The gap analysis is promising in areas where the yields at farmer's field are much lower than the demonstration yields even though the technology (seed and fertilizer mainly) have been adopted (eg., finger millet at Bangalore, cotton at Akola and Rajkot, castor at Hyderabad, and maize at Indore).

Conclusions

The following aspects need investigation in yield gap analysis :

i. Examination of the magnitude of gap in yield under different situations

ii. Determination of the relative contribution of different production inputs when they are used individually or in combination

iii. Estimation of the extent to which the use of the recommended inputs can profitably be increased on farmers' field

iv. Identification of the social, economic and institutional factors preventing farmers from using known technology.

It is also to be emphasised that yield gap analysis has to be a collaborative effort of agronomists and economists, the agronomists sharing the major responsibility of experimentation and economists undertaking analysis of socio-economic constraints through the organisation of village surveys.

Dryland Agricultural Research in India. Thrust in the Eighties: Papers presented at the National Seminar on a Decade of Dryland Agricultural Research in India & the thrust in the Eighties, p. 18-20 Jan. 1982, Hyd. India. (1984).

YIELD GAP ANALYSIS : PERSPECTIVES AND IMPLICATIONS

R. D. GHODAKE AND T. S. WALKER

Yield Gap analysis is a new research methodology that emerged on a formal basis in the 1970s. Developed by the International Rice Research Institute (IRRI), it was extensively used to measure and analyse the determinants of yield gaps in farmers' fields in Southeast Asia where high yielding rice varieties have been adopted It has gained wide-spread popularity with researchers, research administrators, and policy makers. It is easy to visualise and think in terms of yield gaps, and the simple and efficient procedures disigned by IRRI provide a vehicle for potenttially effective inter-disciplinary research.

Although the IRRI yield gap framework gives us a prototype to follow, it requires major modification before it can be applied to dryland agriculture. Many of these modifications were underscored in a Working Group Meeting on yield gap analysis organised by the All India Co-ordinated Research Project for Dryland Agriculture and the International Crops Research Institute for the Semi-Arid Tropics in 1980 In this paper, we evaluate concepts, considerations, approches, and implications for yield gap analysis in dryland agriculture in the 1980s.

Concepts of Yield Gap Analysis

The IRRI Approach : The International Rice Research Institute has pioneered a methodology to identify yield gap factors and estimate their magnitude in rice production (De Datta *et al* 1978: Gomez *et al* 1979). The total yield gap is conceptually divided into two parts. Gap I represents the difference between experimental station yield and potential on-farm yield and is conditioned by "irreducible" environmental factors Gap II is the difference between potential and actual yield at the farm level and is caused by various biological and socio-economic factors operating at the farm and/or village level.

The main focus of IRRI research is on yield gap II and is essentially based on on-farm testing. It has been used to analyse why on-farm yields do not measure up to potential yields following the adoption of high yielding genotypes. The IRRI yield gap analysis is generally conducted for irrigated rice in an assured

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production environment. An integrated approach combining both controlled agronomic experiments on farmer' fields and farm surveys is used.

The IRRI analysis starts with a preliminary survey of 100 farmers who are selected in a random sample The main objectives of the survey are two-fold : 1. To have a basis for selecting farms for on-farm factorial trials and 2. To gain a preliminary idea of farmers' perceptions of yield constraints. Twenty farmers are chosen for on-farm trials in each study area. Three to five location-specific test factors are identified and included in the trials for experimentation. Two levels of each test factor are tested : the farmers' level and the improved level. The farmer's level refers to what the farmer is actually doing in the current crop season, and varies from one farm to another. The improved level is one that the researchers expect will produce maximum yield in the study area. The trial design is a factorial with two to three replications and a small plot size of 4 x 5 meters. All non-test factors are managed at the farmer's level. Potential yield is estimated on plots where treatments are set at the improved level. The estimate of yield gap in the study area is computed as the difference between the potential farm yield and the actual yield as obtained on those plots where all factors are at farmer's levels. Analysis of variance techniques is used to determine individual and joint contributions of various factors. Once the main treatment factors conditioning the yield gap have been determined, adoption surveys are carried out to identify and quantify socioeconomic constraints determining the acceptance and diffusion of the main treatment factors. The I R R I methodology *per se* does not make a methodological contribution towards understanding the underlying socioeconomic determinants of yield gaps.

