MANUAL ON

METHODOLOGICAL APPROACH FOR DEVELOPING REGIONAL CROP PLAN

Under the ICAR Social Science Network Project
Regional Crop Planning for Improving Resource Use Efficiency and Sustainability

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PREFACE

In various regions of India, cropping pattern is inefficient in terms of resource use and unsustainable from natural resource use point of view. This leads to serious misallocation of resources, efficiency loss, indiscriminate use of land and water resources, and it adversely affecting long term production prospects. Indian agriculture confronts with many challenges and problems. Some of them can be formulated as optimization problems. Crop selection at regional level is one such challenge which can be addressed using optimum crop planning. As such regional crop planning is very crucial that helps to formulate region specific crop planning which would optimize the level of each activity of different crops, level of input use and output produced under different resource endowments and price scenarios.

This manual on "Methodological Approach for Developing Regional Crop Plan" has been drawn from the ICAR Social Science Network project "Regional Crop Planning for Improving Resource Use Efficiency and Sustainability". The project has relied on plot level data collected by Directorate of Economics and Statistics, Ministry of Agriculture, Government of India under the Comprehensive Scheme for Studying the Cost of Cultivation of Principal Crops in India. The manual is aimed to provide the methodological approach for developing regional crop plans. The modelling framework has been illustrated with a case study of Punjab state.

The authors thankfully acknowledge the financial support received from ICAR and the technical advice and guidance extended by Prof. Ramesh Chand, Member, NITI Aayog and former Director, ICAR-NIAP.We are also thankful to all the associates and seven project collaborators from various agricultural universities of different agro-eco regions of India.

We would also like to place on record, our gratitude to the ICAR-NIAP for extending the necessary administrative and infrastructural support to develop this manual.

Authors

ACRONYMS AND ABBREVIATIONS

AE	Allocative efficiency
CCS	Cost of Cultivation Survey
CE	Cost Efficiency
CGWB	Central Ground Water Board
CWC	Central Water Commission
DEA	Data Envelopment Analysis
DES	Directorate of Economics and Statistics
DMU	Decision Making Unit
EP	Economic Prices
FAO	Food and Agriculture Organization
GAMS	General Algebraic Modeling System
GCA	Gross Cropped Area
GHG	Green House Gas
GoI	Government of India
GoPb	Government of Punjab
GR	Gross Returns
HP	Horse Power
K	Potassium
LP	Linear Programming
MP	Market Prices
N	Nitrogen
NR	Net Returns
NR_{MP}	Net Returns at Market Prices
NR_{EP}	Net Returns at Economic Prices
NR_{NRV}	Net Returns based on Natural Resource Valuation
NRV	Natural Resource Valuation
P	Phosphorous
RCP	Regional Crop Planning
RGWAA	Replenishable Ground Water Available for Agriculture

$RGW\text{-}NR_{EP}$	Replenishable Ground Water- Net Returns at Economic Prices
$RGW\text{-}NR_{MP}$	Replenishable Ground Water- Net Returns at Market Prices
$RGW\text{-}NR_{NRV}$	Replenishable Ground Water –Net Returns at Natural Resource Valuation
RT's	Record Types
SAS	Statistical Analysis System
SI	Simpson's Index
SRI	System of Rice Intensification
TE	Technical Efficiency
VC	Variable Costs

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Introduction

1

METHODOLOGICAL APPROACH FOR DEVELOPING REGIONAL CROP PLAN

Indian agriculture faces twin challenges of low growth and low per capita income on one hand, and ensuring food security of the nation on the other hand. Un-sustainability of Indian agriculture and inefficient resource-use pattern recognized during the past four decades is well documented. The existing land use pattern of many states is not based on the principle of comparative advantage. The existing cropping pattern of various regions is inefficient in terms of resource use and unsustainable in terms of natural resource use. As such crop production will become more difficult with resource scarcity (e.g. land, water, energy, and nutrients), climate change and environmental degradation (e.g. deteriorating soil quality, increased greenhouse gas emissions etc.). The growth of agriculture in India largely depends on the enhancement in management of different resources. In this context, the question of allocation and distribution of resources in terms of sustainability, efficiency and optimization of crop plans across regions and production environments in the nation becomes vital. In the shifting paradigm of Indian agriculture, proper crop planning and policy plays a crucial role. However there is an absence of right set of policies and needed infrastructure to promote crop pattern consistent with regional resource endowment. As such Regional Crop Planning (RCP) is the need of the hour. RCP is a multi-dimensional concept, associated with determining the best set of crops to be cultivated over season with given constraints in the region. It involves area allocation for each of these crops, the sequencing of crops, and the irrigation plans. Best suitable crops and other enterprises should be selected so as to achieve some set of goals particular to the region. Typically, these goals involve the maximization of net income, the minimization of cost, the maximization of total area cultivated, and/or the minimization of irrigation water.

It becomes imperative to devise a standardized methodology for optimal crop plans. Therefore, this manual has been prepared to facilitate the development of regional crop plans using the common modeling framework. The methodological framework accompanies illustrations for the Punjab state, as case study, under the ICAR Social Science Network Project "Regional Crop Planning for Improving Resource Use Efficiency and Sustainability".

1.1 BACKGROUND

The project has been taken up in a network mode to cover almost all the agro-eco systems of the nation during the XII five-year plan. The study involves seven states from different agro-eco system, namely: (a) Irrigated -Punjab and Bihar; (b) Rain-fed – Maharashtra and Karnataka; (c) Coastal-Tamil Nadu; (d) Semi-Arid-Rajasthan and (e) North-East– Assam. The study has largely used the unit-level Cost of Cultivation Survey (CCS) data of Directorate of Economics and Statistics, Ministry of Agriculture, Government of India.

With this background, the overall objective of the study is to develop regional crop plans for better resource use efficiency and improving natural resource sustainability across production environments. The major objectives of the study are:

1. To study the existing land use, cropping pattern, and resource use efficiency across regions

2. To estimate the cost and returns of selected crops under different regions of the country based on market prices, economic prices and natural resource valuation techniques.

3. To develop optimum crop plan at regional levels for better resource use efficiency, sustainability and maximizing farm net income across production environments.

Data

2

The study is primarily based on plot-level data collected under "Comprehensive Scheme for Cost of Cultivation of Principal Crops" of Directorate of Economics and Statistics, Ministry of Agriculture. It is a rich source of data on the cost of cultivation of major crops, which also covers various aspects of farming across different regions of the country. It is uniform and representative data collected by conducting field surveys by identified nodal agencies in 17 states using uniform schedule and survey methodology. In the CCS, each sample household is surveyed consecutively for three years and the latest available data pertains to the period 2008-09 to 2010-11 (block year ending 2010-11). For Punjab, the plot-wise data was collected from the 300 representative households of 30 tehsils during each year of the block period (2008-09 to 2010-11) by the Punjab Agricultural University, Ludhiana, which is a nodal agency for this state. From three agro-climatic zones of the state, farmers were selected using three-stage stratified sampling technique, with tehsil as stage one, a village or cluster of villages as stage two and operational holdings within the cluster as stage three. From each cluster, a sample of 10 operational holdings, two each from the five size-classes, viz. marginal (< 1 ha), small (1-2 ha), semi-medium (2-4 ha), medium (4-6 ha) and large (> 6 ha), were selected randomly.

Secondary data sources were also used in the study for few indicators like for subsidy rate on fertilizers and electricity the data was procured from Department of Fertilizers, Ministry of Chemicals and Fertilizers, GoI and Punjab State Electricity Regulatory Commission (website: http://www.pserc.nic.in/). The data on district wise ground water depth of observation wells for the three years 2008, 2009 and 2010 has been taken from Central Ground Water Board (CGWB), Ministry of Water Resources, GoI. The data on canal irrigation expenditure and receipts was collected from Central Water Commission (CWC). Statistical Abstract of Punjab, (Various issues) has been used to retain data on various cropping and irrigation parameters of Punjab agriculture.

The following section deals with the data extraction procedure of CCS data while its later portion elaborates the methodological framework and various analytical tools used in the study.

2.1 UNIT-LEVEL COST OF CULTIVATION DATA: EXTRACTION AND RETRIEVING PROCEDURE

Cost of cultivation surveys had always been an important data source for decision making on different aspects of crop production in India. The first such survey was conducted in 1954-55 under a scheme entitled "Studies in the Economics of Farm Management in India". Many useful studies were conducted using that data. However, the data lacked the consistency and uniformity in terms of concepts and definition. This led to discontinuation of the scheme. Later on, with a view to collect uniform and representative data on cost of cultivation of major crops, a scheme entitled "Comprehensive scheme for cost of cultivation of principal crops" was launched in the year 1970-71 by Directorate of Economics and Statistics, Government of India. As mentioned earlier, currently under this scheme a representative data is collected by conducting field surveys by identified nodal agencies in 17 states using uniform schedule and survey methodology.

The data on different aspects of crop and livestock production is conducted by canvassing 40 different record types (RT's). The broad theme of each RT is listed in the table 1. It is to be noted that frequency of data record is different for different RT's. Data on some variables are reported even on daily basis and recorded weekly/monthly basis. The challenge therefore lies in merging RT's with different frequency levels. Further, the data is collected and reported on hard copies of schedules and afterwards recorded digitally using software "FARMAP" developed with the assistance of FAO. Once, the data is entered in FARMAP package, files containing data are encrypted into BIN format.

Table 1: List of RT's with the broad theme area

RT number	Theme
RT110	Household members (yearly)
RT111	Household change (monthly)
RT 120	Attached farm servant (beginning of the year)
RT 121	Attached farm servant (Monthly)
RT 210	Land inventory (yearly)
RT 211	Changes in land (seasonal)
RT 230	Annual crop record (beginning and end of season)
RT 231	Perennial crop inventory (beginning and end of season)
RT 310	Animal inventory (yearly)
RT 311	Animal changes (monthly)
RT 410	Building inventory (yearly)
RT 411	Building changes (monthly)
RT 440	Irrigation structure inventory (yearly)
RT 441	Irrigation structure changes (monthly)
RT 450	Machinery and implements inventory (yearly)
RT451	Machinery and implement changes (monthly)
RT 510	Credit outstanding
RT 511	New Loan taken out (Monthly)
RT 512	Loan repayment (Monthly)
RT 610	Receipts and disposal of important crop production (yearly)

RT 710	Crop operation hours (Daily/monthly)
RT 711	Crop operation labour payments (daily/monthly)
RT 712	Crop physical inputs and other payments (monthly)
RT713	Crop outputs (monthly)
RT 714	Crop transport and marketing operations (monthly)
RT 715	Crop transport and marketing operations payments (monthly)
RT 716	Crop marketing cost incurred (monthly)
RT 720	Animal upkeep operation hours (monthly)
RT 721	Animal upkeep operation causal labour payments (monthly)
RT 722	Animal upkeep physical inputs and other payments (monthly)
RT 723	Animal non-milk outputs (monthly)
RT 724	Animal and milk products (monthly)
RT 730	Special activity operations hours (monthly)
RT 731	Special activity operations payments (monthly)
RT 732	Special activity physical inputs and payments (monthly)
RT 733	Special activity outputs (monthly)
RT 740	Machine upkeep operation hours (monthly)
RT 741	Machine upkeep operations payments (monthly)
RT 742	Machine upkeep physical inputs and payments (monthly)
RT 743	Machine power provided output farm (monthly)

The procedure of data extraction and retrieving includes following broader steps.

i. The BIN file containing raw data on 40 RT's are accessed using MS-DOS (command prompt) and converted into any usable format (DAT, PRN, etc.,) recognizable by any data analysis software. For conversion of file format from BIN to PRN, a software "DATAMAN (FARMAP)" is used.

ii. PRN files are imported in data analysis software (SAS in our case) and different RT's are extracted individually.

iii. Individual RT's are merged together on the basis of requirement of research objectives. We have developed a SAS programme for extracting and merging different RT files and estimating coefficients for different aspects of farm enterprises.

A glimpse of the data extraction and retrieving procedure is shown below by different snapshots in Figures 1 to 6.

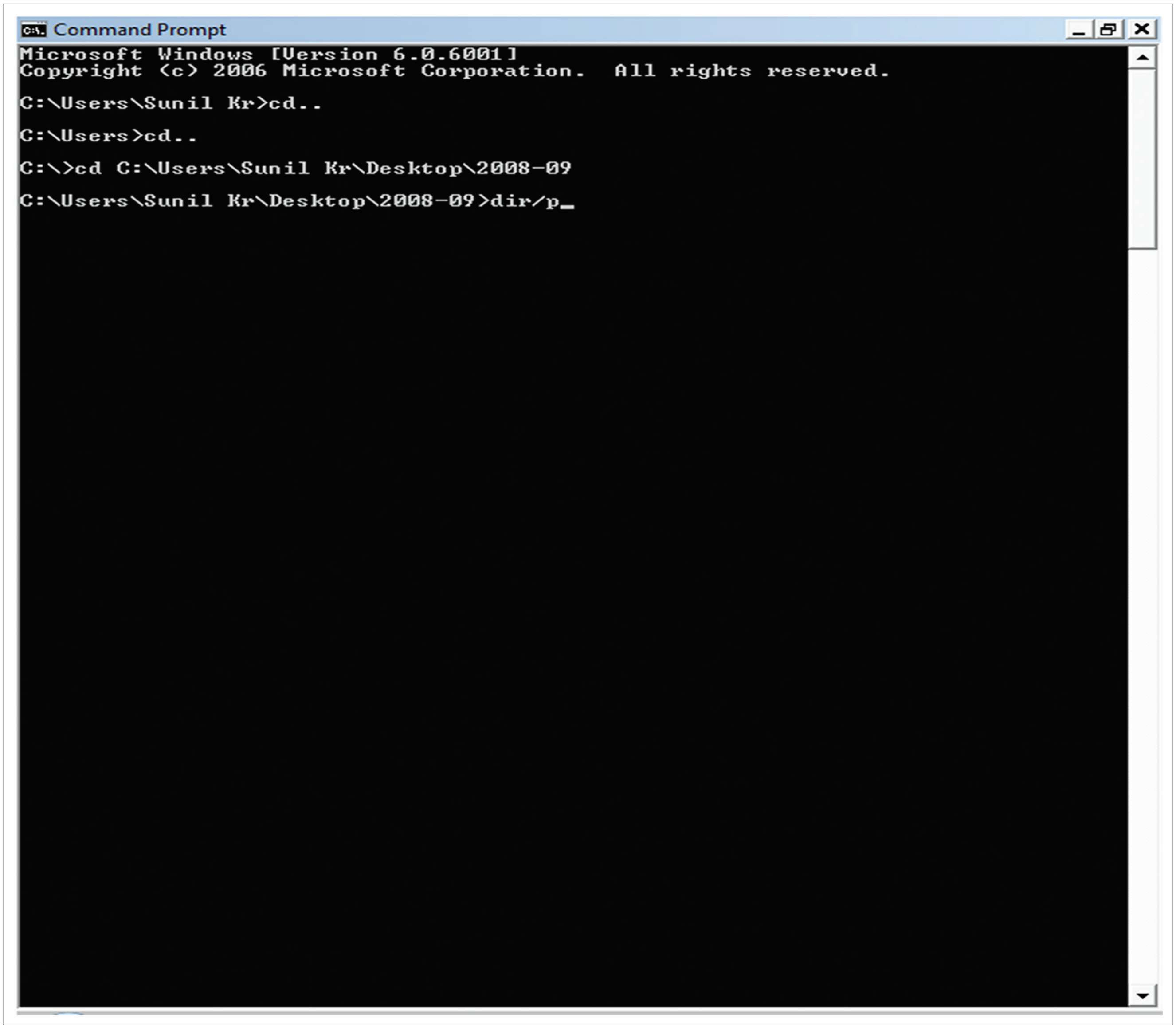


Figure 1 : MS-DOS for merging RT files (BIN format)

