Economics Program
Progress Report 24

The Potential of Mathematical Programming for the Analysis of Yield Gaps in Semi-Arid Tropical Agriculture

R.D. Ghodake

ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O.
Andhra Pradesh 502 324, India

September 1981

THE POTENTIAL OF MATHEMATICAL PROGRAMMING FOR THE ANALYSIS OF YIELD GAPS IN SEMI-ARID TROPICAL AGRICULTURE*

R.D. Ghodake+

INTRODUCTION

The role of technology development and its transfer in agricultural development is now well recognized. However, it has been observed that the performance of technology on farmers' fields is not as satisfactory as at experiment stations. Though some farmers are able to achieve high yields on their farms, they seldom, if ever, reach the levels attained at experiment stations. The following factors may influence such gaps: (i) non-transferable components of technology, (ii) environmental variations, (iii) physical or biological constraints, and (iv) socioeconomic constraints.

Constraint analysis research tries to identify the factors causing the gaps and also to quantify the magnitude of their contributions. The findings of such research have many implications for policy formulation aimed at alleviating the constraints causing the yield gaps. The results also have implications for research to modify technology so as to reduce gaps.

The International Rice Research Institute (IRRI) has pioneered a methodology to identify yield gap factors and estimate their magnitudes in rice production (De Datta *et al.*, 1978). The total yield gap is conceptually divided into two components: Gap I, between experiment station yield and potential yield at the farm level; Gap II, between potential and actual yield at the farm level. Gap I has direct implications for

---

* This is a revised version of the paper presented at the Working Group Meeting on Yield Gap Analysis for Dryland Crops, organized jointly by the All India Coordinated Research Project for Dryland Agriculture, Hyderabad, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P., during 17-23 February 1980. This paper received ICRISAT Journal Article No. 186.

+ Economist, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India. The author is grateful to James Ryan, Matthias von Oppen, Hans Binswanger, Dayanatha Jha, Brian Hardaker, Jere Behrman, and anonymous reviewers for their valuable comments and suggestions. He is thankful to Usha Rani and Mohammed Nayeemuddin for computational assistance.

research and thus for the development of new technology. Gap II deals with the realization of the production potential at farm level with a given technology. Gap II can be further divided into two components: (1) that caused by biological constraints, and (2) that caused by socio-economic constraints.

A wide range of techniques has been employed to analyze yield gaps -- such as simple tabular analysis, analysis of variance, multivariate regression analysis, production function analysis, etc. The use of whole-farm-household analysis to understand and measure variations in inputs that cause yield gaps has also been suggested (Flinn, 1979). The approach of whole-farm-household analysis becomes more relevant in regions where rainfed agriculture is predominant. Besides alternative opportunities available for the employment of farmers' resources, (as in other regions) many crops, crop mixtures and crop rotations are also involved in farming in the rainfed situation. In addition to erratic weather, these regions are characterized by a subsistence type of farming that requires an understanding of many complex decision-making processes. The agroclimatic environment also subjects farmers to substantial risks.

The objective of this paper is to propose and demonstrate the use of a whole-farm modelling approach based on mathematical programming,[1] to partition Yield Gap II, attributable to socioeconomic factors in rainfed agriculture. The first section of the paper deals with existence of yield gaps, expressed in various ways, in different crop production activities in the study location.[2] It also tries to explain them in terms of input gaps. In the second section, the proposed models and concepts are discussed. The third section demonstrates the use of a mathematical programming technique in breaking yield gap into components by using actual input-output data and by considering existing resource and other constraint levels.

I. YIELD GAPS IN RAINFED AGRICULTURE

As part of ongoing research at ICRISAT for assessing technology options available to semi-arid tropical farmers, different crop-production activities have been identified for two villages in the Akola district. These

---

1. Mathematical programming is a group of techniques used for computing the solution of equations based on the objective function of an economic entity. The group includes linear programming, nonlinear programming such as quadratic programming, stochastic programming, parametric programming, etc.

2. The Akola district of Maharashtra State in India is used for this study where ICRISAT's Economics Program has conducted village-level-studies over several years (Jodha *et al.*, 1977).

activities or processes are mainly based on crops, crop varieties, crop mixtures, crop rotations, fertilization levels, irrigation levels, soil types, etc. Synthetic input-output vectors were developed for each process by averaging overall farmer plots. The data used for this purpose pertains to the 1976-77 agricultural year. In total 16 crops have been used here for comparison purposes. However, the final yield gap breakdown, using mathematical programming, considers a larger set of 27 processes.

In order to achieve a "technically most efficient" input-output vector from among the available plots under each process, the criterion of maximum net returns per hectare over variable cost has been used.[3] Thus for each process one plot is selected whose input-output relation has been assumed to be technically efficient over other plots of the same process.[4] This gives another set of vectors for all the defined processes that represent technically efficient means of production.

Examination of a single crop situation for gap analysis will make it easy to express the gap in terms of physical yields. However, in a situation in which outputs consist of different main products and by-products, yield gaps must be measured in terms of either gross or net returns in monetary terms per unit of land. This is particularly relevant when the whole-farm-household approach is to be adopted for gap analysis.

