those constraints which render the system temporarily unacceptable. The small arrows within the subset of all possible cropping systems (in its various stages) indicate that technological, cultural or other changes may cause specific cropping systems to become feasible or infeasible over time.

As can be seen from Figure 1, all these restrictions are equally important in the sense that failure to meet minimum acceptable levels for any restriction automatically excludes a given system from the subset of cropping and animal systems that make up the farming system.

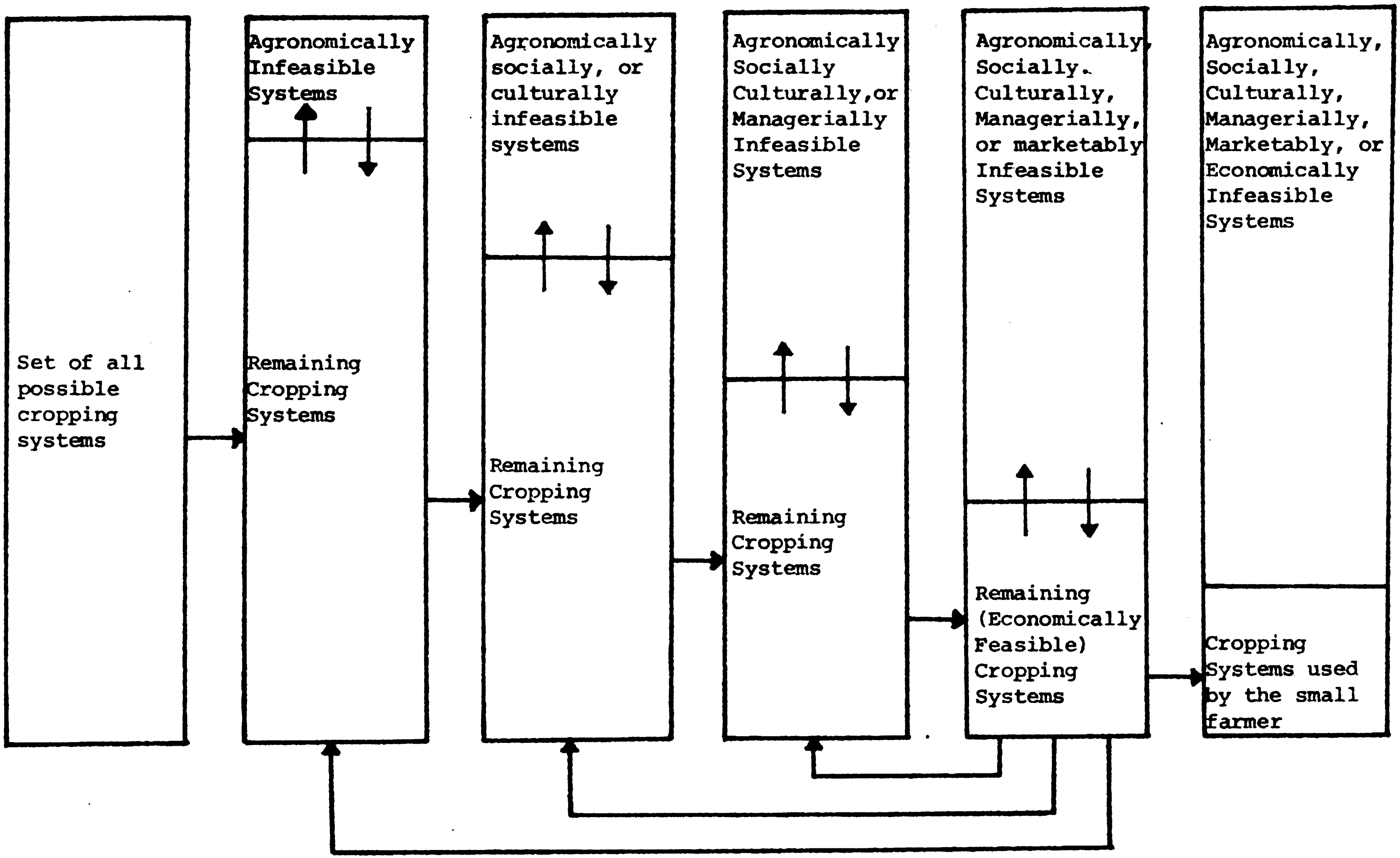


Figure 1. A conceptualization of the decision criteria used by small farmers in choosing cropping systems.

Social and Cultural Restrictions

Social and cultural restrictions are particularly important because they form absolute limits in the short run regarding the types of cropping or animal systems which are possible. Information regarding social and cultural constraints should be obtained when cropping systems research is just beginning in a new area. This information could probably be obtained at the same time the systems researcher gathers baseline data on current cropping systems, resource availabilities, yields, farm gate prices, existing marketing channels, etc.