{Command:

cd..↵

cd..↵

Cd path…dir/p↵

Copy file name.bin new file name.bin↵

Now delete the file with old file name

Copy new file name.bin/b+ space *.bin ↵ }

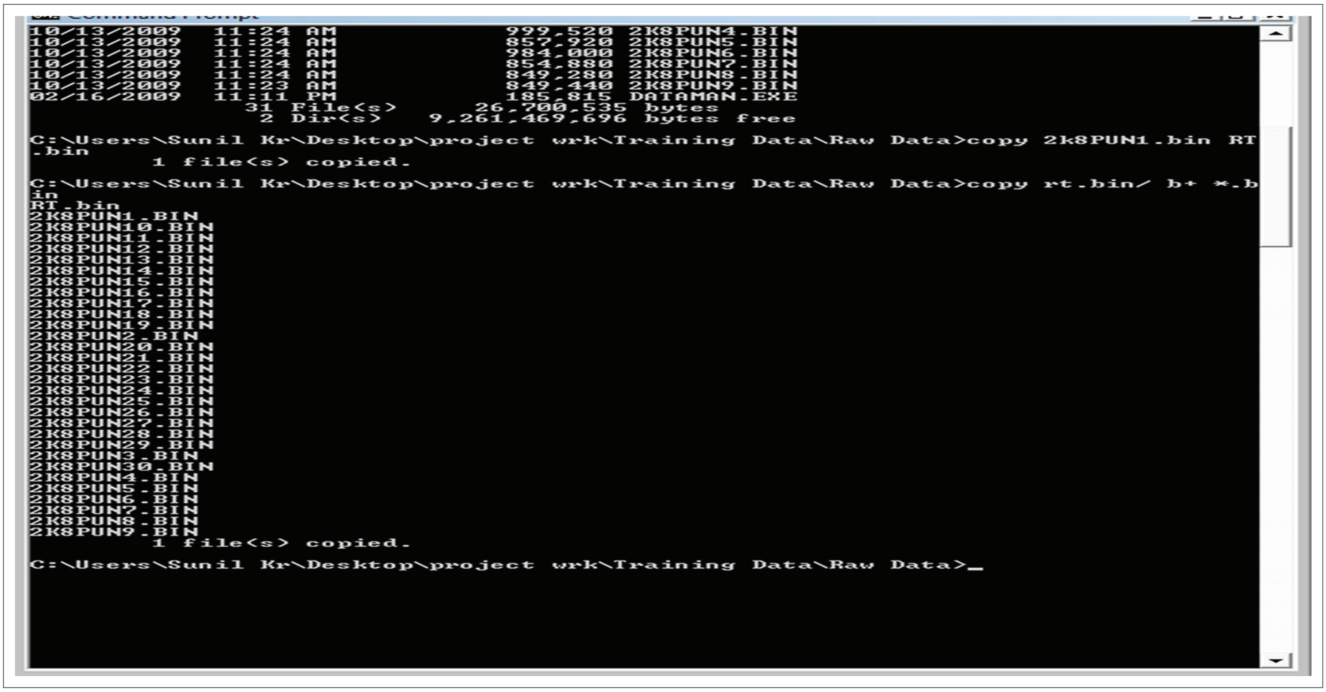


Figure 2 : MS-DOS for merging RT files (BIN format) if they are given separately

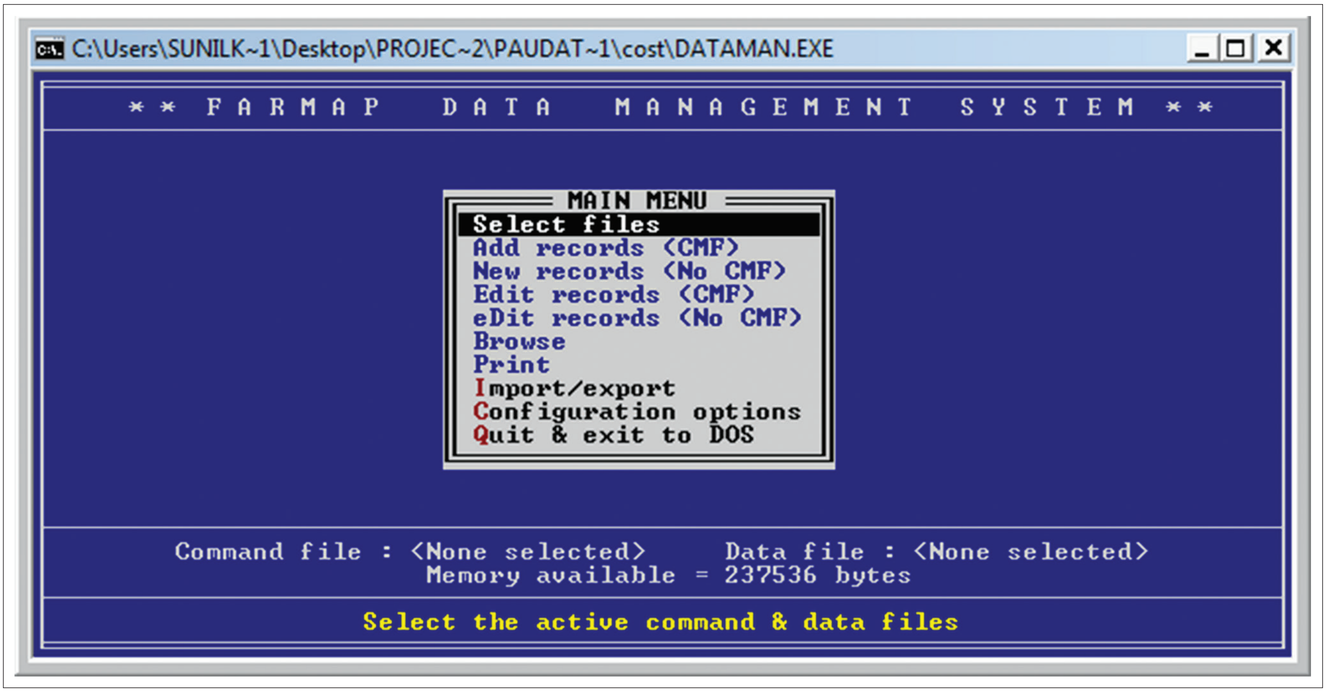


Figure 3 : DATAMAN Window Snapshot

Open DATAMAN and select appropriate option for accessing BIN file. Press 'I' for importing file. After that input file path, output file path and data field need to be specified. As illustrated in the figure 4. Enter data field (1-40 if wish to extract all RT's). Check format and input file (Binary) and opt for output file format ASCII (American Standard Code for Information Interchange) for PRN format. After this press F1 to proceed.

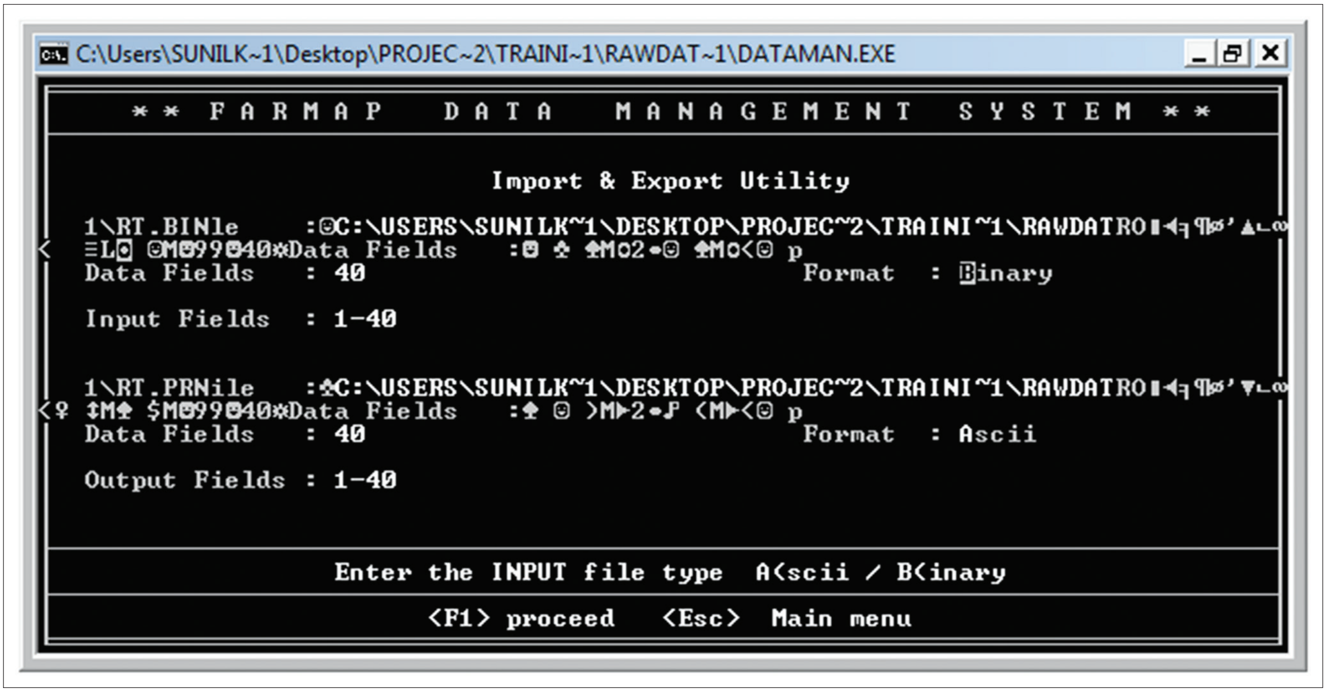


Figure 4 : DATAMAN Import and Export Utility Window

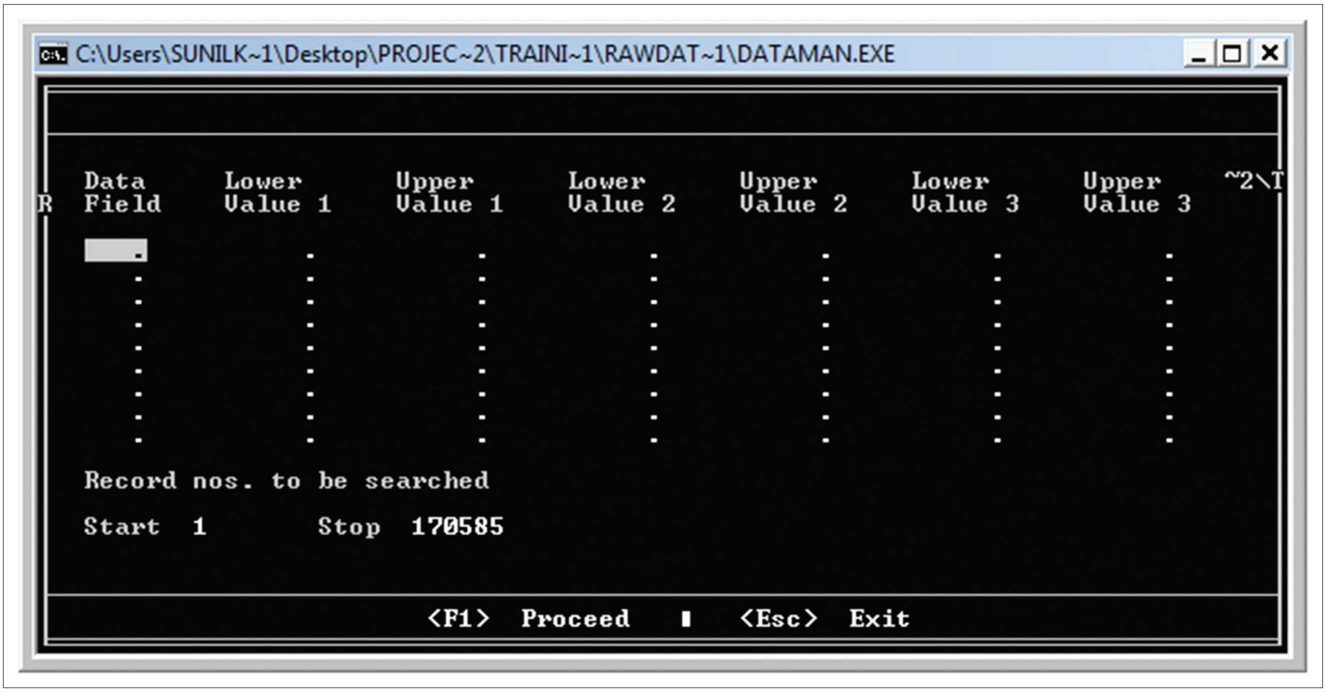


Figure 5 : DATAMAN Window to specify data fields

After pressing F1, the window will pop up as shown in the figure 5. This wizard is used if wish to extract part of the data. Specify options and proceed using F1 command. Do nothing if wish to extract all RT's. Next step will produce output file in PRN format.