General Steps in Yield Gap Analysis

On the basis of the IRRI approach and discussions during the AICRPDA-ICRISAT working group meeting on yield gap analysis, we have divided. the general process of yield gap analysis into four major steps (Fig. 1). The boxes with solid lines indicate steps; while those with dotted lines denote implicit outcome of these steps

The first step addresses the basic question of whether there is any gap in the yield and, if yes, what is its magnitude. Existing knowledge and preliminary surveys are used to answer this question. Answer will be location-and time-specific with due consideration for the type and level of technology practiced by representative farmers in a region.

In the second step the total yield gap is partitioned into two major components to obtain a benchmark for further analysis. This partitioning is performed by analysing data from preliminary surveys, on-station research, and on-farm experimentation. The first part (Yield Gap I) is attributed to environmental differences and non-transferable components to technology while the

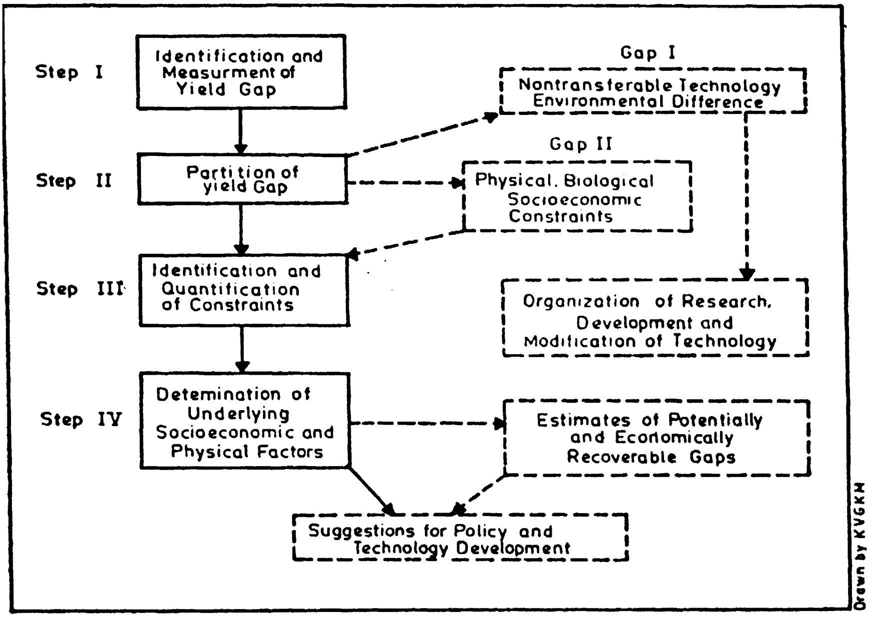

Fig. 1 : General Steps in yield gap analysis

second part (Yield Gap II) is due to inefficient cultural practices and sub-optimal input use by farmers that result in lower yields than those possible on their farms.

The third step deals with the estimation of potential yield and actual yie'd on farmers' fields and with the identification of factors responsible for differences between these two yield levels. How much each factor contributes to the yield gap is measured through on-farm experimentation or field observations. The analysis in this step deals with the realisation of production potential at the farm level with a given technology and has implications mainly for development strategy and technology transfer policy.

After having documented the factors and their contributions to yield gaps, the fourth and last step focuses on why farmers are not doing what is required to realise on-farm economic yield potential. There could be a number of underlying reasons such as capital constraints, profit seeking behaviour, lack of knowledge about technology risk bearing ability, and institutional and social infrastructures. In fact, these are the underlying determinants of yield gaps and need to be understood for making appropriate policy prescriptions. Feasible approaches could encompass adoption studies, whole-farm constraint analysis, and partial budgeting As a consequence, potentially and economically recoverable gaps are estimated. The findings can be utilised to suggest policy alternatives aimed at alleviating the constraints and research priorities oriented towards the reduction of gaps.

Major Considerations in Dryland Agriculture

Because we are dealing with yield gap analysis in dryland agriculture which is different in many respects from the assured rice production environment where IRRI developed and used its methodology, we should analyse some of the more important differences. These considerations should be the basis for the selection of appropriate approaches in designing suitable methodologies for yield gap analysis in dryland agriculture. Table 1 outlines some of the major considerations by comparing and contrasting dryland agriculture with irrigated rice and presented possible implications for yield gap analysis in dryland agriculture.