Personnel sent to identify social or cultural restrictions will also want to identify community leaders and the existence of different groups in the area. This information is valuable because it reduces the risks created by working with only one group (particularly if it is the "wrong" group). Even small villages can be composed of two (or more) distinct groups with different amounts or mixes of agricultural resources, and in some cases important social or cultural differences. Consequently, experiments designed for one group may be completely inappropriate for another group in the same village or in the same area. Knowledge of the relative resource levels, values, beliefs, and goals of all important groups helps the researcher design useful and appropriate experiments for each group.

Cropping Systems, Farming Systems, Resources, and Goals

Cropping systems research is a useful type of partial analysis, but one must realize that all activities on the farm compete for the farmer's resources, and contribute mutually to achievement of the farmer's goals.

Consequently, selection of a particular cropping system for inclusion within the farming system as a whole will depend upon: (1) the degree to which the cropping system contributes to achievement of the farmer's goals; (2) the level of individual resources demanded by the cropping system; and (3) the absolute and relative levels of individual resources at the farmer's disposal. The decision to adopt a particular cropping system will consequently be strongly influenced by its compatibility with the entire set of activities included in the farming system, and with the farmer's goals. Systems which are relatively more effective at utilizing existing resources to achieve farmer's goals will be chosen for inclusion in farming systems.

Food, income, security, and prestige are common small farmer goals, but they are not equally important to all farmers. Each small farmer weighs these goals in accordance with his cultural and personal background, and then chooses cropping systems which are relatively more effective in helping him satisfy his individually weighted set of goals. Resources like land, hired labor, family labor, working capital, irrigation water, etc. are also highly individualistic because their amounts and mixes vary greatly from farm to farm. Land is perhaps the best example of this variability because a farmer is interested in the productive potential of a new system on his farm, i.e., with his soil, altitude, rainfall, and slope characteristics.

Given the individualistic character of each farmer's resources and goals, and given that new cropping systems need to be compatible with existing farming systems, it is logical to expect that individualistic groups or types of small farmer will need cropping systems that are designed specifically for them. This need has been partially recognized by development programs that have defined, and begun to identify agroclimatic analogs which identify areas with equal or similar agronomic potential. These analogs will be used to extrapolate experimental findings from one Central American area to another, and consequently represent an important recognition of small farm differences. Agroclimatic analogs are, however, an incomplete recognition of small farm differences, because they focus on developing different-cropping systems for different agroclimatic areas, and ignore the fact that important differences exist between small farmers in the same agroclimatic (or analog) area.

While any type of difference may be crucial in determining whether a particular system will be adopted, differences in relative resource levels or mixes are less binding, and hence of more importance in designing improved cropping systems than social or cultural characteristics which are usually unchangeable in the short run. Differences in relative resource mixes present the cropping systems researcher with an opportunity to design improved systems which fit each farmer's resource mix by: (1) using less of a resource which is in short supply; or (2) substituting relatively abundant resources for relatively scarce resources whenever possible. These improved systems help the small farmer make more effective use of the complete set of resources at his disposal, and consequently help him achieve his individual goals, including the goal of maximizing family income.

Constrained Income Maximization

Family income maximization is regarded here as a constrained goal in the sense that income will be maximized only after the farmer has attained acceptable levels for his other (more important) personal, social or cultural goals.

The importance of income maximization as a controlling criterion in cropping system adoption decisions is questioned perennially by personnel engaged in small farm research. Some technicians have concluded that small farmers are not interested in choosing systems which maximize farm or family income, and this assertion is supported by many cases in which small farmers have rejected recommended cropping systems which provide higher net or family incomes per hectare and have instead: (1) continued to use traditional cropping systems; or (2) only partially accepted the recommended technologies and consequently have improved yields, but have not achieved yields or incomes comparable to those achieved by the recommended technological packages.

The present methodology concedes that income maximization is not the farmer's only goal, nor is it necessarily the farmer's most important goal. Most small farmers are not income maximizers; but they are constrained income maximizers. Income maximization therefore becomes the controlling criterion determining selection of an important subset of cropping systems -- the subset the farmer uses to increase family income.

The rule small farmers implicitly use in selecting cropping systems which will maximize income, is to select cropping systems which provide the highest returns per hectare per unit of the farmer's most limiting resource*. When the farmer's most limiting resource is land, this reduces to the highest return per hectare, but land is not always the small farmer's most limiting resource.

APPLICATION OF THE LIMITING FACTOR METHODOLOGY TO THE ECONOMIC ANALYSIS PROBLEM

Economic analysis of cropping systems should begin by identifying which factors are most limiting for a particular group of small farmers. Economic comparisons of alternate cropping systems can then be made with respect to their utilization of these most limiting resources. If a researcher is not sure which resources are most limiting, or if he would like to apply experimental results to various groups of small farmers with various types of limiting resources, he can simply calculate the income/ha per unit of all important resources used in the experiment. For example, the researcher might calculate income: per unit of labor; per unit of working capital, per lb. of fertilizer; per cubic meter of irrigation water; per unit of mechanized power (tractor hour); or per CWT (where transportation facilities and costs are the limiting factor). By analyzing alternate cropping systems in this way, one can compare each systems relative efficiency in utilization of small farmer's resources.