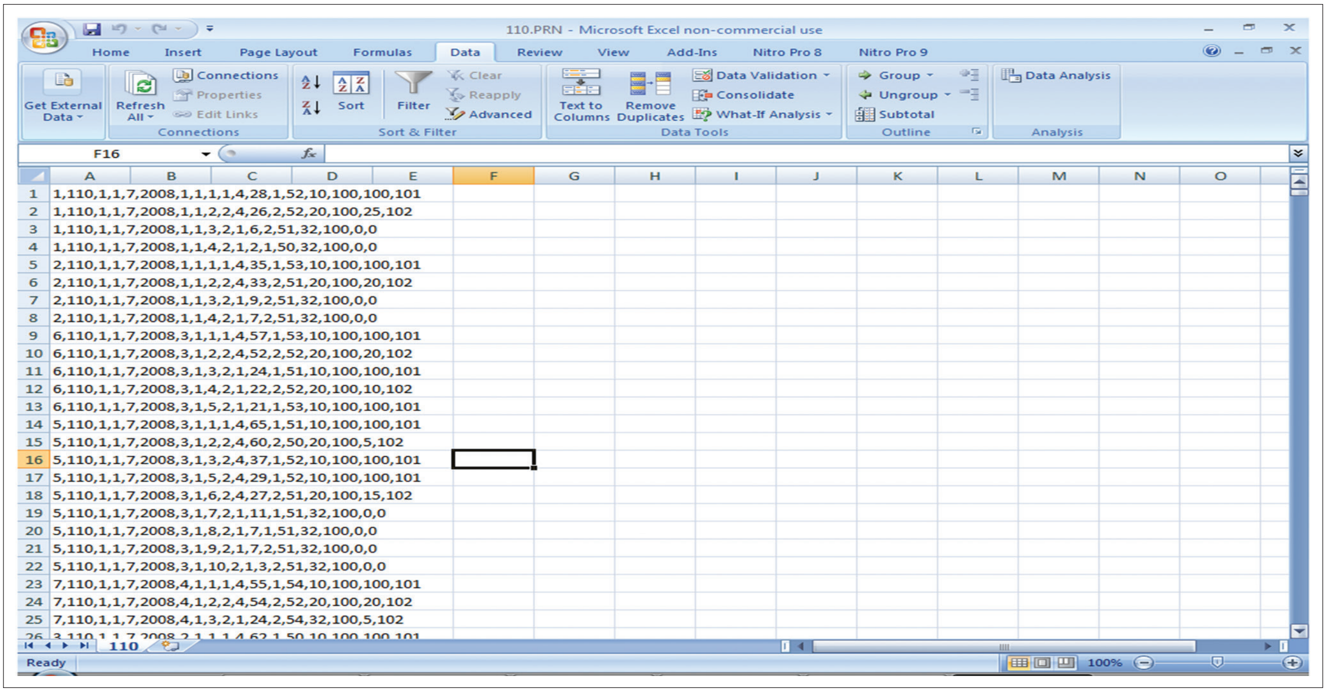


Figure 6 : Output file of DATAMAN in PRN format

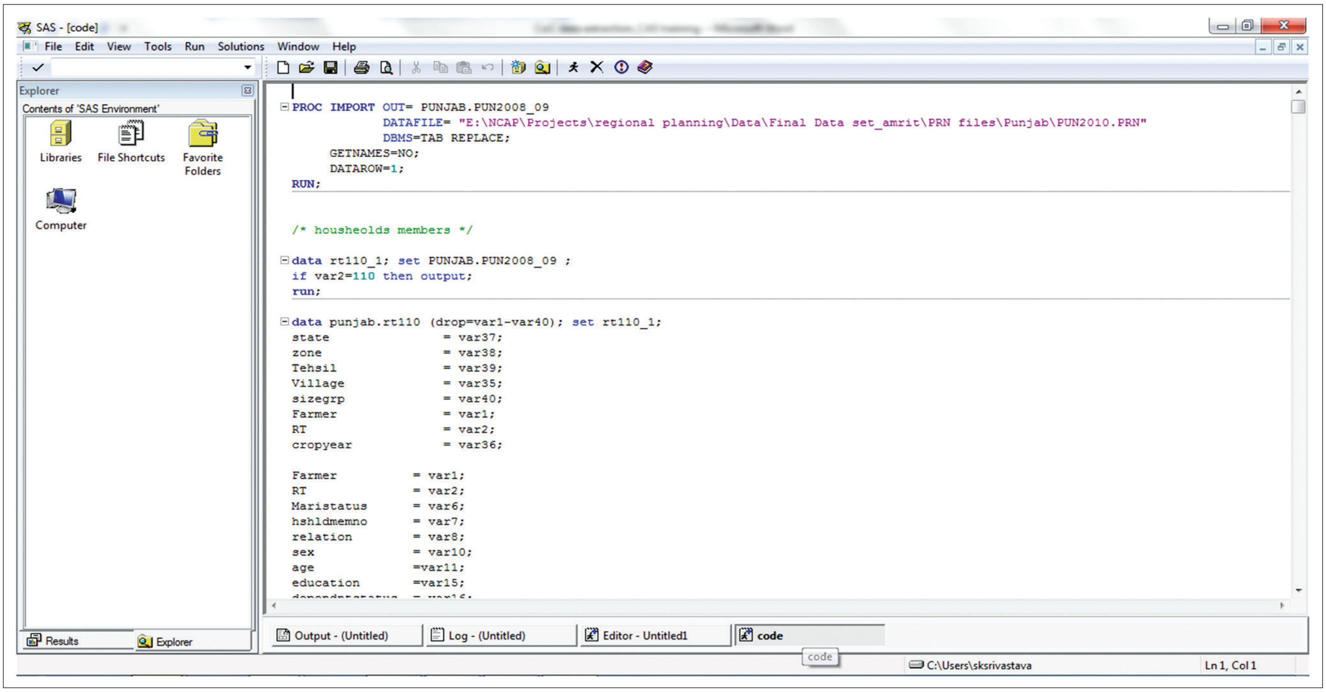


Figure 7 : SAS Software Window

If opening file in Excel, data will look like as given by the snapshot in figure 6. The file includes data for all 40 RT's and underlying variables in PRN format. After that SAS software can be used for importing the PRN file and data extraction and retrieving from each RT (Figure 7). The individual RT's can therefore be merged using the code developed by NIAP.

Methodological Framework and Analytical Tools 3

The first step to develop RCP model, is to understand existing cropping, and resource use pattern at regional level. To gauge the varying land use, cropping pattern and input use viz., seed, fertilizer etc., the tabular and growth analysis can be used. In the ICAR-SSN project, time-series secondary data on production of different crops for selected seven provinces of India representing the different agro-eco systems, namely, Punjab, Bihar, Rajasthan, Assam, Maharashtra, Karnataka and Tamil Naidu for the period 1980-81 to 2010-11 have been used to estimate the change in cropping pattern and crop diversification index for all these states and for all the years. For the purpose of development of optimum crop model, cost and returns based on Market Prices (MP), Economic Prices (EP) and Natural Resource Valuation (NRV) needs to be estimated. To attain the objectives as mentioned earlier, various tools used in the study are summarized in Table 2 followed by further details in sub-sections.

Table 2 : Analytical tools used in the study

Items	Tool
Changes in cropping pattern, Land Use Pattern	Diversification index, location coefficient
Resource Use Efficiency	Data Envelopment Analysis (DEA) approach
Scope of revising crop plans	Cost-return analysis using Market Prices, Economic Prices and Natural Resource Valuation techniques
Development of optimum crop models at regional level	Mathematical Programming (Linear Programming)

3.1 CHANGES IN CROPPING PATTERN

The extent of crop diversification at a given point in time may be examined by using several indices namely: Herfindahl Index (HI); Transformed Herfindahl Index (THI); Ogive Index (OI); Entropy Index (EI); Modified Entropy Index (MEI); Composite Entropy Index (CEI); Gini's Coefficient (Gi); and Simpson Index (SI).

Among these indices, the THI, SI and EI are widely used in the literature of agricultural diversification. All these indices are computed on the basis of proportion of gross cropped area under different crops cultivated in a particular geographical area (Pal and Kar, 2012).

In the given study Simpson's Index (SI) of Diversification has been employed to measure degree of crop diversification and is explained as follows:

$$SI = 1 - \Sigma (pi / \Sigma pi)^2$$

Where, pi is the area proportion of the i^{th} crop in total cropped area
and i = 1,2,3,….n. is the number of crops

The value of index increases with the increase in diversification and assumes 0 (zero) value in case of perfect concentration.

In this study, diversification is also measured in terms of change in level of land allocated to different production activities as a proportion of total land used for the purpose using the following formula (Chand and Sonia, 2002).

$$DIV_{mk} = \left(\frac{1}{2}\right) * \left\{ \frac{\sum ABS(A_{im} - A_{ik})}{TCA} \right\}$$

where: DIV_{mk} refers to diversification in cropping pattern between the year m and k
ABS function is used to get absolute deviation in the area under crop between the two periods
A_{im} refers to area under i^{th} crop in m^{th} year
A_{ik} refers to area under i^{th} crop in k^{th} year
TCA is the average of total cropped area for the m^{th} and k^{th} year

3.2 CHANGES IN LAND-USE PATTERN

There are many methods to measure the changing land use pattern. Location coefficient (L) is useful to identify the pattern of distribution of the given category of lands across different regions of a country or state.

This is defined as follows:

$L = (Lij/Li) / (Lj/Ls)$

where, L_{ij} = area of j^{th} category of land in i^{th} state /region

L_i = area of all categories of land in the state/region

L_j = area of j^{th} category of land in the Country

L_s = area of all categories of land in the Country

A higher value for location coefficient for a state or region indicates the higher concentration of that particular category of land in that state or region.

3.3 RESOURCE USE EFFICIENCY

Efficiency of resource use, which can be defined as the ability to derive maximum output per unit of resource, is the key to effectively addressing the challenges of achieving food security. There are various ways and methods to examine resource use efficiency like Data Envelopment

Analysis (DEA), Stochastic Frontier (SF) production function etc. In the present study, DEA has been applied which is explained below:

3.3.1 Data Envelopment Analysis (DEA) approach

Resource use efficiency under different crop production is estimated on the basis of Data Envelopment Analysis (DEA). DEA is a Linear Programming technique for constructing a non-parametric piece wise linear envelop to a set of observed output and input data. Efficiency is defined as a measure of how efficiently inputs are employed to produce a given level of output. Producing same level of output with lower level of inputs or more output with same level of inputs means higher level of efficiency. The technique of DEA has been used to find the relative efficiency score of each farm in relation to the farms with minimum input output ratio for all inputs. The score of the most efficient farms being one, the score of each farm will lie between zero and one.

In this study the DEA approach has been used to analyze the data for optimizing the performance measure of each production unit and determining the most preferable ones. Unit-level data from CCS for the year 2008, 2009 and 2010 from various regions of Punjab have been used. The information obtained included the amount of input costs which were used in crop production (such as family labour, causal labour, NPK, insecticides, seeds, etc.) and the yield as an output.

In order to specify the mathematical formulation of model, let us assume that we have K farmers Decision Making Unit (DMU) using N inputs to produce M outputs. Inputs are denoted by x_{jk} (j=1,2,…….,n) and the outputs are represented by Y_{ik} (i=1,2,……..,m) for each farmer k (k=1,2,………,K). The technical efficiency (TE) of the farmers can be measured as (Coelli, 1998; Worthington, 1999):

$$TE_k = \sum_{i=1}^{m} u_i y_{ik} / \sum_{j=1}^{m} v_j x_{jk}$$

where, Y_{ik} is the quantity of the i^{th} output produced by the k^{th} farmer, x_{jk} is the quantity of j^{th} input used by the k^{th} farmer, and u_i and v_j are the output and input weights respectively. The farmer maximizes the technical efficiency, TE_k, subject to

$$TE_k = \sum_{i=1}^{m} u_i y_{ik} / \sum_{j=1}^{m} v_j x_{jk} \leq 1$$

where, ui and vj ≥ 0

The above equation indicates that the technical efficiency measure of a farmer cannot exceed one, and the input and output weights are positive. The weights are selected in such a way that the farmer maximizes its own technical efficiency which is executed separately. To select optimal weights the following linear programming model is specified:

Min TE_k

Subject to

$$\sum_{i=1}^{m} u_i\, y_{ik} - y_{jk} + w \geq 0$$

where, k=1,2,……………,K

$$x_{jk} - \sum_{j=1}^{n} u_j x_{jk} \geq 0$$

and u_i and $v_j \geq 0$

The above model shows TE under constant returns to scale (CRS) with an assumption if w = 0 and it changes into variable returns to scale (VRS) if w is used unconstrained. In the first case it leads to technical efficiency (TE) and in the second case pure technical efficiency (PTE) is estimated.

Technical Efficiency (TE) : It can be expressed generally as the ratio of sum of the weighted outputs to sum of weighted inputs. The value of technical efficiency varies between zero and one; where a value of one implies that the DMU is the best performer located on the production frontier and has no reduction potential. Any value of TE lower than one indicates that the DMU uses inputs inefficiently (Mousavi-Avval *et. al*., 2011).

Cost or Economic Efficiency (CE) : One can measure both technical and allocative efficiencies to verify the behavioral objectives such as cost minimization or revenue maximization.

Cost minimization DEA is expressed as

$\text{Min}_{YXk^*}\, w_k'\, X_k^*$,

Subject to $- y_k + YY \geq 0$,

$X_k^* - XY \geq 0$,

$Y \geq 0$,

where w_k' is a vector of input prices for the k^{th} farmer and X_k^* (which is calculated by LP) is the cost minimizing vector of input quantities for the k^{th} farmer, given the input prices w_k and the output level y_k.

Total cost efficiency (CE) or economic efficiency of the k^{th} farmer can be calculated as

$CE = w_k' X_k^* / \, w_k' X_k$

That is the ratio of minimum cost to the observed cost.

While the ***allocative efficiency (AE)*** is calculated as the ratio of cost efficiency to technical efficiency

AE = CE / TE

3.4 COST-RETURN ANALYSIS

The performance of different crops can be assessed by comparing net returns under alternative scenarios. These are: (i) Market prices; (ii) Economic prices net of subsidies; and (iii) Income based on natural resource valuation technique (Raju *et.al.* 2015). Overall framework is illustrated in figure 8. The computation of cost- returns using these three approaches has been explained with example of paddy crop in Punjab state for TE 2010-11 in the respective sections.

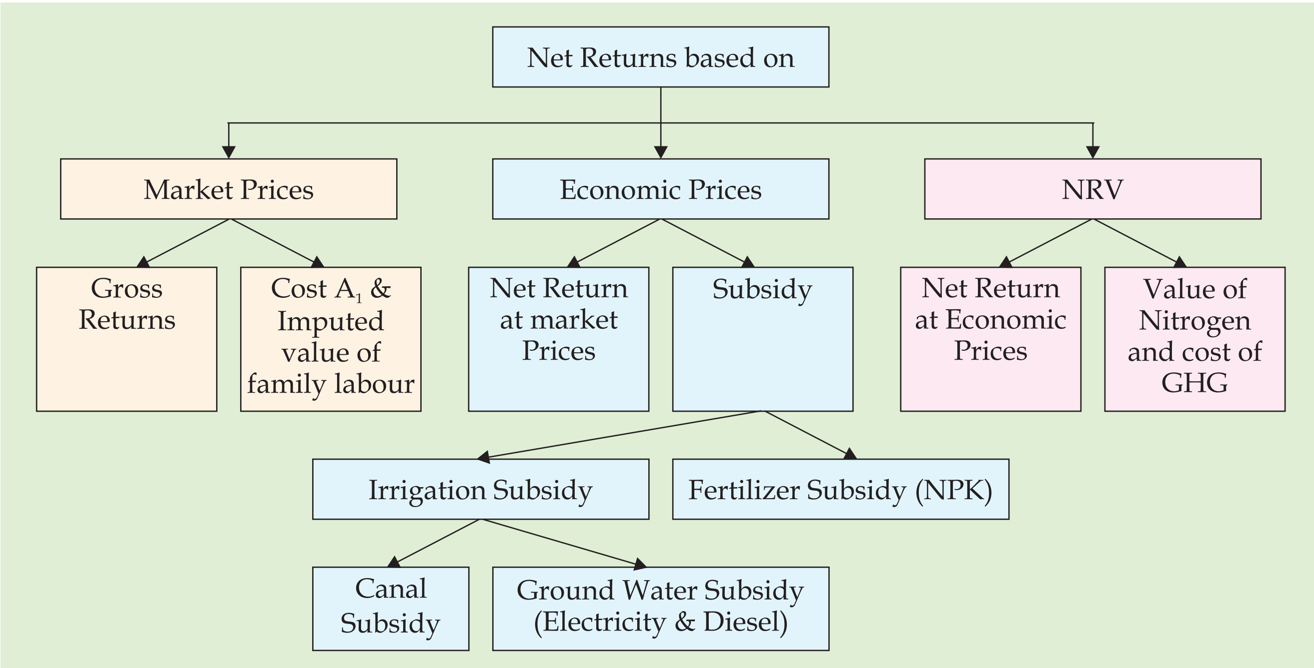


Figure 8 : Alternative ways to measure net returns of crops

3.4.1 Net returns at market prices (NR_{MP})

Net returns at market prices can be defined as the gross return (value of main product and by product) less variable costs (Cost A_1 + imputed value of family labour) at market prices actually paid and received by the farmer or imputed in some cases.

$NR_{MP} = GR - VC$ …….. *(i)*

where, NR_{MP} – Net return at market prices; GR- Gross Returns; and VC- Variable Cost.

This has been explained with an example given in table 3.