Yield gaps in terms of the main product[5] between "technically efficient" plots and "average" plots (Yield Gap II) are presented in Table 1. The highest percentage yield gap was observed for local cotton, and the lowest for the sorghum-chickpea rotation. Among cotton processes, the yield gap was between 60 and 70% in the case of sole cotton, but its magnitude was lowest in the case of cotton mixtures. Gaps in sorghum and sorghum mixtures ranged from 26 to 53%. Local paddy and groundnut when grown as sole crops had relatively small yield gaps.

---

3. Technical efficiency refers to the proper choice of production function among all those actively in use by farms in agriculture (Farrell, 1957). Here "efficient plot" for each crop production activity is the one with the highest net returns to fixed resources.

4. The set of chosen vectors need not necessarily be really technically most efficient, as many other possible relations between input-output coefficients might not have been observed, and the use of different criteria might give different vectors. However, in the absence of this information one can accept this set as a realistically attainable approximation.

5. In case of crop mixtures and crop combinations, main product yield is a simple addition of main product yields of individual crops.

Table 1. Percentage yield and input gaps between efficient plots and average plots for important crops and crop combinations in Akola region, 1976-77.

Crop	Percentage gaps[a]		
	Main product yield	Net returns	Cash input
Cotton (L)	72	64	84
Cotton (H)	63	67	43
Cotton (L) + pigeonpea	45	50	28
Cotton (L) + pigeonpea + sorghum (L)	42	48	27
Sorghum (L)	53	56	41
Sorghum (H)	40	46	-53
Sorghum (L) + pigeonpea	40	39	-129
Sorghum (L) + green gram	48	45	1
Sorghum (L) + black gram	41	42	-4
Sorghum (L) + black gram + pigeonpea	47	51	0
Sorghum (L) + black gram + green gram	51	49	23
Sorghum (L) + black gram + green gram + pigeonpea	26	25	37
Sorghum (H) followed by chickpea	6	7	2
Paddy (L)	13	25	-7
Paddy (L) followed by chickpea	55	52	51
Groundnut	27	49	-7
Average	42	45	7

L = Local variety; H = High-yielding variety.

[a]Percentage gap calculations are always made by using efficient plot figures as the base, irrespective of positive or negative gap values.

It is clear that the pattern of net return gaps is similar to the pattern of main product yield gaps (Table 1). However, the percentage gap figures for net returns in many crop production processes are higher than the main product yield gaps, which imply proportionately higher levels of variable cash inputs on processes with average technical efficiency. An important inference drawn from this table is that the percentage net return gap figures are higher for sole crops than the crop mixtures dominated by the same sole crops.

For five processes the cash input[6] gaps were negative, consistent with our earlier contention that a greater cash input is used on processes with average technical efficiency (Table 1). In these crops the positive gaps in yields do not necessarily arise because of greater cash inputs on selected plots. Therefore, there must be other factors causing these yield gaps. For all four cotton activities the gaps were positive but varied widely from 27 to 84%. In the case of a sorghum and sorghum mixture activities cash inputs were higher for average plots than for technically efficient plots. The range was from -129 to 41%.

To conclude, average yield gaps, when measured in terms of physical yield and net returns, are observed to be 42% and 45%, respectively. The picture is different in the case of cash input gaps, the average gap for all activities being only 7%. The differences in the magnitude of yield and input gaps for at least some crop activities suggest that other factors might be responsible for these gaps. Such factors might be allocative inefficiency, human and bullock labor input levels, pest and disease incidence, management skills, farmers' attitudes towards risk, etc.

II. CONCEPTS OF YIELD GAP PARTITION AT FARM LEVEL

In the IRRI-type of gap analysis for explaining yield gaps, data are generated through complete factorial and minifactorial trials and can be analyzed by conventional analysis of variance techniques to determine individual and joint contributions of the various factors (De Datta *et al.*, 1978). Partial budgeting approaches have also been suggested to compare alternative management practices and in turn to understand the economic incentives for cultivation of the alternative crops. In order to understand the effect of various factors on input use and thereby on yield levels, regression analysis can also be used.

---

6. Cash input includes expenditure on seeds, fertilizers, pesticides, insecticides and farmyard manure.

Flinn (1979) argued that analysis would have to be conducted at the level at which decisions on resource allocation are made, i.e., at the household level. He pointed out two implications of the crop-specific focus as opposed to farm-household analysis. First, in partial budget analysis it is possible that the values of resources to the farmer differ from market prices assumed in the analysis. Second, the real situation in which farmers make decisions (imperfect knowledge, limited resources, availability of capital and labor, risk avoidance, management skill, etc.) may be insufficiently captured in a crop production function analysis. He went on to suggest that instead of positive regression analysis normative models could be used, if designed to simulate an integrated analysis of the objective of the farmer, his resource base, production alternatives, his commitment of resources and produce to the needs of the family, farm and nonfarm activities, and the market.