In general, the lower rate of adoption of genotypes and other practices and the greater variability in the level of adoption across dryland regions compared to the irrigated rice areas suggests the need for classifying areas into relatively homogenous technology by enviromental sets. Unlike the IRRI methodology with its emphasis on adoption of a high yielding variety genotype, the approach for dryland agriculture should be flexible with a focus both on genotype as well as on other practices such as soil-, water-, and crop-management technologies

Table 1 : Major considerations and implications for yield gap analysis in dryland agriculture

Considerations	Irrigated rice agriculture	Dryland agriculture	Implications for dryland agriculture
Stage of technology adoption	—Greater adoption of recommended practices —Less variability in adoption across areas	—Less adoption of recommended practices —More variability in adoption across areas	—Classify areas in different regions by type and level of technology adoption —Flexible approach to focus on genotype, other techniques, and level of adoption
Soil-and water-production environment	—Assured environment —Less variability due to environmental factors	—Undependable environment —Environmental factors dominate output variability	—Difficult to incorporate soil-water management practices in the analysis —Need for special-purpose experiments
Location specificity	—Relatively less soil variability across locations —Irrigation reduces role of environmental factors	—Substantial soil variability across locations, farms,and plots —High variability due to environmental factors	—Greater difficulty in selecting homogenous areas —More plots, larger-size plots and more replications —More emphasis on understanding plot specific characteristics
Time specificity	—Yield variability over time is less within an area than across locations	—High year-to-year variability	—Greater importance assigned to the partitioning of yield gap I as well as II

Table 1 : (Contd.)

Considerations	Irrigated rice agriculture	Dryland agriculture	Implications for dryland agriculture
		—Greater variation in soil moisture regime and its interactions with other factors	—More years of experimentation —More difficult to define optimal cropping system and to quatify test factors
Cropping system	—Sole crop —Monoculture —Homogenous over large areas	—Mixed and intercrops with large number of crops —Heterogeneous over large areas	—Choice of a well defined dominant cropping system or crop —The cropping system may be unstable due to technological and infrastructural changes —Higher priority to evaluate productivity gaps through whole-farm constraints analysis
Valuation	—Single crop —Output gap in terms of yield of main product	—Possibility of many crops and byproducts in cropping system	—Measurement of yield gaps in monetary terms —Relative price changes may lead to obsolescence of cropping system —Expected results are more time and location specific

Table 1 : (Contd.)

Considerations	Irrigated rice agriculture	Dryland agriculture	Implications for dryland agriculture
Data collection	—Some problem of measurement due to diseases and insects	—Greater difficulties in measurement —Scoring problems because of a wider array of pests by crop interactions	—Secondary and unpublished primary agroclimatic data —Field observations to generate environmental and technological plot profiles —Simulation of yield distribution
Interdisciplinary team work	—Considerable complixity —Close collaboration between economist, agronomist & statistician	—More complexities	—Wider role for interdisciplinary collaboration between agronomist, agroclimatologist, economist, soil scientist, entomologist, pathologist, and statistician
Farmers' practices	—Difficult to simulate for non-test practices	—More difficult to simulate for non-test factors	—Field experiments to be supplemented by field observations
Underlying socioeconomic determinants	—Relatively more developed institutional infrastructure	—More difficult to visualize due to additional complexity —Greater heterogeneity in institutional infrastructure	—Partial budgeting —Whole-farm constraints analysis —More difficult to handle

Table 2: Important test factors for different dryland crops and regions for yield gap analysis[1]

Crop	Region	Test Factors		
		First	Second	Third
Sorghum (rainy season)	Hyderabad	Variety	Fertilizer	Weed control
	Akola	Variety	Fertilizer	Weed control
Sorghum (postrainy season)	Bellary	Variety	Fertilizer	Date of sowing and seed rate
	Ahmad-nagar	Variety	Fertilizer	Spacing and intercul-tivation
	Sholapur	Fertilizer	Plant popu-lation	Spacing and interculti-vation
	Bijapur	Fertilizer	Date of sow-ing and plant population	Intercultivation
Pearl millet	Jodhpur	Variety	Method of fertilizer application	Management of fertili-zer application
	Hissar[2]	Fertilizer	Management of fertilizer application	Weed control
	Kovilpatti	Variety	Fertilizer	
	Anantapur	Variety	Fertilizer	Date of sowing
Finger millet	Bangalore	Variety	Fertilizer	Mixed cropping
Upland rice	Varanasi	Variety	Fertilizer	Method of sowing and fertilizer application
	Rewa	Variety	Fertilizer	Method of sowing and fertilizer application
	Ranchi	Variety	Fertilizer	Method of sowing and fertilizer application
	Bhuva-neswar	Variety	Fertilizer	Method of sowing and fertilizer application

Table 2 : (Contd.)