Table 3 : Computation of NR_{MP} for paddy in Punjab during TE 2010-11, (Rs/ha)

Crop	Gross returns (a)	Variable cost (Cost A_1+FL) (b)	Net returns at Market prices (NR_{MP}) (a-b)
Rice	69568	21885	47683

Cost A_1 as defined in *Manual on Cost of Cultivation Scheme, DES,* includes all actual expenses in cash and kind in production by the farmer. The components of cost A_1 are list out in the figure 9. Some of the components of Cost A_1 are directly retrieved from the unit level data set of cost of cultivation scheme, while few are estimated, for example: depreciation of implements and farm buildings, interest on working capital has been computed by using the method elaborated in the Manual on CCS.

The imputed value of family labour has been calculated as:

*Imputed value of family labour = Working hours of family labour * Labour wage rate per hour*

Cost A_1 includes:	
a)	Value of hired human labour
b)	Value of hired bullock labour
c)	Value of owned bullock labour (Cost of maintenance and upkeep charges)
d)	Value of owned machine labour (Upkeep charges)
e)	Hired machinery charges
f)	Value of seed
g)	Value of pesticides
h)	Value of manure
i)	Value of fertilizers (NPK)
j)	Irrigation charges (Canal)
k)	Depreciation of implements and farm buildings
l)	Land Revenue cess and other taxes (Total cess and taxes / GCA)
m)	Interest on working capital (@12.5 % per annum)
n)	Miscellaneous expenses (Other input costs etc.)

Figure 9 : Components of Cost A_1

3.4.2 Net returns at economic prices (NR_{EP})

Net return at economic prices can be defined as the difference between net return or income at market prices and subsidies on inputs like fertilizers and irrigation used in crop production.

i.e $NR_{EP} = NR_{MP} - Subsidy$ ……… *(ii)*

Thus, *subsidy* component has internalized into the model, by covering two aspects viz., *fertilizer subsidy* and *irrigation subsidy*. *Fertilizer subsidy* consists of subsidy on nitrogen (N) and combination of Phosphorous (P) and Potassium (K) (Table 4). The total irrigation subsidy includes canal, electricity and diesel subsidy (Table 5) and has been distributed over selected crops based on area under irrigation of each crop.

Table 4 : Computation of Fertilizer subsidy for paddy in Punjab during TE 2010-11

Paddy	Use(kg/ha) (a)	Subsidy Rate(Rs/kg)* (b)	NPK Subsidy(Rs/ha) (a*b)
Nitrogen (N)	147	19.35	2843
Potassium (P)	49	42.56	2067
Phosphorous (K)	42		1796
Total NPK	238	-	6705

Note: * Subsidy for P & K is in combination prior to Nutrient based subsidy policy, 2010

Crop wise *irrigation subsidy* has two components: *Ground water subsidy and Surface water subsidy*. Ground water subsidy can be estimated by initially calculating the crop-wise ground water use, i.e.

*Groundwater use (cubic metre) = Irrigation hours (hrs/ha) * Groundwater draft (cum/hr)*

The irrigation hours (hrs/ha) for each crop can be taken from plot-wise CCS data. CCS does not collect information of ground water draft. Therefore the groundwater draft can be estimated using the following formula:

$$\text{Ground water draft (lit/sec)} = \frac{Hp*75*Pump\ efficiency}{Total\ head\ (m)}$$

The information on horse power (H P) of the pumps owned by the farmers is available in CCS data set. For the households purchasing groundwater, average HP of the pumps (estimated separately for electric and diesel) in respective tehsil can be taken as proxy. Pump efficiency is assumed to be 40 per cent. The total head can be obtained as per below equation:

Total head =Water level (mbgl) + Draw down (m) + Friction loss (10% of water level+ Draw down)*

The summation of groundwater draft from each category of pump-sets provides total groundwater-use (cum/ha) for each crop cultivated by the farmer. Further, the groundwater cost can be estimated separately for diesel pump, electric pump and submersible pump, by summing depreciation (tube-well and pump-set), interest (tube-well and pump-set) and upkeep costs. The subsidy per hectare of groundwater-use shall be estimated for electricpumps [product of per kilo-watt groundwater volume (cum/kWh) and subsidy rate (Rs/kWh)] and diesel pumps (product of diesel-use in extraction of groundwater and per litre subsidy rate during 2008-2011) separately (Srivastava *et.al.*, 2015). Estimation of groundwater subsidy is illustrated in the table 5 by taking an example of paddy crop in Punjab for the TE 2010-11.

*Metres below ground level

Table 5: Estimation of Ground water extraction cost and ground water irrigation subsidy for paddy crop in Punjab during TE 2010-11

S.No.	Items	Diesel pump	Electric centrifugal	Electric submersible	Overall
a	Irrigation Hours (hrs/ha)	11	124	150	285
b	Power of the Pump (hp)	9	5	10	
c	Water Level (mbgl)	13.5	13.5	13.5	
d	Draw down[#] (m)	0	0	0	
e	Friction loss (%) (10% of water level)	1.4	1.4	1.4	
f	Total Head (m) {c+d+e}	14.9	14.9	18.9[Υ]	
g	Pump Efficiency (%)	0.4	0.4	0.4	
h	Groundwater draft (lit/sec) {(b*75*g)/f}	18.13	10.07	15.92	
i	Groundwater draft (cum/hr) {(h/1000)*3600}	65.26	36.26	57.29	
j	Total groundwater use (cum/ha) (i*a)	718	4496	8594	13808
k	Depreciation of pumpsets and tubewells[@] (Rs)	51	312	778	1141
l	Interest on pumpset and tubewell (Rs)	92	163	1287	1542
m	Upkeep cost (Rs)[$]	571	86	140	797
n	Total fixed cost +maintenance cost (Rs) {k+l+m}	714	561	2205	3480
o	Fixed cost (Rs/cum) {n / j}	0.99	0.12	0.26	0.23
p	Energy use {diesel (lit/cum) / electricity (kwh/cum)} [€]	0.02	0.10	0.13	
q	Groundwater subsidy (Rs/cum) {p*subsidy rate[π]}	0.28	0.33	0.42	0.37
r	Groundwater Subsidy (Rs/ha) {q * j}	203	1480	3581	5264
s	Energy cost (Rs/cum) {p* unit rate of energy[θ]} — s1. Subsidized		0	0	
	s2. Unsubsidized		0.33	0.42	
r	Total groundwater cost (Rs/cum) — r1. Subsidized {O+s1}	0.99	0.12	0.26	0.23
	r2. Unsubsidized {r1+q}	1.28	0.45	0.67	0.60

Notes:
[#] Drawn down in case of Punjab is assumed as 0 because of alluvial type aquifer

[Υ] For submersible pumps additional depth of 4 metre was added to the total head because these pumps are placed far below the groundwater table

[@] Total depreciation and interest on groundwater structure and pump sets is allocated for paddy crop based on working hours of the pumps. The depreciation of hired pump-sets is also assumed to be similar to owned pump-sets

[$] Upkeep cost for diesel pumps includes the cost of diesel

[€] Energy use for electric pumps = (hp*0.746) / groundwater draft, where, 1 hp= 0.746 kwh; Energy use for diesel pumps = (diesel use * Irrigation Hrs) /Total groundwater draft, where diesel use=1.43 lit/hr

[π] Diesel subsidy @ Rs. 12.95 per litre and Electricity subsidy @ Rs. 3.20 per unit in TE 2010-11 respectively

[θ] Unit rate of electricity: 3.20 per unit in TE 2010-11

For estimating Surface / Canal water irrigation subsidy, data can be collected fromthe report on "financial aspects of irrigation projects in India" published by Central Water Commission. By summing over capital expenditure and working expenses on various irrigation projects viz., major, medium and minor irrigation projects, total expenditure can be worked out. Similarly gross receipts can be estimated for various canal irrigation projects in the state.

Gross subsidy can be calculated as follows:

Gross Subsidy = Total Expenditure - Gross Receipts

Gross subsidy is there after allocated across different crops in proportion to respective gross irrigated area. Illustration for computation of canal water irrigation subsidy has been elaborated in the table 6.

Table 6 : Estimation of canal water irrigation subsidy for paddy crop in Punjab during TE 2010-11

S.No.	Items	
a	Expenditure on major, medium and minor projects (Rs lakhs)	101614
b	Gross receipts (Rs lakhs)	2571
c	Total subsidy (Rs lakhs) (a-b)	99043
d	GIA by canal ('000 ha)	2191
e	Subsidy (Rs/GIA) {(c*100000)/(d*1000)}	4520
f	Canal irrigated area under paddy (ha)	554
g	Area under paddy crop (ha)	2364
h	Subsidy total (Rs) (f * e)	2504080
i	Canal water subsidy (Rs/ha) (h/g)	1059

After deriving the different subsidy components, Net return at economic prices (NR_{EP}) can be calculated by subtracting total subsidy from the value of net returns at market prices (NR_{MP}) as shown in the table 7 for paddy crop in Punjab.

Table 7 : Computation of net returns at economic prices (NR_{EP}) for paddy in Punjab during TE 2010-11, (Rs/ha)

Crop	Irrigation Subsidy		NPK subsidy	Total subsidy	Net returns at Market prices (NR_{MP})	Net returns by economic prices (NR_{EP})
	Ground Water (a)	Canal water (b)	(c)	(d=a+b+c)	(e)	(f = e-d)
Paddy	5264	1059	6705	13028	47683	34658

3.4.3 Net returns based on natural resource valuation (NR_{NRV})

Net return based on Natural Resource Valuation (NRV) technique has taken care of nitrogen fixation by legume crops and Green House Gas (GHG) emission from crop production. As such NR_{NRV} is computed as by adding value of nitrogen fixation by legume crops at economic price of nitrogen (Value of N) and deducting the imputed value of increase in GHG emission cost to the atmosphere.

i.e. $NR_{NRV} = NR_{EP} + (\text{Value of N} - \text{cost of GHG})$ ………. *(iii)*

Thus, legumes are environment-friendly crops and are different from other food plants because of the property of synthesizing atmospheric nitrogen into plant nutrients. As such, the economic valuation has been done by taking into account the positive externality of legume crops by biological nitrogen fixation and the negative externality of GHG emissions, as presented in the Appendix 1(a) to 1(d).

The data on contribution of pulses by biological nitrogen fixation and emission of of different crops were collected from various published scientific literature, (Peoples *et al.*, 1995, IIPR, 2003, IARI, 2014).The value of GHG emissions in terms of CO_2Kg equivalent was taken at the rate of 10 US dollar per tonne. Biological nitrogen fixation for various crops has been calculated by taking the average value of nitrogen fixed by various legumes and then multiplied with the economic price of nitrogen prevailed in the TE 2010-11.

Thus net return based on natural resource valuation (NR_{NRV}) has taken into account the environmental benefits and has been illustrated in the table Table 8 for the case of paddy in Punjab.

Table 8: Computation of net returns based on NRV (NR_{NRV}) for paddy in Punjab during TE 2010-11, (Rs/ha)

Crop	Net Returns based on Economic Prices (NR_{EP}) (a)	Value of nitrogen (b)	Cost of GHG emissions (c)	Net returns based on NRV(NR_{NRV}) (d) = (a)+(b)-(c)
Paddy	34658	0	1838	32820

3.5 OPTIMIZATION OF CROP MODEL

The Mathematical Programming can be used for developing optimum crop or land use planning. It is an easy and flexible method for assessing different ways to use limited resources under variable objectives and constraints.

The present study makes an attempt to develop different crop planning strategies by using *linear programming* (LP). It develops the crop model which increases the productivity with minimum input cost under the constraints of available resources like water usage and also labour, fertilizers, seeds, etc., and ultimately getting maximum net benefits. Multi-crop model for two seasons are formulated in LP for maximizing the net returns, minimizing the cost and minimizing the water usage by keeping all other available resources (such as cultivable land, seeds, fertilizers, human labour, pesticides, capital etc.) as constraints.

3.5.1 Mathematical specifications of the model

Mathematically, model specification for Punjab are presented by Equations 1-6 followed by equation wise description.

$$\text{Max } Z = \sum_{c=1}^{n} Y_c P_c - C_c)\, A_c \qquad (1)$$

$$\sum_t \sum_c a_{tc} A_c \;\leq\; NS_t - OA_t \qquad (2)$$

$$A_c \;\geq\; A\min_c \qquad (3)$$

$$A_c \;\leq\; A\max_c \qquad (4)$$

$$\sum_c w_c A_c \;\leq\; RGWAA \qquad (5)$$

$$A_c \;\geq\; 0 \qquad (6)$$

3.5.2 Objective Function: Maximization of net income (Equation 1)

$$\sum_{c=1}^{n} (Y_c P_c - C_c)\, A_c$$

Let Y_c denotes yield of a crop *c* in one hectare of land, *P* the price received for the output from crop c, C_c refers to the cost incurred to cultivate crop c in one hectare of land and A_c is the area under cultivation of crop c then the RHS of the Equation 1 represents sum of net revenue obtained from all the crops considered for the optimum model development. The objective is to maximize the net revenue (z) based on the optimum crop plan.

Land Constraint

Optimum use of land for each month is required. This can be achieved by having separate constraint equation (Equation 2 is a compact form of 12 equations one for each month as shown below). This helps to have separate sown area for each month and ensures that total cultivated area under selected crops in each month should be less than net sown area (NS_t) minus area under orchard (OA_t) crops. Further crop calendar has to be maintained as per format in Figure 10 (Crop calendar for Punjab). Thus, a_{tc} in equation 2 refers to the coefficient of crop calendar matrix (Figure 10) for t^{th} month and c^{th} crop.

$$\sum_c a_{Jan\ c} A_c \;\leq\; NS_{Jan} - OA_{Jan}$$

$$\sum_c a_{Feb\ c} A_c \;\leq\; NS_{Feb} - OA_{Feb}$$

$$\sum_c a_{Mar\ c} A_c \;\leq\; NS_{Mar} - OA_{Mar}$$

$$\sum_c a_{Apr\ c} A_c \;\leq\; NS_{Apr} - OA_{Apr}$$

$$\sum_c a_{May\ c} A_c \;\leq\; NS_{May} - OA_{May}$$

$$\sum_c a_{Jun\ c} A_c \;\leq\; NS_{Jun} - OA_{Jun}$$

$$\sum_c a_{Jul\ c} A_c \leq NS_{Jul} - OA_{Jul}$$

$$\sum_c a_{Aug\ c} A_c \leq NS_{Aug} - OA_{Aug}$$

$$\sum_c a_{Sep\ c} A_c \leq NS_{Sep} - OA_{Sep}$$

$$\sum_c a_{Oct\ c} A_c \leq NS_{Oct} - OA_{Oct}$$

$$\sum_c a_{Nov\ c} A_c \leq NS_{Nov} - OA_{Nov}$$

$$\sum_c a_{Dec\ c} A_c \leq NS_{Dec} - OA_{Dec}$$

$$\sum_t \sum_c a_{tc} A_c \leq NS_t - OA_t$$

3.5.3 Minimum and maximum constraints (Equation 3-4)

Crop planning model using LP primarily captures the supply side behavior specifically area response based on net returns and resource constraints ignoring the demand aspect. Such models tend to over-estimate or under-estimate the area allocations for some crops. As a consequence, a single crop may cover infeasible larger area (over-estimation) or null or negligible area (under-estimation).

In some modelling solutions, some major crops may drastically lose their relevance and the corresponding area allocations may become negligible. Then, even though estimates are robust and mathematically proven, such allocations may not be desirable and practically possible from the view point of food security of the country and livelihood security of the farmer because appropriate changes are required in policy framework of the country to adopt the optimum sustainable model. Similarly, area allocations for some minor crops may be over-estimated ignoring the demand. Such an area allocation is again undesirable as it may lead to glut in the market. To avoid such undesirable over-estimation or under-estimation, assigning values to minimum and maximum area of the selected crops become essential in the model. To eliminate such practically undesirable solutions, concept of min, max constraints is used in the model as specified by the equations 3-4.