---

* The rule is more accurately stated as the system which returns the highest farm income per unit of the farmer's most limiting resource, i.e., the land unit used by the farmer is the entire farm, not one ha. Income/ha/unit of the most limiting resource is used in place of farm income per unit of the most limiting resource because the cropping systems researcher usually presents experimental results on a ha scale instead of on a per farm scale, because farm sizes vary.

The system which is most efficient at utilization of the farmer's scarcest resource will be the system which provides the family with the highest farm income. The series of decisions which the researcher must make before recommending cropping systems which are efficient utilizers of the small farmer's scarcest resources is presented in Figure 2. Figure 2 also serves as a general outline and summary of the material presented in the remainder of this section.

Baseline Estimates of Small Farmer Resource Levels

Since relative resource levels are important in determining the types of cropping systems small farmers can adopt, cropping system researchers should begin their analysis by visiting the areas for which improved cropping systems will be developed to obtain baseline data for each area. Data sources might include: (1) formal or informal surveys; (2) interviews with selected local experts; and (3) existing studies. The researcher often finds different estimates from one (or more) of these sources and will have to rely on his own experience and judgement to resolve these conflicts. The base line data which is collected should include information on: current cropping systems; agronomic and climatic characteristics; the types and amounts of resources on (or available to) small farmers; production coefficients and yield estimates for existing systems; farm gate prices; marketing channels; environmental restrictions, and important socio-cultural constraints which would rule out specific types of cropping systems. From this data one or more typical groups of small farmers will be identified. Inspection of relative resource levels and knowledge of resource requirements for existing cropping