Crop	Region	Test Factors		
		First	Second	Third
Chickpea	Varanasi	Variety	Fertilizer	Plant protection (pod borer)
	Hissar	Variety	Fertilizer	Plant protection
Pigeonpea	Hyderabad	Inter-cropping	Plant protection	Fertilizer
	Akola	Inter-cropping	Plant protection	Fertilizer
Greengram	Jodhpur	Variety	Method of fertilizer application	---
Groundnut	Rajkot	Fertilizer	Plant protection (aphids)	Variety
	Anantpur	Fertilizer	Plant protection	Deep ploughing
Castor	Hyderabad	Variety	Fertilizer	Sowing date

1. These test factors are identified by different working groups formed during the AICRPDA-ICRISAT Working Group Meeting on Yield Gap Analysis in 1980. The test factors are presented according to their importance.
2. BJ 104 Variety of pearl millet has been widely adopted in Hissar area.

or their individual components. Some of the promising crop, areas,and test factors for yield gap analysis are listed in Table 2 and were identified in the working group meeting in 1980.

The dominant role played by the environmental factors, particularly variations in soil moisture regimes and their interactions with many other factors, conditions output variability in dryland agriculture and emphasises the need for identifying and quantifying determinants, not only of yield gap II, but also of yield gap I. From data presented in the working group meeting in 1980, the magnitude of yield gap I is likely to be large in dryland agriculture (Table 3). The average size of yield gap I across several crops where yield gap analysis

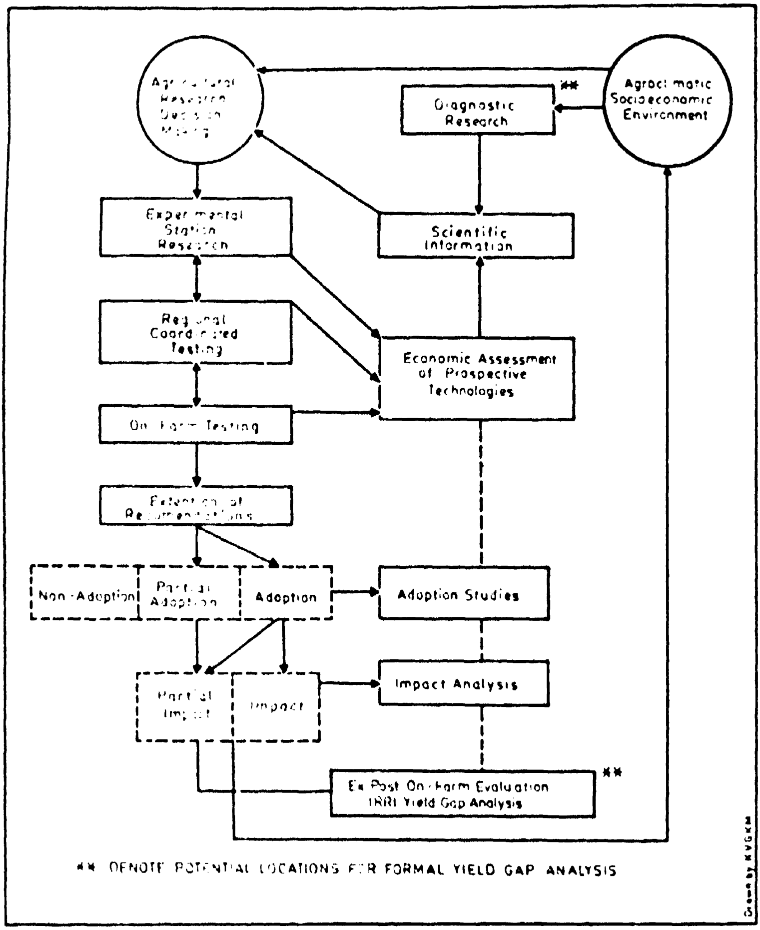

Fig. 2 : Points of intervention for socio economic analysis in the generation of technology.

was considered feasible was 61 per cent. This is probably an underestimate of yield gap I because the demonstrations may have been carried out on relatively fertile land and were not managed by farmers.

The IRRI methodology also has to be adjusted to cope with intercropping and mixed cropping, to define common and optimal cropping systems for analysis, and to measure gaps in productivity in monetary terms. Substantial soil variability across plots, farms, and regions in dryland zones will have strong implications for the choice of homogeneous regions and for experimental design. A greater number of alternative cropping activities and the complexity of dryland agriculture reinforces the need for close collaboration between different disciplines to handle the variety of interaction effects. Field experiments should be supplemented by more field observations and related measurments to generate sufficient data to simulate farmers' practices for non-test factors. Such information is also one of the essential building blocks for later steps in yield gap analysis that focus on underlying constraints.