The approach of whole-farm-household analysis is especially relevant in the case of rainfed agriculture in the semi-arid tropics where as many as 79 crops, crop combinations and rotations may be included in the farming systems of a single village (Jodha, 1977). Furthermore, as in the other climatic zones, farmers may have alternative uses for their resources. Even for monocropping areas, Herdt and Mandac (1979) emphasize the role of differences in real prices of inputs and outputs in determining farmers' input use and therefore yield gaps. A similar logic applies when farmers have many alternative uses for their resources and the marginal value product of each one of them varies, thereby causing varying input use levels and gaps. The issue of real prices is further complicated where subsistence or semi-subsistence farming may be practised to meet household consumption needs or to minimize risk arising from yield and price variations. The existence of segmented labor markets in these areas is another source of complexity. In order to cover all of these effects, there is a need to consider all the activities of a farmer and to measure the yield gap at the farm level per unit of fixed resources as opposed to the yield gap of an individual crop.

For this work I have used mathematical programming (linear programming)[7] models to analyze the yield gap, expressed in terms of gross returns per hectare. My analysis is along the lines suggested by Herdt and Mandac (1979), who formulated a model to split the yield gap into factors such as profit-seeking behavior, allocative inefficiency and technical inefficiency.

---

7. One can use more complicated techniques of mathematical programming, as for instance quadratic programming (Markowitz, 1959) or MOTAD programming (Hazell, 1971) which allow one to deal rigorously with risk in the enterprise returns. However, these techniques need access to reliable computer programs and entail large data assembly and computational costs.

Allocative (or price) efficiency and technical efficiency are two components of overall economic efficiency.[8] Technical inefficiency can result from factors that are within the farmer's management capacity; it can also be due to factors, both physical and social, over which he has no control. Price or allocative inefficiency results from suboptimal input combinations. Total economic efficiency is influenced first by environmental considerations and second by factors operating at the individual or group level. The environment consists of factors that are external to the farmer and that influence his decision but are not under his control (such as the infrastructure available, nature of factor markets, institutional structure, etc.). The model proposed here can attribute yield gaps to technical and allocative inefficiencies only at the individual level.[9]

I earlier described "technically efficient" vectors and "average" vectors for different crop production processes in the Akola region. The detailed specifications of various models to be optimized at different constraint levels based on these two sets of coefficients are given in Table 2. The specifications are given by farm size to account for resource endowment differences.

Model 1 gives existing levels of gross returns, while Model 2 estimates gross returns from existing cropping patterns using technically-efficient coefficients. Model 3 considers risks arising out of net return variabilities and attitudes of the farmers towards risk,[10] and operates

8. The author is aware of the fact that 'efficiency' can only be measured according to some specific criterion. Thus there are semantic difficulties in discussing gaps in terms of efficiency or inefficiency when part of the gap arises from choice of different objective functions viz., maximization of gross output, maximization of expected profits or maximization of expected utility. However, this exercise is based on the assumption that farmers aim to maximize expected profit.

9. In order to find out the nature and sources of economic efficiency in terms of an 'optimizing model,' Sampath (1979) used the linear programming technique.

10. Risk aversion coefficient has been defined as the ratio of changes in the levels of expected net returns (E) and standard deviation (σ) of net returns. Risk aversion coefficients for various categories of farms are taken from Binswanger (1980). The semi-arid tropical farmers were found to be moderately risk-averse without any significant differences in coefficients of various categories of farms. Nevertheless, we assume decreasing risk aversion as farm size increases and set the coefficients at 0.66, 0.50, and 0.33 for small, medium and large farms, respectively. The coefficients are set at these levels because Binswanger found that about 80% of all farmer respondents came under the two central risk aversion classes -- intermediate and moderate -- which represent risk aversion in the range of 0.66 and 0.33.

Table 2. Detailed specification of models used for yield gap analysis.

Model No.	Method	Detailed specification
1.	Estimation from sample	Synthetic situation with average input-output coefficients at existing level of resource use and cropping pattern for each category of farm.
2.	Estimation from sample	Estimated with improved input-output coefficients by using existing cropping pattern and required level of resources for each category of farm.
3.	Linear programming solution	Net return maximization with risk considerations and with constrained labor and capital availability. Risk aversion coefficients of 0.66, 0.50 and 0.33 for small, medium and large farmers, respectively. Human labor availability relaxed by 10, 15 and 20% on small, medium and large farms, respectively, in critical labor use period.[a] Bullock availability relaxed by 10% for all categories in critical labor-use periods. Capital availability up to existing use for each category.
4.	Linear programming solution	Net return maximization with risk considerations and constrained labor availability as in Model 3, but capital relaxed up to Maximum Borrowing Limit[b] applicable at present cropping pattern level for each category of farm.
5.	Linear programming solution	Net return maximization with risk considerations as in Model 4, but human labor availability relaxed by 20, 30 and 40% on small, medium and large farms, respectively; bullock labor availability relaxed by 20% for each category of farm in critical labor-use periods.
6.	Linear programming solution	Net return maximization with relaxed labor and capital availability as in Model 5, but without risk considerations.
7.	Linear programming solution	Gross return maximization without risk considerations and with relaxed labor and capital availability as in Model 6.