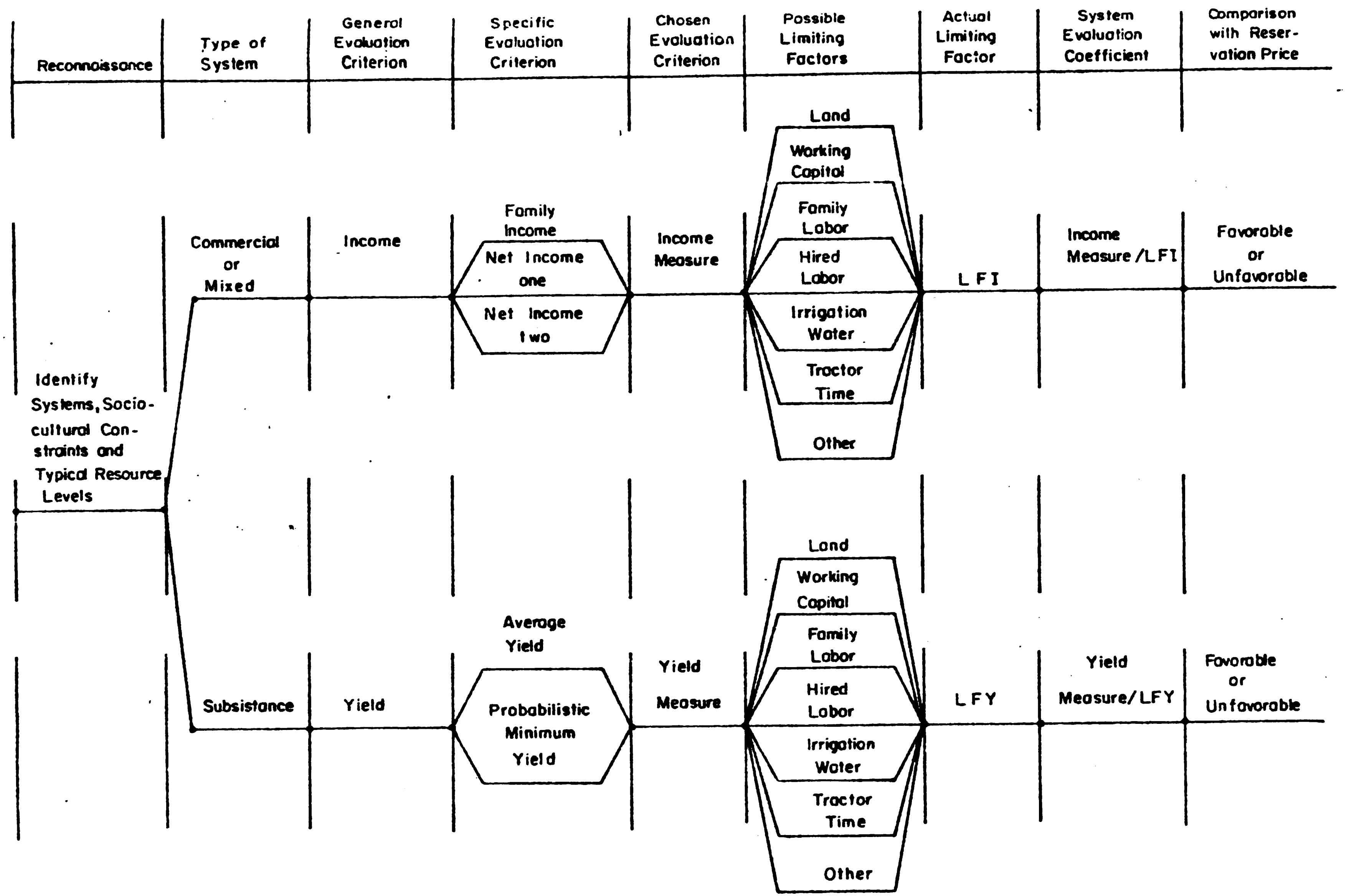


Fig. 2 The decision process used to apply limiting factor analysis to the problem of evaluating alternate cropping systems

systems will point out which resources are scarcest for each group, and cropping systems experiments may then be specifically designed for each "typical" group.

Choice of an Income Measure

As was noted earlier, this methodology is principally aplicable to those cropping systems the farmer employs to increase his income. It may however be altered slightly to indicate preferable systems used by pure subsistence farmers or by farmers who include food provision systems within the farming system. In these types of systems yield is used in place of income to evaluate different cropping systems. In most cases average yields will be used as the relevant yield measure, but in cases where the farmer has a very low tolerance for risk, yields may be defined in terms of the probability of experiencing a certain minimum yield. For example, if, Y_i is the yield for a given system, p_i is the probability of the farmers achieving that yield, and Y^* is the yield for which the cumulative probability of achieving a yield less than Y^* is 25%, then Y^* becomes the relevant yield measure for farmers who insist that the system actually produce the "recommended" yield (or more) at least 75% of the time. The choice of 25% was arbitrary here, the actual percentage must be chosen by the farmer or estimated by the researcher after talking with the farmer and evaluating his risk preferences. Once a standard yield measure which can be used for all systems has been defined, the farmer's decision rule for making comparisons between mono-crop systems (which produce the same crop) is to select the system with the highest yield evaluation coefficient. Yield evaluation coefficients are computed by dividing the standard yield measure for each system by that system's requirements for the farmer's most limiting resource. The system with the highest yield evaluation coefficient, i.e., with the highest standard yield measure/ha/unit of the farmer's most limiting resource will be preferred.

For multiple crop systems, the analysis becomes a little more complicated, but the same principles apply. One alternative for evaluating multi-crop systems is to have the farmer specify indifference ratios between all crops in the system. For example, the farmer may state that he is indifferent between 1 lb. of beans and 3 lbs. of corn. Standard yield measures could then be stated in terms of these indifference weights. For example, if a corn-bean subsistence cropping system has standard yields that average 200 lbs. of corn and 50 lbs. of beans, the system could be given a yield indifference score of 350 [(200 x 1) + (50 x 3) = 350]. Yield evaluation coefficients would then be computed by dividing each system's indifference score by the number of units of the farmer's most limiting resource used up by the system. The system with the highest yield evaluation coefficient would be preferred. In cases where it is difficult to get data on farmer's indifference ratios, local price ratios could probably be used to estimate the indifference weights.

A second alternative for evaluating multi-crop systems would be to ask farmers to identify minimum acceptable production levels for each crop in the system, and then choose the system which produces these minimum acceptable levels using the least amount of the farmer's scarcest resource.

Researchers developing cropping systems whose principle function is family food production should be wary of varietal preferences when they design systems. New varieties should not be introduced into food production systems unless the researcher has verified that the new varieties appearance, flavor, storage characteristics, etc. compare favorably with those of the varieties currently being consumed.

For cropping systems whose principal function is to increase family income, the farmer will prefer systems with higher income evaluation coefficients. The income evaluation coefficient is calculated by dividing an appropriate income per hectare measure by the system's requirements for the farmer's most limiting resource, and the system with the highest income/ha/unit of the farmer's most limiting resource will be preferred. Before this can be done, however, one must decide how income should be measured.

Two commonly used income measures are net income and family income, and either of these measures can be used with this methodology. Family income, net income one and net income two are defined here as:

$$FI = TR - VC1$$

$$NIO = TR - VC2$$

$$NIT = TR - VC3$$

Where: FI = Family Income

NIO = Net Income One

NIT = Net Income Two

TR = Total Revenue = $\sum_{i=1}^{n} P_i Y_i$

P_i = the farm gate price of the ith crop in the cropping system

Y_i = the standard yield/ha for the ith crop in the cropping system

i = the number of crops included in the cropping system

VC1 = out of pocket expenses or variable cost/ha for items such as: seed, fertilizer, other agricultural chemicals, irrigation water; custom hire machinery charges; the cost of non-family hired labor; and rent paid for farmland used by the cropping system (on the farmer's own land, rent is zero)

VC2 = VC1 plus interest paid (or imputed) on working capital used by the system plus depreciation charges per ha on capital inputs such as: pumps; sprayers, hoes; tractors; and other agricultural equipment used by the cropping system.