In brief, dryland agriculture calls for a more flexible, eclectic approach to yield gap analysis. For a number of reasons sketched in Table 1, the benefits from yield gap analysis in dryland agriculture will be more time and site specific. Yield gap analysis in dryland agriculture equivalent to those carried out for irrigated rice areas will require more time, resources, and skilled personnel. In terms of methodology, it will also probably not have the high degree of transferability across regions and countries that the IRRI yield gap analysis exhibited. Component parts of the frame-work may have fairly wide transferability, but they will have to be pieced together again to face new situations in different dryland locations.

Yield Gap Approaches and Technology Generation

Where does yield gap analysis or an analysis of determinants of yield fit into the process of technology generation and diffusion ? We answer this question by charting in Fig. 2 the sequences or chronological steps followed in the generation and diffusion of dryland technology. It is merely illustrative and depicts in detail the points of intervention where different types of studies and analyses contribute information for making decisions on agricultural research. Approaches that directly relate to yield gap analysis are found in diagnostic research, in the assessment of prospective technologies and in the ex-post evaluation of technology.

Diagnostic Research : On-farm Observations and Production Function Analysis

In order to identify researchable problems and associated priorities, diagnostic research relies on severel methodologies, including baseline and reconnaissance surveys, base data analysis, and on-farm experimentation. One such

Table 3 : Promising crops and regions for yield gap analysis in dryland agriculture

Crop	Regions	Observed yields (q/ha)			Yield gaps %		
		Research stations[1]	Demonstrations[2]	Farmers' fields[3]	Total yield gap	Yield Gap I	Yield Gap II
Rainy season sorghum	Hyderabad	36.1	13.0	4.1	89	64	25
	Akola	18.4	19.5	2.4	87	0	87
Postrainy season sorghum	Bellary	14.3	7.7	3.4	76	46	30
Pearl millet	Jodhpur	18.3	13.3	4.8	74	27	47
	Hissar	34.0	15.0	6.7	80	56	24
	Rajkot	18 3	14.0	10.7	42	23	19
Finger millet	Bangalore	16.1	6.3	2.9	82	61	21
Wheat	Varanasi	24.0	18.6	10.2	58	23	35
Setaria	Anantapur	10.4	4.0	0.2	98	62	36
Upland rice	Varanasi	30.2	20.6	14.7	51	32	19
Chickpea	Varanasi	34 6	16.6	15.3	56	52	4
Greengram	Jodhpur	14.9	10.4	3 1	79	30	49
	Hissar	11.1	10.1	9 8	12	9	3
Groundnut	Rajkot	9.7	8 7	7 0	28	10	18
	Anantapur	15.1	4.9	1.4	91	68	23
Castor	Hyderabad	15.0	5.2	1.9	87	65	22
	Average :				69	42	27

1. Data available from various reports of All India Co ordinated Research Project for Dryland Agriculture.
2. Based on results of study on recommended practices as a brief of the Agro-Economic Research of Dryland Agricultural Research Project.
3. Based on results of farm structure studies of the Agro-Economic Research of Dryland Agricultural Research Project.

Source : Constructed from data presented in the report of AICRPDA-ICR SAT Working Group Meeting, 1980.

methodology used by the Centro International de Agriculture Tropical (Pinstrup-Andersen *et al* 1977) to evaluate on-farm constraints to higher bean yield in Colombia is a type of yield gap analysis that applies to situation where researchers have little information about the size of yield reducers.

This procedure is based on the collection of data from a representative sample of farms. Field measurements are taken to develop detailed environmental and technological plot profiles specific to a cropping system. Qualitative and quantitative information is gathered on the incidence and severity of each of the variables expected to limit yields in the crop for which the analysis is carried out. In general, these determinants include biological, agroclimatic, edaphic, and management variables. Yield losses are estimated from a production or response function analysis in which observed yields are regressed on factors expected to influence yields. Each regression co-efficient multiplied by the mean value of the particular yield limiting factor provides an estimate of the overall impact of this factor on sampled yields.

The success of this approach requires observations on at least 30 fields, variation in environmental and technological variables, and an inter-disciplinary team effort. Depending on the cropping system studied, field observations need to be taken during critical periods such as planting, germination, flowering, and harvesting. In order to increase management variability, some supplemental trials and demonstration plots at high levels of management may be included in the analysis.