[a]Critical labor use periods are as follows:

Human labor	period 1	second week of June to July end;
	period 2	second and third weeks of September;
	period 3	last week of September to middle of December.
Bullock labor	period 1	middle of June to middle of July;
	period 2	last week of September to middle of December.

[b]Maximum Borrowing Limit is calculated on the basis of maximum credit limit prescribed for each crop by District Central Cooperative Bank, Akola, and by considering existing cropping pattern.

under labor and capital restrictions. Models 4 to 6 relax these constraints one by one so as to account for the contribution of these restrictions to the total yield gap. The order in which these constraints are relaxed is based on the rationale that some constraints can easily be alleviated and hence receive priority for relaxation over others that are relatively difficult to manipulate.[11] The final model maximizes gross returns at relaxed levels of all these constraints for the farmer who is indifferent towards risk.

The concept of yield gap partition at the farm level based on the results of these models is depicted in Figure 1. Yield Gap II is expressed in terms of gross returns per hectare and is shown along the Y axis, while model numbers are indicated along the X axis. Ideally, the X axis should, indicate the value of the input, which is implicit when one presents for simplicity a one-variable model (i.e., the cash value of all the inputs required under each model along X axis). The TVP 1 (Total Value Product) shows the response to cash input when used with full technical efficiency. Hence all the points lying below TVP 1 are technically less efficient. TVP 2 is the technically less efficient "average" response curve. Y_1 is the level of yield obtained from the least efficient means of production at existing levels of resource use and cropping patterns (results of Model 1). Model 7 generates the level of yield from a technically-efficient means of production at relaxed levels of resources and with the sole objective of maximizing gross returns. The difference between Y_7 and Y_1 is then defined as potential Yield Gap II at the farm level, and it can be decomposed.

The farmer who is at point A adopts a technically-inefficient production process with Y_1 level of yield. He then becomes technically efficient at point B by using the efficient set of input-output coefficients with existing cropping patterns. Point B need not necessarily be an efficient allocation at the given level of resources. Hence the farmer can move upward along TVP 1 to point C and produce yield level Y_3 (not all upward moves along TVP 1 improve allocative efficiency). When the capital constraint is relaxed, as indicated in Model 4, the yield goes up to Y_4 at point D. The relaxation of human and bullock labor constraints, in addition to capital, results in yield Y_5 at E. The total difference between Y_5 and Y_3 is the yield gap caused by capital and labor restrictions. Risk neutrality at relaxed levels of resources increases yield further to Y_6 at point F. Point G might simulate a research station situation where profit

11. The most relevant and important constraints in the case of rainfed agriculture are human labor, bullock labor, capital, consumption needs of farm household, preferences, degree of knowledge and skill, moisture availability, other input availabilities, attitude towards risk, etc.

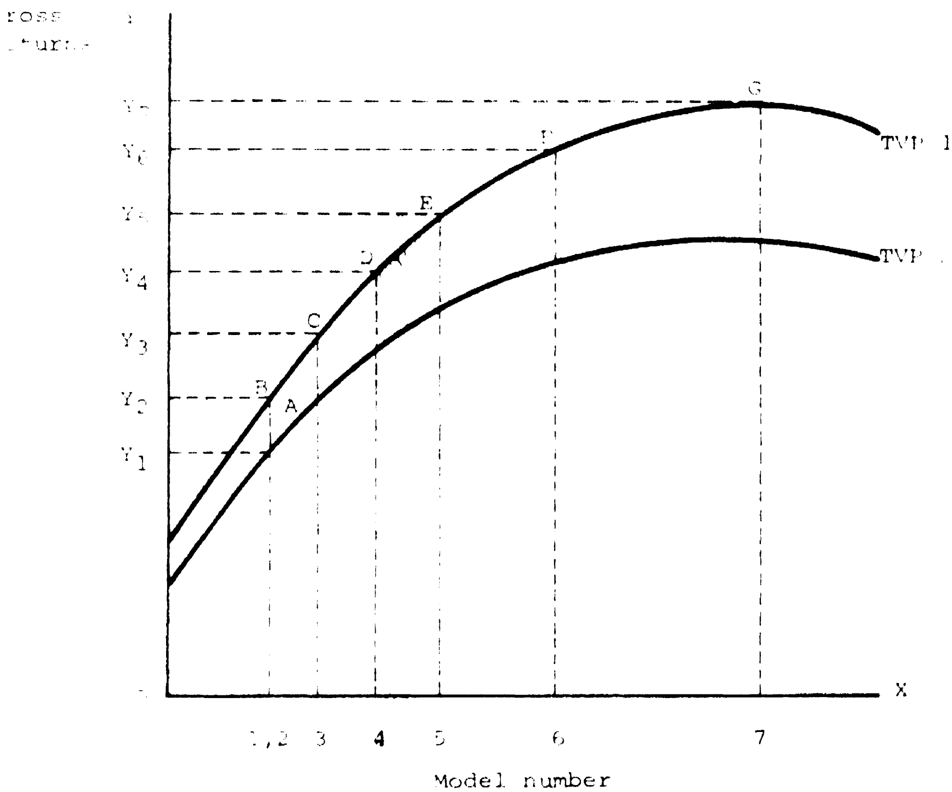

Figure 1. Concepts of yield gap partition at the farm level

maximization and risk aversion are seldom considered and maximizing expected value of yield is the (perhaps implicit) objective. This gives Y_7 level of yield per hectare.