VC3 = VC2 plus the actual or an inputed variable cost/ha for family labor plus an inputed value for land used by the cropping system (this is the farmer's own land -- if the land were rented, the rental value was netted out as part of VC1).

Farmers who use only family labor to care for their crops and who are not accustomed to thinking about depreciation and interest charges will probably prefer using family income as the appropriate income measure. This is particularly true in cases where the farm is too small to fully employ the family and off-farm wages are low compared to the family income per hour earned when labor is devoted to crop production activities. Net income one would be used for more sophisticated small farmers who wish to net out interest and depreciation charges before calculating income. Net income two would be appropriate for farmers who use both family and hired labor and who wish to impute costs to all farm resources used by cropping systems in order to make more precise estimates of incomes and costs.

The allocation of specific costs to VC1, VC2, and VC3; and the resultant specification of FI, NIO and NIT is somewhat arbitrary, and can be altered to suit the characteristics and preferences of the group of farmers for which the systems are being prepared. The choice of an income measure is important because different income measures sometimes give slightly different results regarding the preferability of competing systems. This is another reason why the researcher needs to maintain close contact with and throughly understand the group of farmers he is working for.

Reservation Prices

Most small farmers have an expectation of a "reasonable return" from production when they commit resources to a specific cropping system. The level which this "reasonable return" takes is partly determined by need and partly determined by social or cultural values. When the income/ha/unit (or the yield/ha/unit) of a specific resource is not at least as high as the farmers expectation of a "reasonable level", he will refuse to invest his stock of this resource in the cropping system in question. In other words he withholds or researves his stock of resources for use in cropping systems which have more "reasonable" returns, hence the term reservation price.

All resources have reservation prices and in general, the scarcier the resource, the higher will be its reservation price. Since labor is often considered to be one of the most abundant small farm resources, one would expect the reservation price of labor to be as low as labor's opportunity cost. Observations of farmers who are willing to devote very large amounts of labor to cropping systems on very small farms supports this hypothesis, but again, not all small farmers are the same. It also seems that a farmer's reservation price increases as farm size and income (or total product) increase. This is particularly evident after the farmer has reached the point where he is producing more food than is needed by his family. The increasing reservation price after subsistence needs have been met explains why one frequently finds small farmers who devote one or two hectares of land to food production, but who will leave the remainder of their farm in unimproved pasture, or who simply let part of their land lie fallow. This pattern sometimes occurs in areas where government credit programs and technical assistance programs are operative and in families with underemployed labor resources. When asked about this underutilization of land resources, farmers often state that they prefer spending an extra hour in their hammocks instead of in their fields, but this decision could also be explained by noting that the income/ha/hr of labor effort expended in food production activities is less than the farmer's reservation price for family labor*.

---

* This pattern might also be explained as an implicit acceptance of soil fertility, erosion, ecological or marketing restrictions by the small farmer.

An Example

To illustrate the methodology, an example has been prepared using data obtained by interviewing small farmers from the area surrounding Parrita, a small town near the Pacific Coast in central Costa Rica (latitude 9°30' North, longitude 84°19' West). Small farmers near Parrita grow corn, beans, and rice for home consumption and sell their excess production to increase family income. Perennial crops such as coffee and achiote (used locally as a food colorant) are also grown by some farmers in the area and limited numbers of cattle are common on many of these small farms. Average farm size for the group of farmers interviewed was about 10 ha. Most of their land is very hilly. The only cropping systems which will be compared here are: traditional corn; working capital intensive corn; rice (which is also working capital intensive); broadcost bean with mulch; and a working capital intensive row bean.

Tables 1 and 2 give data on yields, prices, total revenue, variable costs, total working capital requirements, total labor requirements, total land requirements, Family Income (table 1) and Net Income Two (table 2) for each cropping system being considered. This data has been used in table 3 to calculate Family Income/ha, Family Income per ha/hr and Family Income/ha/₡ for each system. Table 3 shows that if the farmer's scarcest resource is land, system 5 (the capital intensive row bean) would be the preferred system because it provides the highest family income/ha (₡2200). If, however, the family's scarcest resource is labor, system 4 (the broadcost bean with mulch) is preferred; and if the family's scarcest resource is working capital, system 1 (traditional corn) is

Table 1. Calculation of Family Income

No.	CROPPING SYSTEM	YIELD (qq/ha)	FARM GATE PRICE (₡/qq)	TOTAL REVENUE (₡/ha)[a]	VARIABLE COST 1 (₡/ha)[b]	FAMILY INCOME (₡/ha)[c]
1.	Traditional Corn	18.50	60.00	1,110.00	20.00	1,090.00
2	Working Capital Intensive Corn	35.00	60.00	2,100.00	220.00	1,880.00
3	Rice	20.00	120.00	2,400.00	350.00	2,050.00
4	Broadcast Bean with Mulch	8.50	200.00	1,700.00	100.00	1,600.00
5	Working Capital Intensive Row Bean	15.00	200.00	3,000.00	800.00	2,200.00

a) Total revenue = $\sum_{i=1}^{n} P_i Y_i$. Pi is the farm gate price of each crop included in the cropping system. Yi is the yield of each crop in the system, and i is the number of crops included in the system per time period used for the analysis.

b) Variable cost 1 consists of out of pocket expenses for seed, fertilizer, agricultural chemicals, irrigation water, custom hire machinery charges; the cost of non-family hired labor; and rent paid for farmland used by the system (on the farmer's own land, rent in zero). In this example the costs of irrigation water, custom hire machinery, non-family hired labor and rent on farmland are all zero.

c) Family Income is defined as Total Revenue minus Variable Cost 1.