3.5.4 Ground water constraints

Water is a scarce natural resource. The ground water usage should be less than or equal to replenishable ground water available for agriculture (RGWAA) for making the agriculture sustainable. Data of RGWAA is published by Central Ground Water Board. RGWAA can be estimated by deducting water consumed by industries and other non-farm sectors from total replenishable ground water.

Ground water constraint to be used in linear programming (LP) model for Punjab agriculture is as follows:

$$\sum_c w_c A_c \leq RGWAA$$

where w_c is actual water drafted for a crop c in recent years based on Cost of Cultivation data. A_c refers to the area allocation for a crop c.

For the Punjab state, different scenarios have been developed by using different values of RGWAA *e.g.* (1) unlimited use of water by not using the water constraint, (2) sustainable water use (20 BCM) (Table 9). Data for development of RCP for Punjab has been taken from both secondary sources as well as household survey data from COC. However there can be some variations in other regions depending on the regional specific constraints and objective functions.

Existing land area allocations under different crops are useful to make comparison with optimum crop plan model. The data is available from statistical abstracts of Punjab. This data is further useful for defining minimum and maximum area allocation limits for the selected crops. Existing area is based on the three years average land use under the crops. Minimum and maximum area has been determined based on expert elicitation method.

◆◆◆

Optimum Crop Model for Punjab – A Case Study 4

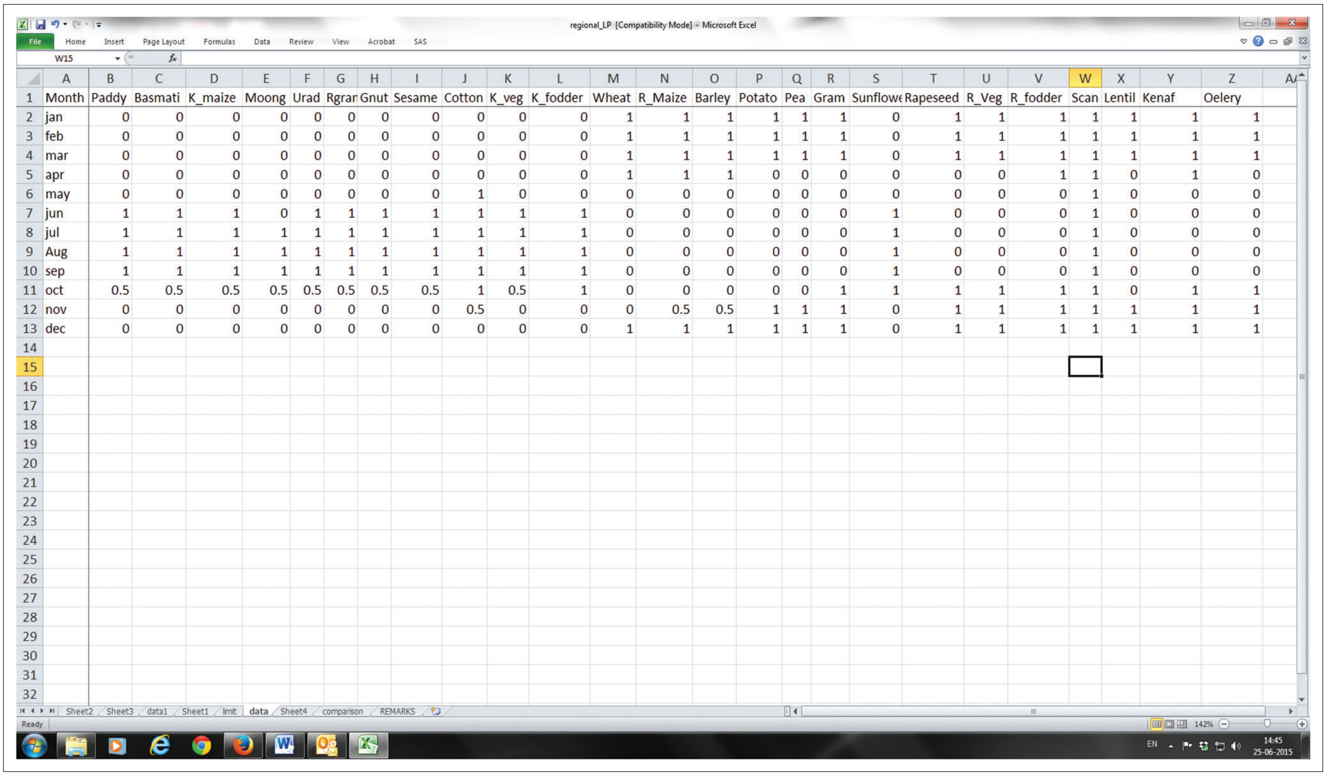
Regional Crop Planning model in this manual is based on optimization using linear programming. LP model in this manual is explained using GAMS software. LP formulation using GAMS is presented in Annexure 2 with the help of a hypothetical example. Based on compiled data and methodologies as explained above, datasheet is prepared in Excel format as shown in Figure 10 and Figure 11 and imported into the GAMS Code for preparation of optimum crop plan. The Excel sheets are very handy in development and refinement of crop plans during various stages of the model development. Code excerpts for importing the data from Excel are explained in Figure 12.

To develop optimum regional crop plan for Punjab, six different scenarios have been developed (Table 9).

Table 9 : Scenarios used for development of optimum crop models

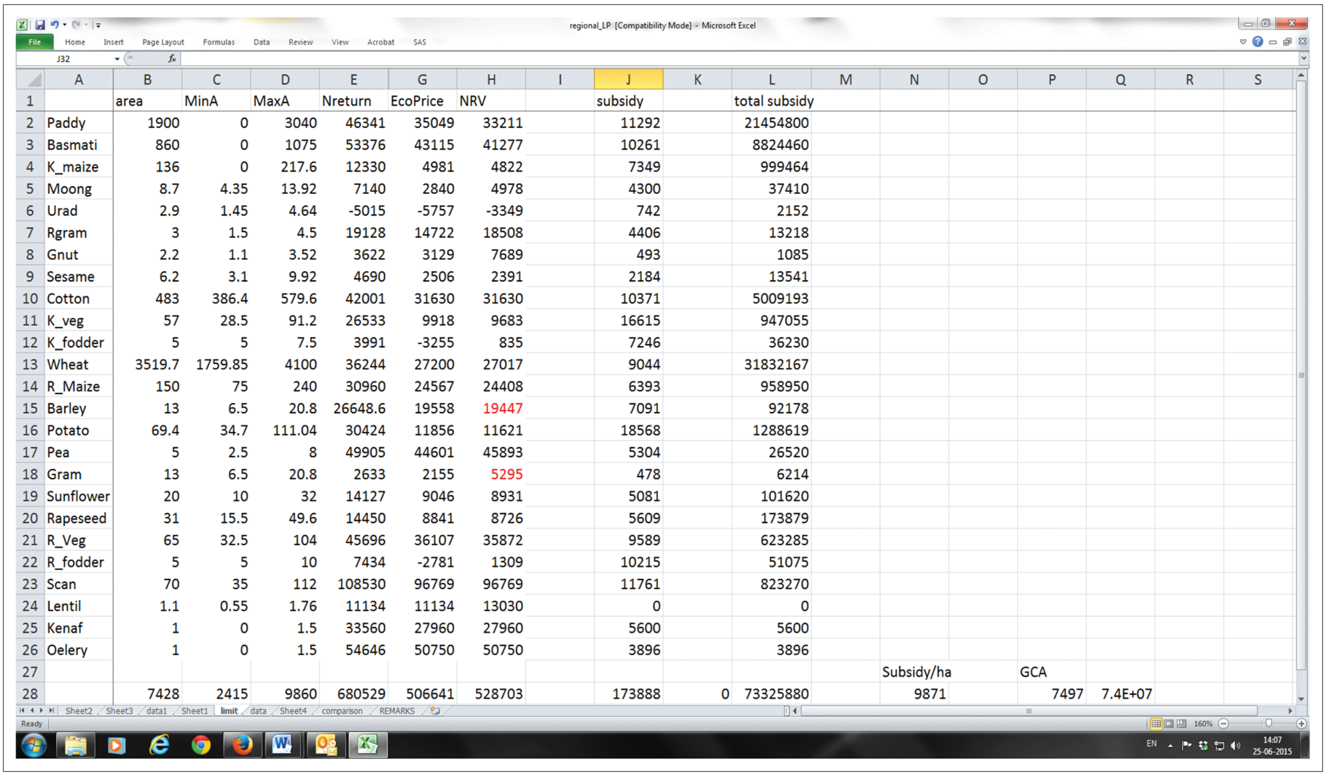
S. No.	Model Name	Objective function	Land constraint	Water constraint
	Business As Usual : Unlimited Ground Water			
1	$UGW\text{-}NR_{MP}$	Net Returns at Market Price	√	-
2	$UGW\text{-}NR_{EP}$	Net Returns at Economic Price	√	-
3	$UGW\text{-}NR_{NRV}$	Net Returns at Natural Resource Valuation	√	-
	Sustainability : Restricting Ground Water to 20 BCM			
4	$RGW\text{-}NR_{MP}$	Net Returns at Market Price	√	√
5	$RGW\text{-}NR_{EP}$	Net Returns at Economic Price	√	√
6	$RGW\text{-} NR_{NRV}$	Net Returns at Natural Resource Valuation	√	√

In table 9, objective function is characterized by net returns which can be based on market price, economic price or natural resource valuation. Each of these models uses land constraint as shown by column 'Land constraint'. Set of first three models i.e. $UGW\text{-}NR_{MP,}$ $UGW\text{-}NR_{EP}$ and $UGW\text{-}NR_{NRV}$ are developed for the existing business scenario where no water constraint is assumed i.e. ground water is assumed to be available in unlimited quantity and there is no restriction on the use of ground water. Set of last three models *i.e.* $RGW\text{-}NR_{MP}$, $RGW\text{-}NR_{EP}$, $RGW\text{-}NR_{NRV}$ are developed for the sustainability of groundwater where groundwater availability is limited to be 20 BCM which is a replenishable limit estimated by CGWB, 2014. The estimates provide the expected changes based on optimum crop model computed under different scenarios with reference to existing cropping pattern.



Month	Paddy	Basmati	K_maize	Moong	Urad	Rgran	Gnut	Sesame	Cotton	K_veg	K_fodder	Wheat	R_Maize	Barley	Potato	Pea	Gram	Sunflowe	Rapeseed	R_Veg	R_fodder	Scan	Lentil	Kenaf	Oelery
jan	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1
feb	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1
mar	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1
apr	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	1	0	1	0
may	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
jun	1	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
jul	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Aug	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
sep	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
oct	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	0.5	1	0	0	0	0	0	1	1	1	1	1	1	0	1	1
nov	0	0	0	0	0	0	0	0	0.5	0	0	0	0.5	0.5	1	1	1	0	1	1	1	1	1	1	1
dec	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1

Figure 10 : Excel sheet named 'data' for showing crop calendar for selected crops



	area	MinA	MaxA	Nreturn	EcoPrice	NRV		subsidy		total subsidy					
Paddy	1900	0	3040	46341	35049	33211		11292		21454800					
Basmati	860	0	1075	53376	43115	41277		10261		8824460					
K_maize	136	0	217.6	12330	4981	4822		7349		999464					
Moong	8.7	4.35	13.92	7140	2840	4978		4300		37410					
Urad	2.9	1.45	4.64	-5015	-5757	-3349		742		2152					
Rgram	3	1.5	4.5	19128	14722	18508		4406		13218					
Gnut	2.2	1.1	3.52	3622	3129	7689		493		1085					
Sesame	6.2	3.1	9.92	4690	2506	2391		2184		13541					
Cotton	483	386.4	579.6	42001	31630	31630		10371		5009193					
K_veg	57	28.5	91.2	26533	9918	9683		16615		947055					
K_fodder	5	5	7.5	3991	-3255	835		7246		36230					
Wheat	3519.7	1759.85	4100	36244	27200	27017		9044		31832167					
R_Maize	150	75	240	30960	24567	24408		6393		958950					
Barley	13	6.5	20.8	26648.6	19558	19447		7091		92178					
Potato	69.4	34.7	111.04	30424	11856	11621		18568		1288619					
Pea	5	2.5	8	49905	44601	45893		5304		26520					
Gram	13	6.5	20.8	2633	2155	5295		478		6214					
Sunflower	20	10	32	14127	9046	8931		5081		101620					
Rapeseed	31	15.5	49.6	14450	8841	8726		5609		173879					
R_Veg	65	32.5	104	45696	36107	35872		9589		623285					
R_fodder	5	5	10	7434	-2781	1309		10215		51075					
Scan	70	35	112	108530	96769	96769		11761		823270					
Lentil	1.1	0.55	1.76	11134	11134	13030		0		0					
Kenaf	1	0	1.5	33560	27960	27960		5600		5600					
Oelery	1	0	1.5	54646	50750	50750		3896		3896					
												Subsidy/ha		GCA	
	7428	2415	9860	680529	506641	528703		173888	0	73325880		9871		7497	7.4E+07