Using the concepts given above, the potential yield gap (Y_7-Y_1) at the farm level can be attributed to the following factors:

1. Profit-seeking behavior of the farmer with perfect knowledge and with indifferent attitude towards risk at a given level of resources, i.e., the desire of the farmer to maximize profit rather than yields (Y_7-Y_6).

2. Risk aversion of the farmer who chooses a lower level of yield at a lower level of risk, resulting in reduction in output (Y_6-Y_5).

3. Inadequacy of resources, i.e., restriction of output because of inadequate resource availabilities to achieve risk-adjusted optima (Y_5-Y_3).

4. Allocative inefficiency, i.e., operating at a level of yield that does not maximize profit (Y_3-Y_2) subject to risk and resource constraints.

5. Technical inefficiency, i.e., not obtaining the potential yield level at a given level of resources and existing resource allocation (Y_2-Y_1).

III. AN APPLICATION

Technically-efficient set of coefficients were used to obtain solutions for Model 2 to Model 7 while Model 1 used the average set of coefficients.[12] Input coefficients were considered only for some critical resource constraints keeping in view the crop cultivation calendar in the region. Requirements of other resources that are assumed to be not limiting were not specified. However, they were accounted for in the cash input calculation. The cash input values were subtracted from the gross return values to arrive at net returns. Thus, the net returns represent income to the fixed and farmer's family-owned resources like land, family labor, machines, tools, implements, farm building, etc.

The programming problem involved 27 crop production activities -- the main crops being cotton, sorghum, black gram, chickpea, paddy, and groundnuts -- besides five labor-hiring activities, one cash-borrowing activitv.

12. The solutions for Models 3 to 7 were obtained by using the computer program (LINPRO), available in the CRISP package on the DEC PDP 11/45 machine at ICRISAT.

and one standard deviation transfer activity included for risk considerations. In all, 14 restrictions were imposed, which included unirrigated land, family labor in five periods, bullock labor in two periods, annual cash, annual borrowing, labor hiring in three critical labor periods, and one standard deviation transfer restriction.

The general format of the linear programming model is:

$$\text{max.} \qquad U = \bar{c}' x$$

$$\text{subject to} \qquad Ax \leq b, \quad x \geq 0$$

Where x is a vector of activity levels
$\bar{c}$ is a vector of returns
A is a matrix of resource requirements or technical coefficients
b is a vector of fixed resource and other restrictions

In addition to the usual assumptions of linear programming the following assumptions were made:

The technology of each crop is identical across farm size groups, which means that the input-output matrix and objective function coefficients are identical for every farm size group.

There is no mobility of factors of production across farm size groups.

Risk considerations are introduced via a model in terms of mean net returns (E) and standard deviation of net returns (σ):

$$\text{max.} \qquad U = \bar{c}' x - \Phi (\sigma x)$$

$$\text{subject to} \qquad Ax \leq b, \quad x \geq 0$$

Where $\bar{c}$, x, A and b are the same as in the earlier model.

Φ is a risk-aversion coefficient of the farmer specifying his indifference/trade-off between net returns and risk. The coefficient is defined as the ratio of changes in the levels of expected net returns (E) and standard deviation (σ) of net returns.
σ is a vector of standard deviations of net return values.

The model allows the farmer to maximize his expected net returns, minus a risk term comprising a specific number Φ and the weighted sum of the standard deviations of net returns;[13] considers effects of risk on the farmer's decisions to allocate his resources to different crops; and retains all the assumptions of ordinary linear programming model and requires the following additional assumptions:

1. The covariances of net return values across different activities are zero.

2. To measure variability we assume that the cross-section variance among plots of a given process can be used to estimate variability over time. For average plots the standard deviation is used directly, while for efficient plots the standard deviation is set such that the coefficient of variation remains the same for both means of production.[14]

3. It is assumed that risk aversion decreases with farm size. In other words, small farmers are assumed to be more risk-averse than large farmers.

The summary results of these models for different categories[15] of farms are depicted by histograms in Figures 2-6. On these farms, gross returns increase by more than three-and-one-half times from the present

13. The risk model used here is crude. Ideally one should use the model that considers Ω, the variance-covariance matrix of net returns that are stochastic over time, i.e., a quadratic objective function:

$$\text{Max } U = \bar{c}'x - \Phi(x'\Omega x)^{\frac{1}{2}}$$

The Ω matrix indicates the variability of net returns and also considers the covariance among enterprises. This allows the calculation of total variance of any farm plan that may be regarded as a measure of overall riskiness of the plan.

14. While there is an evidence from Ryan and Sarin (1981) that the coefficient of variation of profits from improved technology is lower than that from traditional technology, in absence of any such evidence in the cases of efficient and average means of production under the same basic technology, the coefficient of variation here is assumed to be the same for both means of production.