Table 2. Calculation of Net Income Two

No.	CROPPING SYSTEM	TOTAL REVENUE (₡/ha)[a]	VARIABLE COST 3 (₡/ha)[b]	NET INCOME TWO (₡/ha)[c]	TOTAL WORKING CAPITAL REQUIRED (₡/ha)[d]	TOTAL LABOR REQUIRED (hrs/ha)	TOTAL LAND REQUIRED PER CROPPING SYSTEM (ha)
1	Traditional Corn	1,110.00	871.00	239.00	20.00	175.00	1.
2	Working Capital Intensive Corn	2,100.00	1,431.00	669.00	220.00	250.00	1.
3	Rice	2,400.00	1,948.00	452.00	350.00	345.00	1.
4	Broadcast Bean with Mulch	1,700.00	655.00	1,045.00	100.00	100.00	1.
5	Working Capital Intensive Row Bean	3,000.00	1,760.00	1,240.00	800.00	180.00	1.

a) Total revenue = $\sum_{i=1}^{n} Pi\ Yi$. Pi is the farm gate price and Yi is the yield/ha

For each crop included in the system.

b) Variable Cost 3 is defined as variable cost 2 plus the actual or an imputed variable cost/ha for family labor plus an imputed value for land used by the cropping system.

c) Net Income Two is defined as total revenue minus variable cost 3.

d) Total Working capital required is equal to variable cost 1.

Table 3. Family Income per hectare per unit of land, labor, and working capital.

NO.	CROPPING SYSTEM	FAMILY INCOME per ha (₡)	FAMILY INCOME per ha/hr (₡)	FAMILY INCOME per ha/₡ (₡)
1	Traditional Corn	1,090	6.23	54.50
2	Working Capital Intensive Corn	1,880	7.52	8.55
3	Rice	2,050	5.94	5.86
4	Broadcast Bean with Mulch	1,600	16.00	16.00
5	Capital Intensive Row Bean	2,200	12.22	2.75

preferred. Table 4 gives rankings for each system when land, then labor and finally working capital are considered the most limiting factors. Table 4 demonstrates that the relative preferability of the various systems changes completely when a different factor is considered most limiting.

Tables 5 and 6 repeat this exercise using Net Income Two as the appropriate measure of income. A comparison of tables 4 and 6 reveals that the income measure used has an effect upon the preferance rankings. For example, if Family Income/ha is used as the preference criterion, rice is the farmer's second choice, but if Net Income Two/ha is the farmer's preferance criterion, broadcast bean with mulch is the farmer's second choice and rice is the farmer's fourth choice. Consequently, use of the appropriate income criterion based upon knowledge of the small farmer's resource set, his relative supplies of resources, the relative demands which each system has for each type of resource and the small farmer's experience and sophistication in measuring income, all interact to determine how he views the relative desirability of different cropping systems which could be used to increase Family Income (or Net Income Two).

Resource Flows

The methodology as presented thus far has considered resource requirements and availabilities as blocks or amounts needed and made available at a single point in time. This is unrealistic since resources such as labor, machine time, irrigation water, etc., are available and required as flows through time. These flows can be approximated by

Table 4. Ranking of preferred cropping systems using the Family Income per hectare per unit of most limiting resource criterion.

NO.	CROPPING SYSTEM	FAMILY INCOME per ha	FAMILY INCOME per ha/hr	FAMILY INCOME per ha/₡
1	Traditional Corn	5	4	1
2	Working Capital Intensive Corn	3	3	3
3	Rice	2	5	4
4	Broadcast Bean with Mulch	4	1	2
5	Capital Intensive Row Bean	1	2	5

Table 5. Net Income Two per hectare per unit of land, labor, and working capital

NO.	CROPPING SYSTEM	NET INCOME TWO per ha (₡)	NET INCOME TWO per ha/hr (₡)	NET INCOME TWO per ha/₡ (₡)
1	Traditional Corn	239.00	1.37	11.95
2	Working Capital Intensive Corn	669.00	2.68	3.04
3	Rice	452.00	1.31	1.29
4	Broadcast Bean	1,045.00	10.45	10.45
5	Capital Intensive Row Bean	1,240.00	6.89	1.55

Table 6. Ranking of preferred cropping systems using the Net Income Two per hectare per unit of most limiting resource criterion