Figure 11 : Excel sheet named 'limit' for data inputs to GAMS program

Figure 12 : GAMS code for developing RCP with code description

```
*setting working directory *
$setglobal path "J:\RCPModel1\"

*Sets command is used to Define Object which consist of elements (usually names)*
*This facilitate vector or matrix computation by working like index items*
*C is Set or group of object, labelled as "crops", consists of many element -crop names*
*C is imported (not imputed directly as in the other set)*
*call=xls2gms.exe command is used to import crop names from Excel file "specified input location: I " *
*to "specified output location :O" as include file* and the range specified by R:
*$include %path%regional_LP.inc command is used to include data into gams running environment from
specified file *
Sets c crops
/
$call =xls2gms.exe I=%path%regional_LP.xls O=%path%regional_LP.inc R=limit!a2:a26
$include %path%regional_LP.inc
/ ;

*display command used to display the set or objects*
*Here it is used to check whether object has been created or not *
display "crops List", c;

*Group of object "t" defined using set command and labelled as period *
*Object "t" consist of elements - month names*
*Group of object "st" defined using set command and labelled as stat *
*Object "st" consist of elements like "area", "minA" and etc: names of variables*
*Set command part has to be terminated with semicolon*
set
   t period /jan,feb,mar,apr,may,jun,jul,aug,sep,oct,nov,dec/
st stat /area,minA,MaxA,Nreturn,water,EcoPrice,NRV/ ;

*parameter are defined and used to import data (usually numeric)*
*Precaution: Here name of crops should match in the same order in both Excel files set c and land(t,c)
*parameter land is imported in two steps*
*First step : using gdxxrw.exe data are converted from Excel file to gdx format "*
* initiate the command of GDXIN to read/accessed gdx format data by gams*
*load the data in to "land"*
* stop GDXIN
parameter land(t,c) ;
$call gdxxrw.exe %path%regional_LP.xls par=land rng=data!a1:z13
$GDXIN %path%regional_LP.gdx
$load land
$GDXIN
display land;

*parameter "Arealmt" is defined and displayed *
```

```
parameter Arealmt (c,st) ;
$call gdxxrw.exe %path%regional_LP.xls par=Arealmtrng=limit!a1:h26
$GDXIN %path%regional_LP.gdx
$load Arealmt
$GDXIN
display Arealmt;

*new parameters are defined and explained by respective labels*
PARAMETER
NR (c) net revenue per ha
AR (c) Existing Area in ha
jal(c) water requirement per hectare cubic meter
mnA(c) Minimum limit of area in ha
mxA(c) Maximum limit of area in ha
;

*newly defined parameters are populated by the values from the Arealmt parameter*
NR(c)= Arealmt(c,"NRV") ;
AR (c)= Arealmt (c,"area") ;
jal(c)= Arealmt(c,"water") ;
mnA (c)= Arealmt(c,"MinA") ;
mxA (c)= Arealmt(c,"MaxA") ;
display NR;
display AR;
display jal;
display mnA;
display mxA;

*Scalars are defined and inputted directly*
*scalars are single value constants*
*nca Net sown area in Thousand Ha*/
*gwa total ground water available in Billion Cubic Meter (BCM) /20/
Scalars
nca Net sown area in Thousand Ha /4000 /
gwa total ground water available in Billion Cubic Meter (BCM) /20/

*Variables are endogenous variables*
*positive variables are nonnegative endogenous variables*
*Equations command is used to declare Names of equations that will appear in the models*

variables
prof profit (in RS)
carea (c) quantity (in hectares)
positive variables
carea (c)
Equations
landeq (t) land allocation
minArea (c) Minimum area restriction
maxArea (c) Maximum area restriction
```

```
waterc water constraint
profit profit form production
;

*/ landeq (t): area under cultivation will be limited by total cropped area in each month
landeq (t).. sum(c, carea(c)*land(t,c)*1000) =l= nca*1000;

*/ minimum area under each crop is constrained by the user
minArea (c).. carea(c)*1000 =g= mnA(c)*1000 ;

*/ maximum area under each crop is constrained by the user
maxArea (c).. carea(c)*1000 =l= mxA(c)*1000 ;

*Ground water use across the crops should be subject to availability of ground water availability*
waterc.. sum(c, jal(c)*carea(c)*1000) =l= gwa*1000000000*Aag;

*Profitability is sum of net return from optimized regional crop plan*
profit.. prof =e= sum(c, NR(c)*carea(c)*1000);

*Model consist of set of equation, to be solved *
Model regional regional crop production /all/;

*Executing the solver using linear programming *
*lp is a solver module*
*objective is to maximize the profit under given set of constraints*

solve regional using lp maximizing prof
```

For expounding purpose, business as usual scenario result is presented for market price (UGW-NR_{MP}) in detail using GAMS solve summary which is output of GAMS program (Figure 13). First part of the output shows the model statistics and summary of the model followed by objective function value. Second part shows the equation solution report and the third part presents variable solution report (Figure 13). Similarly GAMS solve summary can be obtained for other models of Table 9. Variable solution report from each of the GAMS solve summary of all these models has been used for consolidation of results, comparing net returns, GCA change and gains from the optimum model (Table 10-12, Figure 13).

Table 10 shows Optimum area allocations for *Kharif* and *Rabi* season crops separately for different prices and unlimited water availability scenarios (UGW-NR_{MP}, UGW-NR_{EP}, UGW-NR_{NRV}). It is observed that cropping pattern is similar in all the three price scenarios (Table 10). On comparing the optimum pattern with existing cropping pattern, it is to be noted that during *Kharif*, paddy area tends to further increase in all three price scenarios (Table 10). Area under wheat and vegetables show increase in cropped area under all three scenarios.

Table 10 : Optimum crop model for unrestricted GW use : Business as usual scenario

Crops	Existing area (000 ha)	Optimum area (000 ha)			Direction of Change
		Market Price	Economic Price	Natural Resource Valuation	
Kharif Season					
Paddy (including Basmati)	2760.0	3523.6	3523.6	3523.6	+ + +
Maize	136.0	0	0	0	_ _ _
Cotton	483.0	386.4	386.4	386.4	_ _ _
Vegetables	57.0	28.5	28.5	28.5	_ _ _
Others (including fodder)	28.0	16.5	16.5	16.5	_ _ _
Rabi Season					
Wheat	3519.7	3707.8	3706.3	3706.3	+ + +
Maize	150.0	75.0	75.0	75.0	_ _ _
Vegetables	65.0	104.0	104.0	104.0	+ + +
Potato	69.4	34.7	34.7	34.7	_ _ _
Oilseeds (Rapeseed+Sunflower)	51.0	25.5	25.5	25.5	_ _ _
Others (including fodder)	39.1	28.1	29.6	29.6	_ _ _
Sugarcane	70.0	35.0	35.0	35.0	_ _ _
Gross Cropped Area	7428.2	7965.0	7965.0	7965.0	+ + +

Table 11 shows optimum area allocations for *Kharif* and *Rabi* season crops separately for different prices and water availability restricted to 20 BCM scenarios represented by the models RGW-NR$_{MP}$, RGW-NR$_{EP}$ and RGW-NR$_{NRV.}$

In Table 11, it is observed that cropping pattern is similar in all three price scenarios. On comparing the optimum pattern with existing cropping pattern, it is observed that during *Kharif*, paddy, vegetables and other crops area tends to decrease in all three price scenarios while maize and cotton area tends to increase (Table 11). In *Rabi* season, wheat and vegetables show increase in cropped area but all other crops show decrease in the respective cropped area.

Table 11 : Optimum crop model for GW use restricted to 20 BCM : Ground water sustainability scenario

Crops	Existing area (000 ha)	Optimum area (000 ha)			Direction of Change
		Market Price	Economic Price	Natural Resource Valuation	
Kharif Season					
Paddy (including Basmati)	2760.0	724.0	729.8	729.8	_ _ _
Maize	136.0	217.6	217.6	217.6	+ + +
Cotton	483.0	579.6	579.6	579.6	+ + +
Vegetables	57.0	28.5	28.5	28.5	_ _ _
Others (including fodder)	28.0	29.1	19.5	19.5	_ _ _
Rabi Season					
Wheat	3519.7	3707.8	3707.8	3707.8	+ + +
Maize	150.0	150.0	75.0	75.0	_ _ _
Vegetables	65.0	104.0	104.0	104.0	+ + +
Potato	69.4	34.7	34.7	34.7	_ _ _
Oilseeds(Rapeseed+Sunflower)	51.0	47.5	25.5	25.5	_ _ _
Others(including fodder)	39.1	28.1	28.1	28.1	_ _ _
Sugarcane	70.0	35.0	35.0	35.0	_ _ _
Gross Cropped Area	7428.2	5610.8	5585.0	5585.0	_ _ _

Expected changes based on optimum crop model estimated under different price and water scenarios with reference to existing cropping pattern are presented in Table 12.

Table 12: Gains due to optimum crop model over existing scenario

Optimum Scenario (1)	Change in GCA % (2)	Existing Revenue (00 Crores) (3)	Optimal Net Returns (00 Crores) (4)	Change in Farmer Revenue (00 Crores) (Optimal - Existing $_{MP}$) (5)	Gain to society (00 crore) (6)	Net Gain (00 crore) (7)=(5)+(6)
Unrestricted water use						
Market Price	7.2	297.3	332.0	34.7	-	34.7
Economic Price	7.2	213.5	240.8	-56.5	83.8	27.3
Natural Resource Valuation	7.2	207.7	233.6	-63.7	78	14.3
Sustainable water use (20 BCM)						
Market Price	-24.5	NA	211.4	-85.9	NA	NA
Economic Price	-24.8	NA	152.1	-145.2	NA	NA
Natural Resource Valuation	-24.8	NA	150.0	-147.3	NA	NA

Figure 13 : GAMS solve summary

SOLVE SUMMARY

First Part

MODEL	regionalN_MP	OBJECTIVE	prof
TYPE	LP	DIRECTION	MAXIMIZE
SOLVER	CPLEX	FROM LINE	201

**** SOLVER STATUS	1	Normal Completion
**** MODEL STATUS	1	Optimal
**** OBJECTIVE VALUE		332019607401.4761

RESOURCE USAGE, LIMIT	0.015	1000.000
ITERATION COUNT, LIMIT	1	2000000000

IBM ILOG CPLEX 24.3.3 r48116 Released Sep 19, 2014 WEI x86 64bit/MS Windows
Cplex 12.6.0.1

Space for names approximately 0.00 Mb
Use option 'names no' to turn use of names off
LP status(1): optimal
Cplex Time: 0.00sec (det. 0.07 ticks)
Optimal solution found.
Objective : 332019607401.476070

Second Part

—————————————————— EQU landeq land allocaton —————————————————

	LOWER	LEVEL	UPPER	MARGINAL
Jan	-INF	4.0000E+6	4.0000E+6	.
Feb	-INF	4.0000E+6	4.0000E+6	.
Mar	-INF	4.0000E+6	4.0000E+6	.
Apr	-INF	3.8293E+6	4.0000E+6	.
May	-INF	4.2140E+5	4.0000E+6	.
Jun	-INF	3.9957E+6	4.0000E+6	.
Jul	-INF	4.0000E+6	4.0000E+6	.
Aug	-INF	4.0000E+6	4.0000E+6	.
Sep	-INF	4.0000E+6	4.0000E+6	46198.000
Oct	-INF	2.3507E+6	4.0000E+6	.
Nov	-INF	4.4470E+5	4.0000E+6	.
Dec	-INF	4.0000E+6	4.0000E+6	36244.325

---------------- EQU min Area Minimum area restriction ----------------

	LOWER	LEVEL	UPPER	MARGINAL
Paddy	.	2.4486E+6	+INF	.
Basmati	.	1.0750E+6	+INF	.
K_maize	.	.	+INF	.
Moong	4350.000	4350.000	+INF	-3.906E+4
Urad	1450.000	1450.000	+INF	-5.121E+4
Rgram	1500.000	1500.000	+INF	-2.707E+4
Gnut	1100.000	1100.000	+INF	-4.258E+4
Sesame	3100.000	3100.000	+INF	-4.151E+4
Cotton	3.8640E+5	3.8640E+5	+INF	-4011.000
K_veg	28500.000	28500.000	+INF	-3.166E+4
K_fodder	5000.000	5000.000	+INF	-4.221E+4
Wheat	1.7598E+6	3.7077E+6	+INF	.
R_Maize	75000.000	75000.000	+INF	-5284.757
Barley	6500.000	6500.000	+INF	-9812.785
Potato	34700.000	34700.000	+INF	-9106.325
Pea	2500.000	8000.000	+INF	.
Gram	6500.000	6500.000	+INF	-3.361E+4
Sunflower	10000.000	10000.000	+INF	-3.207E+4
Rapeseed	15500.000	15500.000	+INF	-2.179E+4
R_Veg	32500.000	1.0400E+5	+INF	.
R_fodder	5000.000	5000.000	+INF	-2.881E+4
Scan	35000.000	35000.000	+INF	-5.566E+4
Lentil	550.000	550.000	+INF	-2.511E+4
Kenaf	.	.	+INF	.
Oelery	.	1500.000	+INF	.

―――――――――――――― EQU Max Area Maximum area restriction ――――――――――――――

	LOWER	LEVEL	UPPER	MARGINAL
Paddy	-INF	2.4486E+6	3.0400E+6	.
Basmati	-INF	1.0750E+6	1.0750E+6	7178.793
K_maize	-INF	.	2.1760E+5	.
Moong	-INF	4350.000	13920.000	.
Urad	-INF	1450.000	4640.000	.
Rgram	-INF	1500.000	4500.000	.
Gnut	-INF	1100.000	3520.000	.
Sesame	-INF	3100.000	9920.000	.
Cotton	-INF	3.8640E+5	5.7960E+5	.
K_veg	-INF	28500.000	91200.000	.
K_fodder	-INF	5000.000	7500.000	.
Wheat	-INF	3.7077E+6	4.1000E+6	.
R_Maize	-INF	75000.000	2.4000E+5	.
Barley	-INF	6500.000	20800.000	.
Potato	-INF	34700.000	1.1104E+5	.
Pea	-INF	8000.000	8000.000	8304.675
Gram	-INF	6500.000	20800.000	.
Sunflower	-INF	10000.000	32000.000	.
Rapeseed	-INF	15500.000	49600.000	.
R_Veg	-INF	1.0400E+5	1.0400E+5	12705.793
R_fodder	-INF	5000.000	10000.000	.
Scan	-INF	35000.000	1.1200E+5	.
Lentil	-INF	550.000	1760.000	.
Kenaf	-INF	.	1500.000	.
Oelery	-INF	1500.000	1500.000	18401.437

	LOWER	LEVEL	UPPER	MARGINAL
—— EQU profit MP	.	.	.	1.000

profit MP profit form production

Third Part

	LOWER	LEVEL	UPPER	MARGINAL
—— VAR prof	-INF	3.320E+11	+INF	.

prof profit (in RS)

—— VAR carea quantity (in hectares)

	LOWER	LEVEL	UPPER	MARGINAL
Paddy	.	2448.600	+INF	.
Basmati	.	1075.000	+INF	.
K_maize	.	.	+INF	-3.387E+7
Moong	.	4.350	+INF	.
Urad	.	1.450	+INF	.
Rgram	.	1.500	+INF	.
Gnut	.	1.100	+INF	.
Sesame	.	3.100	+INF	.
Cotton	.	386.400	+INF	.
K_veg	.	28.500	+INF	.
K_fodder	.	5.000	+INF	.
Wheat	.	3707.750	+INF	.
R_Maize	.	75.000	+INF	.
Barley	.	6.500	+INF	.
Potato	.	34.700	+INF	.
Pea	.	8.000	+INF	.
Gram	.	6.500	+INF	.
Sunflower	.	10.000	+INF	.
Rapeseed	.	15.500	+INF	.
R_Veg	.	104.000	+INF	.
R_fodder	.	5.000	+INF	.
Scan	.	35.000	+INF	.
Lentil	.	0.550	+INF	.
Kenaf	.	.	+INF	-2.684E+6
Oelery	.	1.500	+INF	.

**** REPORT SUMMARY : 0 NONOPT
0 INFEASIBLE
0 UNBOUNDED

The results pinpoint that unrestricted ground water use will further tend to increase the gross cropped area by 7 per cent while restricting the ground water use to replenishable limit of 20 BCM will tend to reduce the gross cropped area by 25 per cent. Optimal net returns are found to be relatively large with unrestricted ground water use while relatively low with restricted ground water use which decreases the cropped area under the water intensive crops. Further, optimal returns are found to be larger with market price and tend to decrease with economic price and natural resource valuation. Largest optimal net returns are observed in UGW-NR_{MP} while smallest net returns are observed in RGW-NR_{NRV}. Changes in farmers' revenue from each of six models are estimated by subtracting the corresponding optimal model revenue from the existing revenue at market price. For example in Table 12, gains in farmers' revenue at economic price (UGW-NR_{EP}) are estimated by subtracting optimal revenue of the model UGW-NR_{EP} from existing revenue of the model UGW-NR_{MP}. This revenue change was found positive only in UGW-NR_{MP}. However, this positive change is at the cost which is paid by the society in terms of declining water table and cost of subsidy on fertilizers, diesel, water and electricity. All other models show the negative change in farmer revenues. But there are positive gains to society. These gains are not estimated for sustainable water use scenario, because of the problems of estimation of cost of water saved. Finally net gains are estimated by adding changes in farmers' revenue and gains to society. It is observed that net gains are positive in all the three model of business as usual scenario. The comparative results of the two scenarios show that it is difficult to shift to sustainable ground water use because of negative change in farmers' revenue due to decrease in GCA. However, gradual decrease in ground water use is recommended which should be further supplemented by increasing ground water use efficiency, better package of practice for water intensive crops e.g. SRI cultivation, direct seeding for paddy cultivation.