15. Farm categories were decided on the basis of operational land areas and are given as follows:

Small farms - 0.21 to 2.27 ha of operated land.
Medium farms - 2.28 to 5.60 ha of operated land.
Large farms - >5.60 ha of operated land.

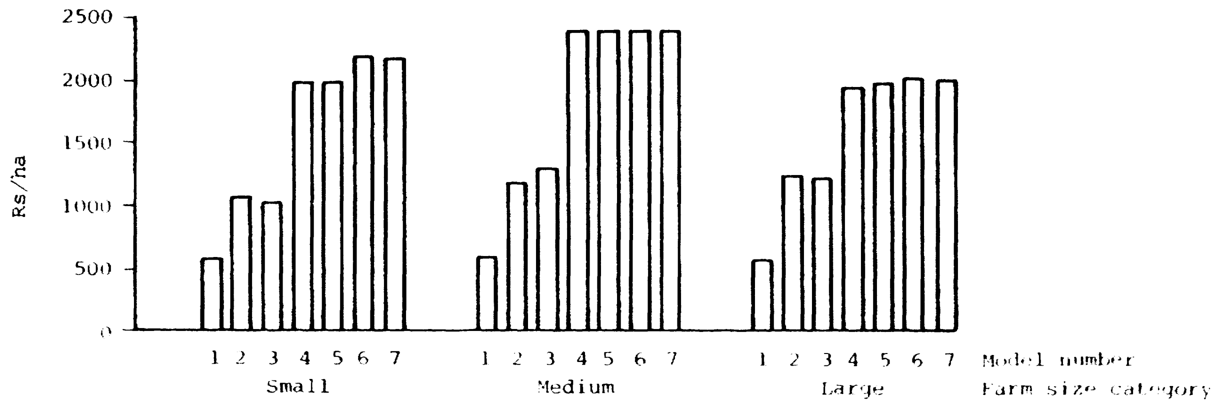

Figure 2. Gross returns with different models

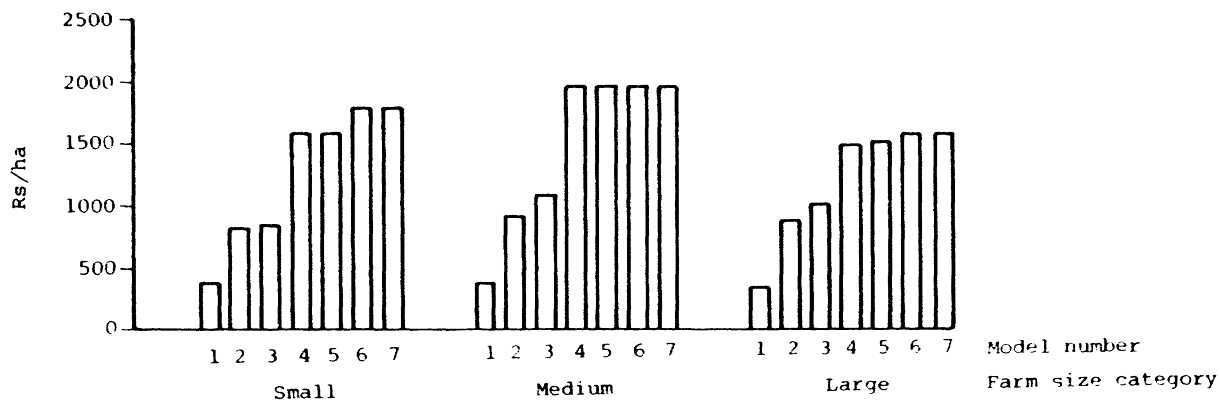

Figure 3. Net returns with different models

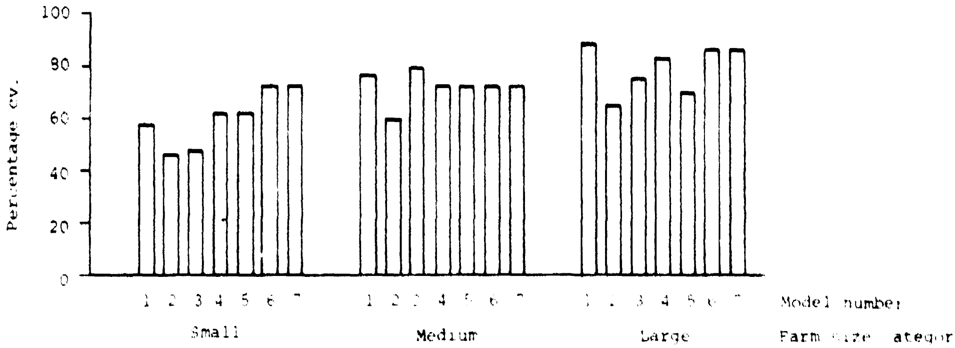

Figure 4. Coefficients of variation of net returns with different models

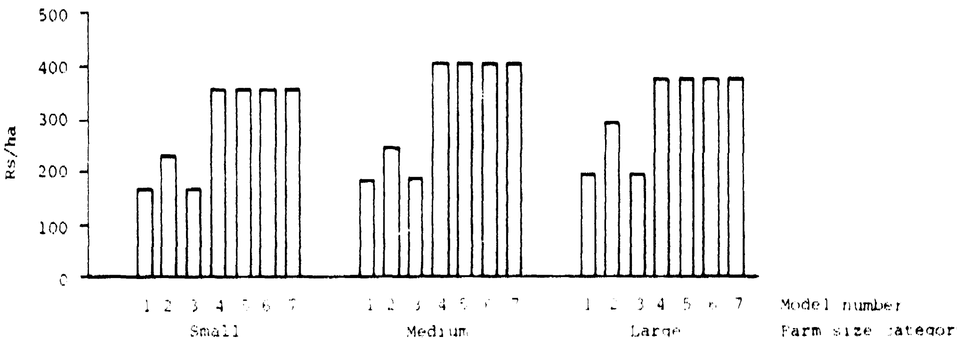

Figure 5. Cash input with different models

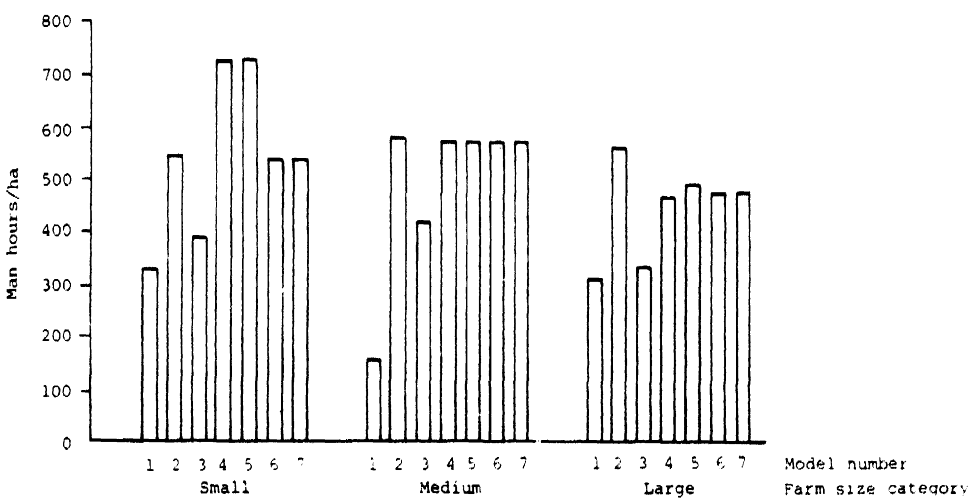

Figure 6. Human labour use with different models

level (Model 1) to the potential level (Model 7), while the net returns increase by more than four times. Cash input and bullock labor rise to more than double their original levels. Human-labor use increases by three-and-one-half times on medium farms, while it increases only by a little more than one-and-one-half times on small and large farms. The first major increase for all these parameters occurs with Model 2, when technically-efficient coefficients are used. Coefficients of variation drop by more than 12 percentage points.

In the case of Model 3 as compared with Model 2, on small and large farms all the input levels as well as gross return levels decline, while net returns increase slightly with increased variability. Hence more efficient allocation of resources results when the objective is to maximize net returns. This implies that after achieving technical efficiency at point B (Fig. 1), the producer moves downwards along the TVP 1 curve in order to become allocatively efficient, subject to risk considerations. In the case of medium farms, Model 3 generates higher levels of net as well as gross returns with lower inputs. This demonstrates a case of upward movement (B to C in Fig. 1) along TVP 1 to achieve allocative efficiency. The second major increase in all these parameters occurs when the capital constraint is relaxed in