NO.	CROPPING SYSTEM	NET INCOME TWO per ha	NET INCOME TWO per ha/hr	NET INCOME TWO per ha/₡
1	Traditional Corn	5	4	1
2	Working Capital Intensive Corn	3	3	3
3	Rice	4	5	5
4	Broadcast Bean with Mulch	2	1	2
5	Capital Intensive Row Bean	1	2	4

viewing the cropping season as being divided into discrete blocks of time. The length of these blocks is very important since they must reflect the agronomic requirements of the system. Resources must then be specified with respect to their availabilities within each of these discrete blocks of time. For example, each production activity such as land preparation, weeding, harvest, etc., has to occur within a specific time frame (planting can often be delayed a week, but only in very unusual circumstances can it be delayed 6 months). Similarly, the farmer may have 1000 labor hours available for production activities per cropping season, but he will have only (for example) 125 hours available during the period when planting must occur. By dividing the cropping season into blocks of time which correspond to the time periods within which each cropping activity occurs, and then by comparing resource availabilities with resource requirements during each period, the researcher can estimate which resources are most limiting during each time period. This in turn allows one to identify the specific time period when a particular resource becomes the most limiting. Different systems are then compared with respect to their income/ha/unit of the farmer's most limiting resource during this time period. For example, if the researcher discovers that the farmer's most limiting resource is labor during the first three weeks of July, the preference ordering among competing systems is based upon income/ha/hr of labor utilized during the first three weeks of July. It should be noted at this point that a system which earns only ₡10/year but which requires no labor during the first three weeks of July would have a family income/ha/hr coefficient of infinity and might consequently be highly desirable because of its complementarity with other sytems which provide higher incomes/ha but also make higher demands upon the family's labor supply during the first three weeks of July. The researcher would then have to compare this system's income (or yield) evaluation coefficients with the reservation price for each of his resources. If the income evaluation coefficients are all greater than the reservation prices, then this system would be included in the farming system.

CONCLUSSION

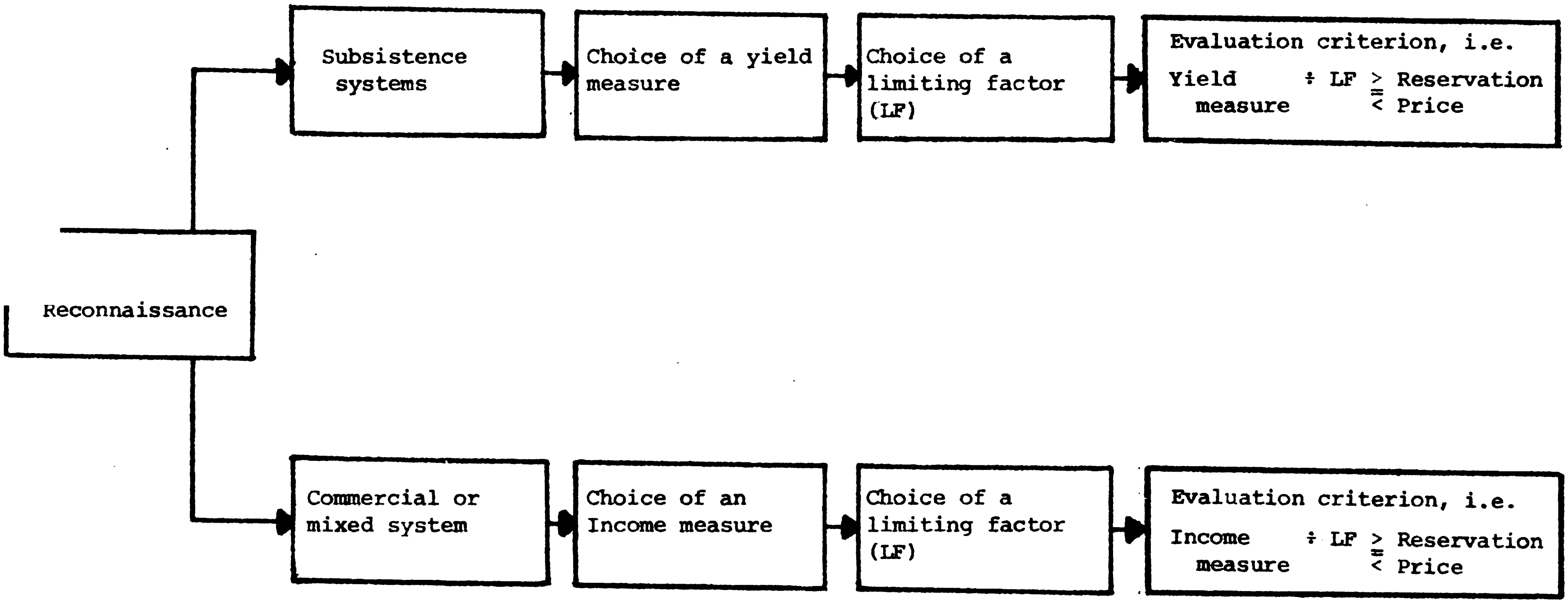
"What constitutes an improved cropping system?"