References

Chand, Ramesh; Sonia Chauhan, (2002), *Socio Economic Factors in Agricultural Diversification in India*, Agricultural Situation in India, February.

CGWB (2013), Master Plan for Artificial Recharge to Groundwater in India, Central Groundwater Board, Ministry of Water Resources, Government of India. http://cgwb.gov.in/documents/MasterPlan-2013.pdf.

CGWB (2014), Dynamic Groundwater Resources of India (As on 31st march, 2011), Central Groundwater Board, Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad.

Coelli, T. (1998), *A Multi-Stage Methodology for the Solution of Orientated DEA Models*, Operation Research Letters, Volume- 23(3-5): 143-149.

CWC (Central Water Commission) (various issues), *Report on Financial Aspects of Irrigation Projects in India*. Information technology directorate information system organization, Water planning and projects wing.

DES (Directorate of Economics and Statistics), *Manual on Cost of Cultivation Surveys*, Department of Agriculture, Government of India, available at http://mospi.nic.in/Mospi_New/upload/manual_cost_cultivation_surveys_23july08.pdf

GoI (Government of India) (2011) Central Ground Water Board, Ministry of Water Resources, New Delhi, available at: http://cgwb.gov.in/

GoI (Government of India) (various issues), *Annual Report of Ministry of Chemicals and Fertilizers*, Department of Fertilizers, New Delhi

GoPb (Government of Punjab) (2011), *Report on Environment Statistics of Punjab*, Economic and Statistical Organisation, Chandigarh.

GoPb (Government of Punjab) (various issues), *Statistical Abstracts of Punjab*, Chandigarh.

GoPb (Government of Punjab), Punjab State Electricity Regulatory Commission, available at: http://www.pserc.nic.in/

IARI (Indian Agricultural Research Institute) (2014), *GHG Emission from Indian Agriculture: Trends, Mitigation and Policy Needs*. Centre for Environment Science and Climate Resilient Agriculture, pp.16.

IIPR (Indian Institute of Pulses Research) (2003), *Pulses in new perspective*, In Proceedings of the National Symposium on Crop Diversification and Natural Resource Management, Kanpur. pp. 20 – 22.

Mousavi-Avval SH, Rafiee S., Jafari A, Mohammadi A. (2011), *Optimization of energy consumption for soybean production using Data Envelopment Analysis (DEA) approach*. Applied Energy. **35:** 2156-2164.

Pal, Swades and Kar, Shyamal (2012), *Implications of the methods of agricultural diversification in reference with Malda district: drawback and rationale,* International Journal of Food, Agriculture and Veterinary Sciences 2 (2): 97-105.

Peoples, M. B., Ladha, J. K. and Herridge, D. F. (1995), Enhancing legume N_2 fixation through plant and soil management. *Developments in Plant and Soil Sciences*, 174: 83-101.

Raju, S.S., Ramesh Chand, S. K. Srivastava, Amrit Pal Kaur, Jaspal Singh, Rajni Jain, Kingsly Immaneulraj and Parminder Kaur (2015), *Comparing Performance of Various Crops in Punjab Based on Market and Economic Prices and Natural Resource Accounting*, Agricultural Economics Research Review, 28 (Conference issue).

Ramachandra, T.V. and Shwetmala, (2012), *Decentralized carbon foot print analysis for opting climate change mitigation strategies in India,* Renewable and Sustainable Energy Reviews, 16 (8): 5820-5833.

Srivastava, S.K., Ramesh Chand, S.S. Raju, Rajni Jain, Kingsly I., Jatinder Sachdeva, Jaspal Singh and Amrit Pal Kaur (2015), *Unsustainable Groundwater Use in Punjab Agriculture: Insights from Cost of Cultivation Survey,* Indian Journal of Agricultural Economics, 70 (Conference issue).

Worthington AC (1999), *Measuring Technical Efficiency in Australian Credit Unions*, Manchester School 67(2): 231-248.

Annexure 1

ECONOMIC VALUATION OF NITROGEN FIXATION AND GHG EMISSION BY VARIOUS CROPS

(a) Estimates of nitrogen fixed by legumes (Kg/ha)

Crop	Source I	Source II	Source III
Chickpea	23-97	26-63	120-140
Red gram	4-200	68-200	150
Green gram	50-66	50-55	112
Black gram	119-140	-	55-72
Cow Pea	9-125	53-85	47-188
Soybean	19-450	49-130	93-138
Cluster bean	37-196	37-196	-
Pea	46	46	-
Ground nut	-	112-152	240-260

Source : I. Peoples *et al.*, (1995); II . IIPR (2003); III. Residual effects of legumes in Rice-Wheat Cropping systems Pg. No. 109.

(b) Economic contribution of legumes through nitrogen fixation (Rs/ha)

S. No.	Crop	Contribution
1	Soybean	3865
2	Black gram	2506
3	Cluster bean	3533
4	Red gram	3412
5	Cowpea	3110
6	Lentil	1993
7	Green gram	2235
8	Chickpea	3140
9	Peas	1389
10	Groundnut	4560
11	Lucerne	4952
12	Stylo	3322

Source: Calculated by using Peoples *et al*., (1995) and IIPR (2003)

(c) Methane emission factors for paddy cultivation

State	Integrated Seasonal Methane Flux (g/m^2)	Global Warming Potential (Kg CO_2 equivalents per hectare)	GHG cost (Rs /ha)
Punjab	18.9	3969	1838
Bihar	18.9	3969	1838
Maharashtra	11.6	2436	1128
Karnataka	11.0	2310	1070
Tamil Nadu	11.0	2310	1070
Rajasthan	11.6	2436	1128
Assam	46.0	9660	4475

Note: Cost is calculated @10 USD per tonne of CO_2 equivalents.
Source: Ramachandra, T.V. and Shwetmala, (2012).

(d) Green House Gas (GHG) emission from selected crops in India

Crop	CO_2equivalent (Kg/Ha) (Global Warming Potential)	GHG Cost (Rs/ha)
Wheat	340-450	157-208
Maize	320-365	148-169
Millets	230-250	107-116
Oilseeds	220-275	102-127
Pulses	180-240	83-111
Vegetables	440-575	204-266

Note: Cost is calculated @10 USD per tonne of CO_2 equivalents.
Source: Calculated by using IARI (2014).

Annexure 2

GAMS BASICS FOR SOLVING CONSTRAINED OPTIMIZATION PROBLEMS

This appendix is a ready reckoner for the beginners in GAMS. It explains the GAMS software and basic features of a GAMS program with the help of a small example. Further it also explains the interpretation and analysis of the GAMS output.

A2.1 ORIGIN OF GAMS SOFTWARE

The GAMS software (General Algebraic Modelling System) was originally developed by a group of economists from the World Bank in order to facilitate the resolution of large and complex non-linear models on personal computer. As a matter of fact, GAMS allows solving simultaneous non-linear equation system, with or without optimization of some objective function. (i) Simplicity of implementation, (ii) portability and transferability between users and systems and (iii) easiness of technical update because of the constant inclusion of new algorithms are the main advantages of GAMS. The seminal GAMS system was file oriented. The program must be created in ASCII format with any one of the usual text editor run by a DOS command. The development of GAMS-IDE interface in the late 1990s makes it even easier to use. GAMS-IDE works as a general text editor compatible with WINDOWS and offers the ability to launch and monitor the compilation and execution of typical GAMS programs. In this introduction note we will present the general structure of the GAMS program, followed by a detailed illustration, including a description of the output file.

A2.2 HOW TO START GAMS

Double clicking the GAMS IDE icon will show the GAMS window as in Figure A2.1

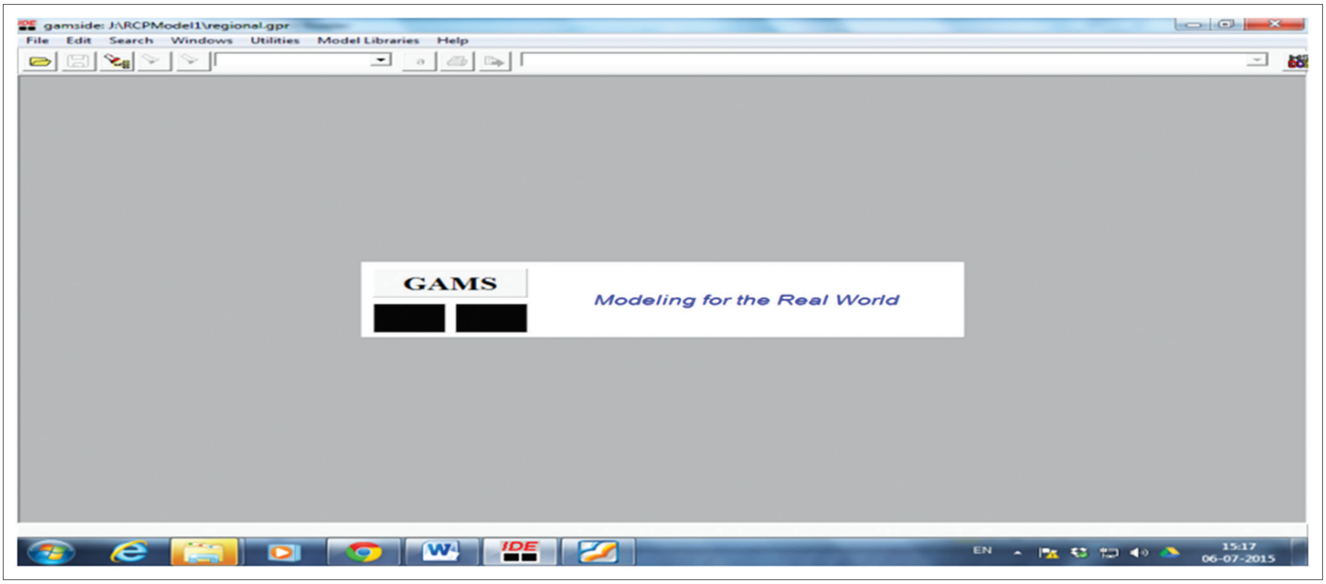


Figure A2.1: GAMS window

A2.3 HOW TO START A NEW PROJECT

Once, IDE window opened, go to File → Project → New Project (Figure 2).

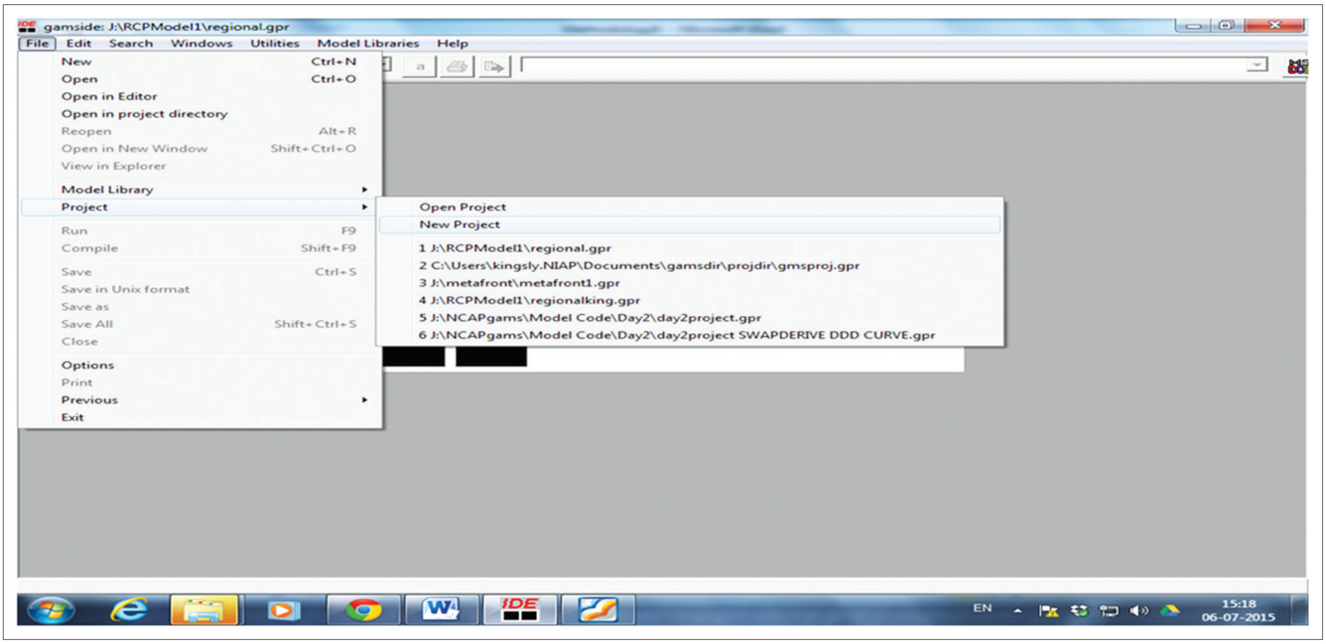


Figure A2.2: Creating a new project

New window will open. Let us call our working folder name as optimization. Indicate this folder (Optimization) for working directory and give new name (here GAMS newproject) for newly created project file. Then click open (Figure A2. 3).

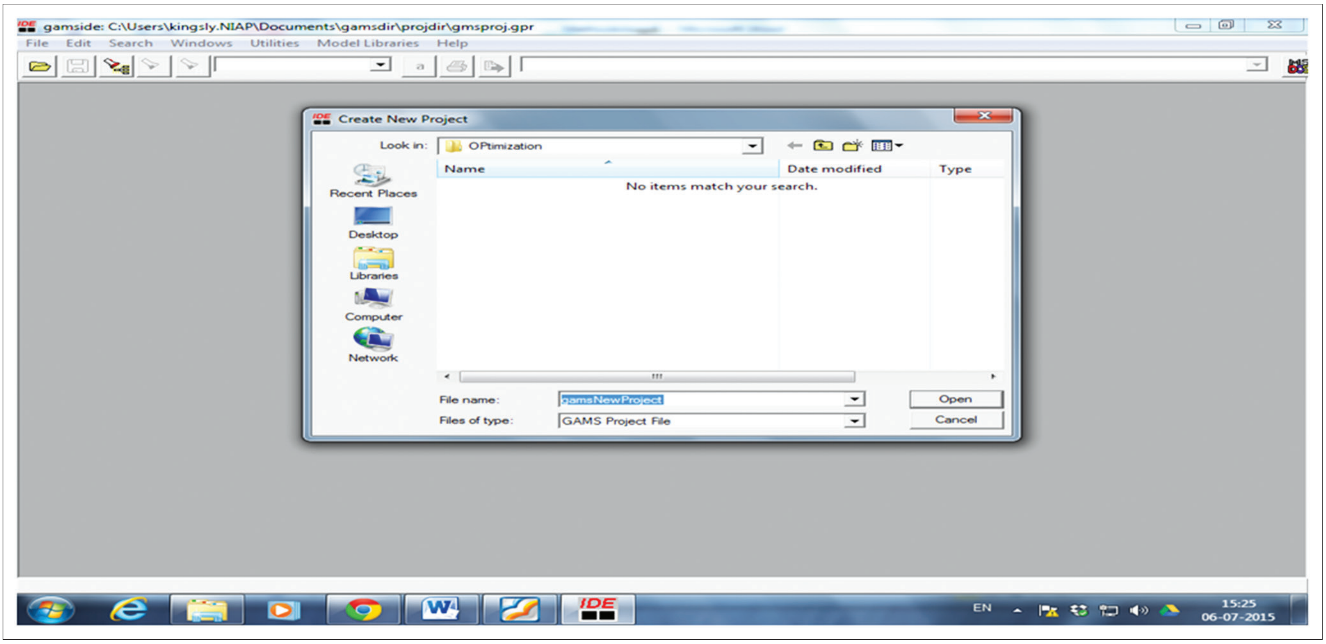


Figure A2.3: Opening a new project

Then go to file menu → click new → click open (Figure A2. 4). New untitled.gms file will open (Figure A2. 5).