Model 4. Thus, if one moves from the allocatively efficient point under resource constraints to a relaxed level of capital, a substantial change in output level takes place. But the relaxed level of labor along with capital (Model 5) does not add to the levels of gross and net returns, except in the case of large farms where it shows some positive contribution.

Neutral attitudes of small and large farmers towards risk, depicted by Model 6, shift the allocation pattern and bring more risky (coefficients of variation increase by 13 and 17 percentage points, respectively) but high-return enterprises into the plan, resulting in slightly increased returns. However, these increases are smaller than those associated with technical efficiency or capital access. About 12% of operated land on large farms remains fallow when the farmer's indifference towards risk is caused by capital restrictions. However, when the farmer is risk-averse, the less risky crop activities allow him to achieve around 125% cropping intensity with, of course, reduced levels of returns. On medium farms the increase in output at the level of indifferent risk attitudes is not significant. This is because the enterprises chosen under Model 5 dominate all the other enterprises. In other words, they yield sufficiently higher returns than the other alternatives so the trade off between expected net returns and its standard deviation at his level of risk aversion does not affect the allocation pattern.[16] In general, capital is the crucial input

16. It may partly be a consequence of the very crude representation of risk.

and is complementary to human labor, thus reducing the significance of risk at a given level of resources.

At the same level of resources as in Model 6 and with neutral attitudes towards risk, Model 7 shows that maximizing gross returns changes neither the input nor the output levels. This is because of the linearity assumption, which necessitates proportional changes in input and output levels, and non-realization of the maximum gross return point.