This methodology recognizes that there are no easy, generally applicable answers to this question because small farmers are not a homogeneous group. Improved cropping systems are usually recognizable after they have been adopted, but not all improved sytems will be adopted by all farmers. Each farmer must decide if a new system is really an improvement over his existing systems and this decision will be made with respect to his own personal, social, cultural, agronomic, ecological, and climatic constraints. These constraints reduce the set of all possible cropping systems to a much smaller subset of feasible alternate systems, and it is at this point that the present methodology may be used to economically evaluate and compare the farmer's current systems with new systems developed by cropping systems researchers.

Constrained income maximization is considered an important small farmer goal because income provides resources which farmers may use to satisfy or partially satisfy other more important goals. Small farmers are not considered to be income maximizers because attainment of minimum acceptable levels for other goals is viewed as being at least as important as income maximization. It is the interaction of these other goals with the farmers resources and agroclimatic constraints which cause income maximization to be constrained.

The importance of the levels and mixes of each small farmer's resources in determining if a given cropping system is an improvement over existing systems implies that cropping systems should (ideally) be individually designed for every small farmer. At present, this is logistically impossible but it is a goal toward which cropping systems research should strive because it may become critical when cropping system extension agents try to transmit experimental results to individual farmers. In the meantime, researchers should be aware of the need to design different types of cropping systems for different groups of small farmers who have different goals, resources, farming systems, agro-climatic characteristics, etc. Researchers who are aware of differences between groups of small farmers have a better understanding of the restrictions affecting adoption of improved cropping systems by each group. Consequently, they are able to design improved systems which make more efficient use of each group's most limiting resource and are therefore able to design systems which are useful and appropriate for each group.

Figure 3 gives us an overview of the decision process the cropping systems researcher must go through before he can recommend a particular cropping system to a given (individual or representative) small farmer. The researcher must begin by studying the small farmer. This is shown in Figure 3 as the reconnaissance stage in which the researcher identifies: socio-cultural constraints; current cropping and animal systems used by



ɿure 3. An overview of the limiting factor methodology

small farmers; estimates of production coefficients for each system; estimates of the types and amounts of resources the farmer has to work with; and an estimate of which activities can be regarded as typical for the group of small farmers being studied. Systems which are regarded as typical are then divided into: (1) subsistence; and (2) commercial or mixed subsets (mixed is used here to identify a set of systems which the farmer uses to provide food and income).

Systems whose goal is food provision will be evaluated by comparing each system's yield evaluation coefficient. The yield evaluation coefficient is obtained by dividing the system's yield by its requirements for the farmer's most limiting (or scarcest) resource. This coefficient is then compared with the farmer's reservation price (expressed as a yield measure) to asssure that the evaluation coefficient is greater than the farmer's reservation price, and therefore that the farmer is willing to invest his scarcest resource in this system. Assuming that several systems have yield evaluation coefficients greater than the farmer's reservation price, the farmer will then prefer the system(s) with the highest yield evaluation coefficient(s).

Systems whose goal is to increase family income are evaluated in a similar manner. The only difference is that one computes an income evaluation coefficient instead of a yield evaluation coefficient. Income evaluation coefficients are found by dividing the amount of income the system earns by the system's requirements for units of the farmer's most limiting resource. A comparison with the farmer's reservation price is again made and the system(s) with the highest evaluation coefficient(s) will be preferred for inclusion within the small farming system.

The methodology can be made more realistic by dividing the cropping season into blocks of time which correspond to the periods when cropping activities such as planting, cultivating, etc. must take place. A comparison of resource requirements by competing systems and resource availabilities within each of these periods will reveal the period when a limiting resource becomes most limiting. Alternate systems can then be compared with respect to their income (or yield) evaluation coefficients within this critical period.

BIBLIOGRAPHY

1. DYCKMAN, T.R., S. SMITH and A.K. MACADAMS. Management Decision Making Under Uncertainty, London, Mac Millan, 1969.

2. HART, ROBERT D., El Sistema de Cultivos como Unidad de Experimentación, Turrialba, Costa Rica, CATIE, 1976. 11 p. 3 ref.

3. JOHNSTON, T. DAVID. El Achiote como Alternativa promisoria para incluirla en Sistemas del Pequeño Agricultor. Turrialba, Costa Rica, CATIE, 1977, 63 p. 12 ref.

4. MORENO, RAUL A. and J.L. SAUNDERS. A Farming System Research Approach for Small Farms of Central America. Turrialba, Costa Rica, CATIE, 1978, 28 p.

5. ZANDSTRA, H.G. SWANBERG and L.A. ZULBERTI. Venciendo las limitaciones a la Producción del Pequeño Agricultor, International Development Research Center, Ottawa, Canada, 1975.

FITO 834/78

TDJ/idev