Economic Assessment of Prospective Technologies : Whole-Farm Constraints Analysis

Whole-farm constraints analysis places yield gap analysis in a farm management perspective and evaluates the impact of resource constraints, risk, and farmers' objective on output and the allocation of resources. Because the analysis is carried out at the farm level, it is more appropriate to talk of output gaps. An example of how to partition output gaps (Gap II) into their component parts is illustrated in Table 4. Linear risk programming method was employed to analyse the productivity gaps. In this example, capital was the most important constraint, contributing about 50 per cent to the gap in potential gross returns.

Whole-farm constraints analysis is especially suited to dryland agriculture where cropping patterns are diverse and resource constraints are numerous. There exists a wide range of methods of whole-farm modelling (Hardaker 1979), including mathematical programming approaches that can be used to carry out whole farm constraints analysis. It can be argued that mathematical programming approaches particularly those that account for risk, provide the most suitable framework for whole-farm constraints analysis. The important proviso to this argument is that reliable and suitable computer facilities are available. Until such facilities become available, reliance must be placed on intimate knowledge of farm circumstances to carry out an intuitive assessment of constraints with a whole-farm budgeting approach. Partial budgeting can also be useful especially for analysing the on-station experiments wherein farmers' technologies are simulated as 'controls'

Table 4 : Determinants of output gap II by farm size groups in Akola region (Contribution in %)

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

1. Output gap due to each source being measured as percentage of the potential gap.

2. 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.

Ex-Post Evaluation of Technology : IRRI Yield Gap Analysis

The IRRI-type yield gap analysis is designed for those situations of partial adoption and/or partial impact when technologies once adopted do not measure up to expectations in farmers' fields (Fig.2). The combination of on-farm surveys and experimentation recommended in the IRRI approach have been described earlier in this paper.

Less Formal Approaches

Other steps in the process of technology generation depicted in Fig. 2 can function as locil to generate valuable information for a more informal yield gap analysis. For example, on-farm trials organised along steps-in-improved technology methodology (Ryan and Sarin 1977) have been conducted both in AICRPDA and ICRISAT. These factorial trials with improved and traditional treatment combination provide information on the separate contributions of different treatments to yields and returns; if the trials are managed by the farmer they are equivalent to an ex-ante or before-the-fact IRRI yield gap analysis. Furthermore, information from secondary data, baseline surveys, and on-farm testing can be judiciously and skillfully blended to construct an insightful evaluation of the determinants of productivity gaps.

Implications for the Eighties

For the reasons cited earlier in the paper, we do not believe that researchers on dryland agriculture in the 1980s should allocate a significant share of their scarce resources for formal yield gap analysis to make it more cost effective for dryland agriculture. An interest in formal yield gap analysis should not divert researchers from the more routine tasks involved in generating a steady flow of technical information for drylands agriculture. For example, the field testing of technologies on a routine basis in dryland operational research projects has generated valuable information on the relative profitability of practices and on institutional and other constraints to adoption (Rastogi and Annamalai 1981). Yield gap analysis should complement and not substitute for these important activities

Formal yield gap analysis should continue on a pilot exploratory basis at a few locations and its progress should be reviewed annually. As more information from several sources accumulates in the 1980s, informal yield gap analysis should also become more effective.

In dryland agriculture, more attention needs to be focussed on the determinants of yield gap I than of yield Gap II. Reliable estimates over time are needed not only on farmers' fields but also on operational sized fields on dryland experimental stations. Location-specific supplemental trials and on-farm operational research can generate reliable estimates.

Whole-farm constraints analysis is complex and it may be advisable to adopt this approach at a few locations using whole-farm budgeting. A microprocessor for use at the headquarter's location in Hyderabad could place whole-farm constraints analysis on a sounder footing.

A team approach is indispensable to yield gap analysis in dryland agriculture. We highlighted the need to collect information on insect and disease damage and the levels of infestation. This means that entomologists and pathologists should play prominent roles in such a team, or at least participate in the training of the team.

Another way to approach yield gap analysis in dryland agriculture is to do more in-depth, problem oriented diagnostic research. For instance, diagnostic research on stand establishment may allow researchers to arrive at a preliminary indication of whether or not poor stands are important in conditioning yield gaps.

Data from many sources including farm structure studies and demonstrations can be used to arrive at estimates of the contributions of different factors to yield gap II. This type of analysis would require a production function approach and compatible data sets.

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