The total yield gap, expressed in terms of gross returns per hectare, is partitioned into different predetermined factors in Table 3. The six sources of yield gaps tested here are: technical inefficiency, allocative inefficiency, capital constraints, labor restrictions, risk aversion of the farmer and his profit-seeking behavior. The potential gross return gaps are 73, 75 and 72% on small, medium and large farms, respectively.[17]

The partition reveals that capital is the most important single constraint, contributing about 50% or more of the gap in potential gross returns. It is highest on medium farms and lowest on large farms. This is logical, as many of the other physical inputs are expressed in terms of capital. It can also restrain labor use through the mechanism of wage payments to hired labor. The second important gap component is farmers' lack of technical efficiency. Here the gap ranges from 31% on the small farm to 50% on the large farm (Table 3). Labor constraints do not create any gap on small and medium farms but cause about a 2% output gap on large farms. The attitude of the farmer towards risk is more important on small farms, followed by large farms, and is of negligible importance on medium farms. This is because the constrained levels of labor and capital do not permit the medium farmer to opt for alternatives other than those under his earlier plan at his level of risk aversion. The decision in fixing the resource constraint levels might lead to these results. Hence the interpretation of the results depends on how realistic are the constraints. The gap due to allocative inefficiency is relatively small on all farms. The linearity assumption of the models does not allow us to find the magnitude of yield gaps arising from the profit-seeking behavior of the farmer. Models that take into account nonlinear relationships would be required.

17. This is the difference between actual gross returns (Model 1) and potential gross returns (Model 7) expressed as a percentage of potential gross returns.

Table 3. Partition of yield[a] gap into various components on different size farms in Akola region (%).

Source of gap	Farm size: Small		Medium		Large	
	Gross returns	Net returns	Gross returns	Net returns	Gross returns	Net returns
Technical inefficiency	31	31	33	34	50	48
Allocative inefficiency	-3[b]	1	6	11	-4[b]	6
Capital constraints	59	53	61	55	48	40
Labor constraints	0	0	0	0	2	2
Risk aversion	13	15	0	0	4	4
Profit-seeking behavior	0	0	0	0	0	0
Potential percentage gap	73	78	75	80	72	78

[a]Output gap due to each source is measured as percentage of the potential gap.

[b]Negative sign of gross return gap on small and large farms does not indicate negative contribution of allocative inefficiency; the absolute value indicates the allocative inefficiency.

CONCLUSION

The use of mathematical programming models to analyze yield gaps at farm level, rather than to analyze yield gaps of individual crops, is more appropriate in the case of rainfed agriculture. The existence of technical inefficiency suggests a need for improvement in the extension service, and in the management skills of the farmer. The importance of capital scarcity in yield gaps emphasizes the potential of credit agencies and calls for research on labor-using and capital-saving technologies for labor-surplus economies.

RDG:vsssm
21-9-1981

References

Binswanger, H.P. 1980. Attitudes toward risk: experimental measurement in rural India. American Journal of Agricultural Economics, 62(3): 395-407.

De Datta, S.K., Gomez, K.A., Herdt, R.W., and Barker, R. 1978. A handbook on the methodology for an integrated experiment - survey on rice yield constraints. International Rice Research Institute (IRRI), Los Baños, Philippines.

Farrell, M.J. 1957. The measurement of productive efficiency. Journal of the Royal Statistical Society, Series A Journal, 120(3):253-290.

Flinn, J.C. 1979. Considerations for future emphasis of the IRAEN constraints project. Presented at the Workshop on Rice Yield Constraints, Kandy, Sri Lanka, IRRI, Agri. Economics paper 79-06, 30 April-3 May, 1979.

Hazell, P.B.R. 1971. A linear alternative to quadratic and semi-variance programming for farm planning under uncertainty. American Journal of Agricultural Economics, 53(1):53-62.

Herdt, R.W., and Mandac, A.M. 1979. Overview, findings and implications of constraints research. Presented at the Workshop on Rice Yield Constraints, Kandy, Sri Lanka, IRRI, Agri. Economics paper 79-04, 30 April-3 May, 1979.

Jodha, N.S. 1977. Resource base as a determinant of cropping patterns. ICRISAT Economics Program occasional paper 14, Patancheru, A.P., India.

Jodha, N.S., Asokan, M., and Ryan, J.G. 1977. Village study methodology and resource endowments of the selected villages. ICRISAT Economics Program occasional paper 16, Patancheru, A.P., India.

Markowitz, Harry M. 1959. Portfolio selection: efficient distribution of investment. New York: John Wiley and Sons.

Ryan, J.G., and Sarin, R. 1981. Economics of technology options for deep vertisols in the relatively assured rainfall regions of the Indian semi-arid tropics. Presented at the Seminar on Management of Deep Black Soils sponsored by the Indian Ministry of Agriculture, the Indian Council of Agricultural Research and the International Crops Research Institute for the Semi-Arid Tropics, New Delhi, 21 May, 1981.

Sampath, R.K. 1979. Nature and measurement of economic efficiency in Indian agriculture. Indian Journal of Agricultural Economics, 34(2):17-34.