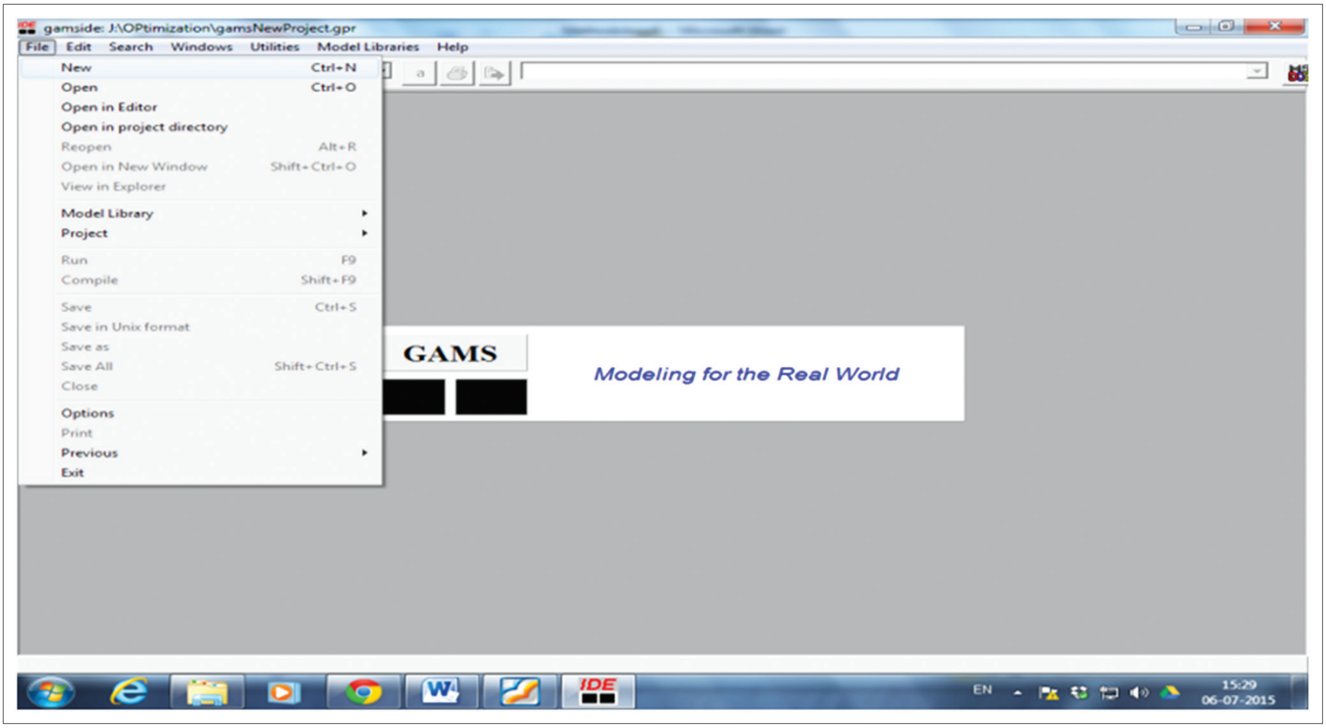


Figure A2. 4: Opening a new GAMS code file

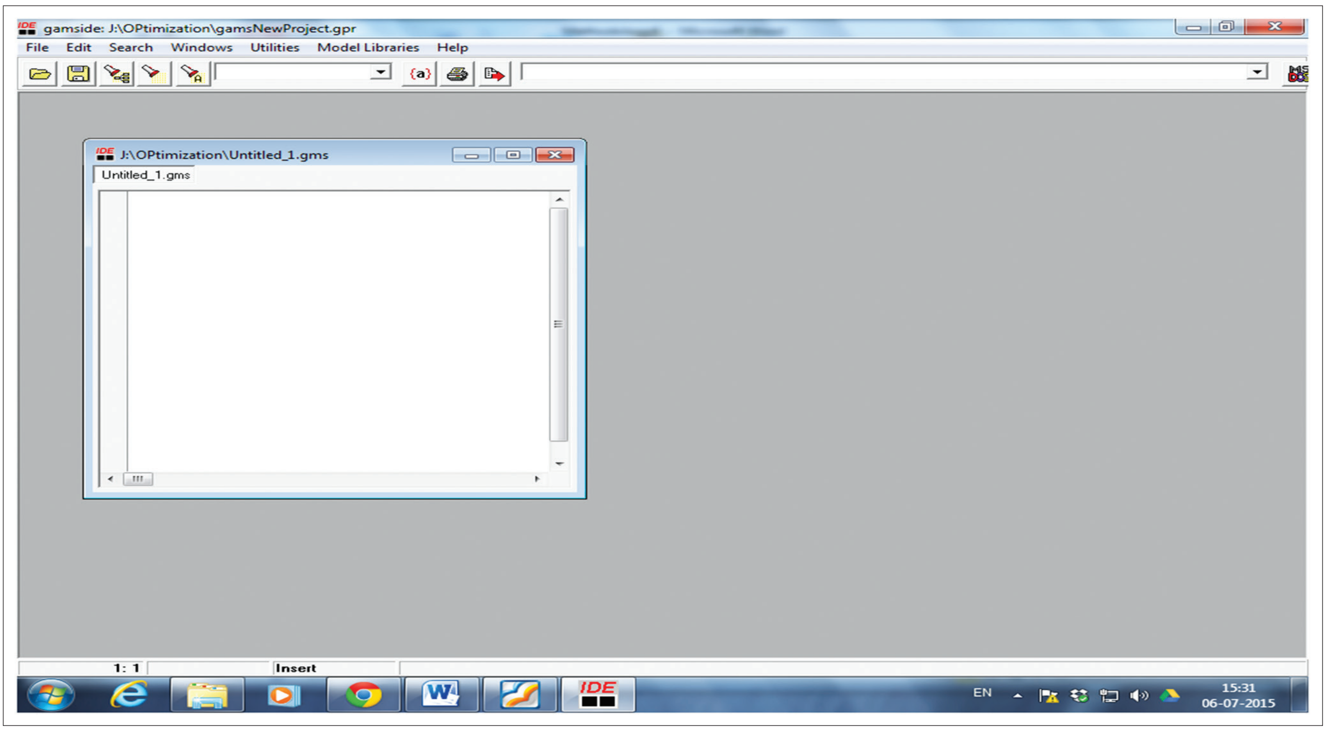


Figure A2. 5: New untitled GAMS file

A2.4 HOW TO WRITE GAMS CODE

GAMS program can be written in two different styles. (1) Without algebraic form (2) With algebraic form. The former forms are useful for beginner to understand the formulation each equation basis. It is suitable for small optimization problem and explanatory purpose. Later form is useful for larger optimization problem. Here text book equations can be easily translated in to problem formulation. It reduces the writing program time. It is suitable for experienced programmer.

GAMS Program Structure (Without algebraic language)

Variables
Equations
Model
Solve

GAMS Program Structure (With algebraic language)

Set
Data entry (Scalar, Parameter and Table)
Variables
Equations
Model
Solve

Example

$$
\begin{array}{llllll}
Max & 109^* X_{corn} & + 90^* X_{wheat} & + 115^* X_{Cotton} & & \\
s.t. & X_{corn} & + X_{wheat} & + X_{Cotton} & \leq 100 & (land) \\
 & 6^* X_{corn} & + 4^* X_{wheat} & + 8^* X_{Cotton} & \leq 500 & (land) \\
 & X_{corn} & X_{wheat} & X_{Cotton} & \geq 0 & (non\ negativity)
\end{array}
$$

LP formulation in GAMS (Without algebraic language)

```
VARIABLES Z;
POSITIVE VARIABLES Xcorn, Xwheat, Xcotton;
EQUATIONS OBJ, land, labor;
OBJ..   Z=E=109* Xcorn + 90* Xwheat + 115* Xcotton;
land..  Xcorn + Xwheat + Xcotton =L= 100;
labor.. 6* Xcorn+ 4* Xwheat + 8* Xcotton = L=500;
MODEL farm PROBLEM /ALL/;
SOLVE farm PROBLEM USING LP MAXIMIZING Z;
```

Explanation

```
VARIABLES Z;
POSITIVE VARIABLES Xcorn, Xwheat, Xcotton;
```

Variables : *list of variable in model can assume both positive and negative values*
Positive variables : *list of variable in model can assume only positive values*
Non Negative Variables : *list of variable can assume zero or positive values.*

Equations

GAMS requires that the modeler name each equation, which is active in the optimization model. Later each equation is specified using the notation as explained just below. These equations must be named in an EQUAT ION or EQUATIONS instruction. This is used in each of the example models as reproduced below.

EQUATIONS OBJ, land, labor; OBJ.. Z =E= 109 * Xcorn + 90 * Xwheat + 115 * Xcotton;	Naming Equation
land.. Xcorn + Xwheat + Xcotton =L= 100; labor.. 6*Xcorn+ 4 * Xwheat + 8 * Xcotton =L= 500;	Equation Specification

Equation specification

The GAMS equation specifications actually consist of two parts.

The first part naming equations was discussed just above.

The second part involves specifying the exact algebraic structure of equations. This is done using the notation. In this notation we give the equation name followed by a then the exact equation type as it should appear in the model. The equation type specification involves use of a special syntax to tell the exact form of the relation involved. The most common of these are (see the Variables, Equations, Models and Solves chapter for a complete list):

=E= is used to indicate an equality relation

=L= indicates a less than or equal to relation

=G= indicates a greater than or equal to relation

Model

Once all the model structural elements have been defined then one employs a MODEL statement to identify models that will be solved. Such statements are as follows in the given example.

MODEL farm PROBLEM /ALL/;

In the Model Statement in the model contents field

Using /ALL/ includes all the equations.

One can list equations in the model statement like that below.

MODEL FARM /obj, Land, labor/;

Solve

Once one believes that the model is ready in such that it makes sense to find a solution for the variables then the solve statement comes into play. The SOLVE statement causes GAMS to use a solver to optimize the model or solve the embodied system of equations.

SOLVE farm PROBLEM USING LP MAXIMIZING Z;

Solve model name using model type; where Solve is required. A model name follows that must have already been given this name in a Model statement using is required. The model type is one of the known GAMS model types LP**.**

Linear Programming formulation (With algebraic language)

$$\begin{array}{lllll} Max & \sum_j C_j X_j & & & \\ s.t. & \sum_j a_{ij} X_j & \leq & b_i & \textit{for all } i \\ & X_j & \geq & 0 & \textit{for all } j \end{array}$$

where

j =	{	com		wheat	cotton }	
i =	{	land		labor	}	
x_j =	{	X_{corn}	X_{wheat}	X_{cotton}	}	
C_j =	{	109	90		115	}
a_{ij} =		1			1	1
		6			4	8
b_i =	{	100		500		}'

```
SET j /Corn, Wheat, Cotton/
i /Land, Labor/;

PARAMETER
c(j) / corn 109, wheat 90, cotton 115/
b(i) /land 100, labor 500/;

TABLE a(i,j)
land 1 1 1
labor 6 4 8 ;
POSITIVE VARIABLES x(j);
```

Data Entry Portion

```
VARIABLES PROFIT;
EQUATIONS OBJective , constraint(i) ;                 }  Naming Equation

OBJective.. PROFIT=E= SUM(J,(c(J))*x(J)) ;            }  Equation Specification
constraint(i).. SUM(J,a(i,J) *x(J)) =L= b(i);

MODEL RESALLOC /ALL/;
SOLVE RESALLOC USING LP MAXIMIZING PROFIT;
```

Sets

Set is mathematically collection of distinct objects or elements. Software exploits this concept to create array or matrix data. That is useful in easy handling and computation of large data file. In order to use any subscript in GAMS, one must declare an equivalent set. The set declaration contains.

- i the set name
- ii a list of elements in the set (up to 63 characters long spaces etc allowed in quotes)
- iii optional labels describing the whole set
- iv optional labels defining individual set elements

Data Entry

GAMS provides for three forms of data entry. These involve PARAMETER, SCALAR and TABLE formats. Scalar entry is for scalars, Parameter generally for vectors and Table for matrices.

Scalars

SCALAR format is used to enter items that are not defined with respect to sets.

scalar item 1 name optional labelling text /numerical value/

Item 2 name optional labeling text /numerical value/

...

Examples include

scalar data item /100/;

scalar land on farm total arable acres /100/;

Parameters

Parameter format is used to enter items defined with respect to sets. Generally parameter format is used with data items that are one-dimensional (vectors) although multi dimensional cases can be entered. The general format for parameter entry is:

Parameter itemname(setdependency) optional text

/ firstsetelementname associated value,

Secondsetelementname associated value,

... /;

Parameter and Table statements are only used in above LP example.

LP Example:

PARAMETERS

PRICE(PROCESS) PRODUCT PRICES BY PROCESS

/X1 3,X2 2,X3 0.5/;

RESORAVAIL(RESOURCE) RESOURCE AVAILABLITY

/CONSTRAIN1 10 ,CONSTRAIN2 3/;

Tables

TABLE format is used to enter items that are dependent on two more sets. The general format is

Table itemname(setone, settwo...) descriptive text

set_2_element_1 set_2_element_2

set_1_element_1 value_11 value_12

set_1_element_2 value_21 value_22;

LP Example

TABLE a (i,j) crop data

corn wheat cotton

land 1 1 1

labor 6 4 8 ;

When one moves to algebraic modeling the variable and equation declarations can have an added element of set dependency as illustrated in our examples and reproduced below:

POSITIVE VARIABLES x(j) ;

VARIABLES PROFIT ;

EQUATIONS Objective , constraint(i) ;

The equations and variables in a model are defined by the evaluation of the equation specifications.

The equations for our examples are

Objective.. PROFIT=E= SUM(J,c(J)*x(J)) ;

constraint(i).. SUM(J,a(i,J) *x(J)) =L= b(i);

General Guidelines for a GAMS program

Some tips for writing a GAMS program are given below:

1. A GAMS program is a collection of statements in the GAMS language. Statements must be ordered so that items are initially declared before they are used. So the actual order of a statement in GAMS is declaration, definition and use.

2. Individual GAMS statements can be formatted in almost any style. Multiple lines may be used for a statement, blank lines can be embedded, any number of spaces or tabs may be inserted and multiple statements may be put on one line separated by a;

3. Every GAMS statement should be terminated with a semicolon (;).

4. GAMS is not case sensitive, thus it is **equivalent** to type the command VARIABLE as variable or the variable names XCOTTON as XCOTTON.

5. The use of a named item (which in GAMS can be a set, parameter, scalar, table, acronym, variable, equation, model or file) involves the following three steps:
   a. Declaration where one announces the existence of a named item giving it a name.
   b. Assignment giving it a specific value or replacing its value with the results of an expression.
   c. Subsequent usage.

6. The item names, elements and explanatory text must naming rules. Interested readers may refer to user guide [http://www.GAMS.com/mccarl/mccarlGAMSuserguide_web.pdf] for more details.

A2.5 HOW TO RUN GAMS CODE

Run the file with GAMS by punching the run button

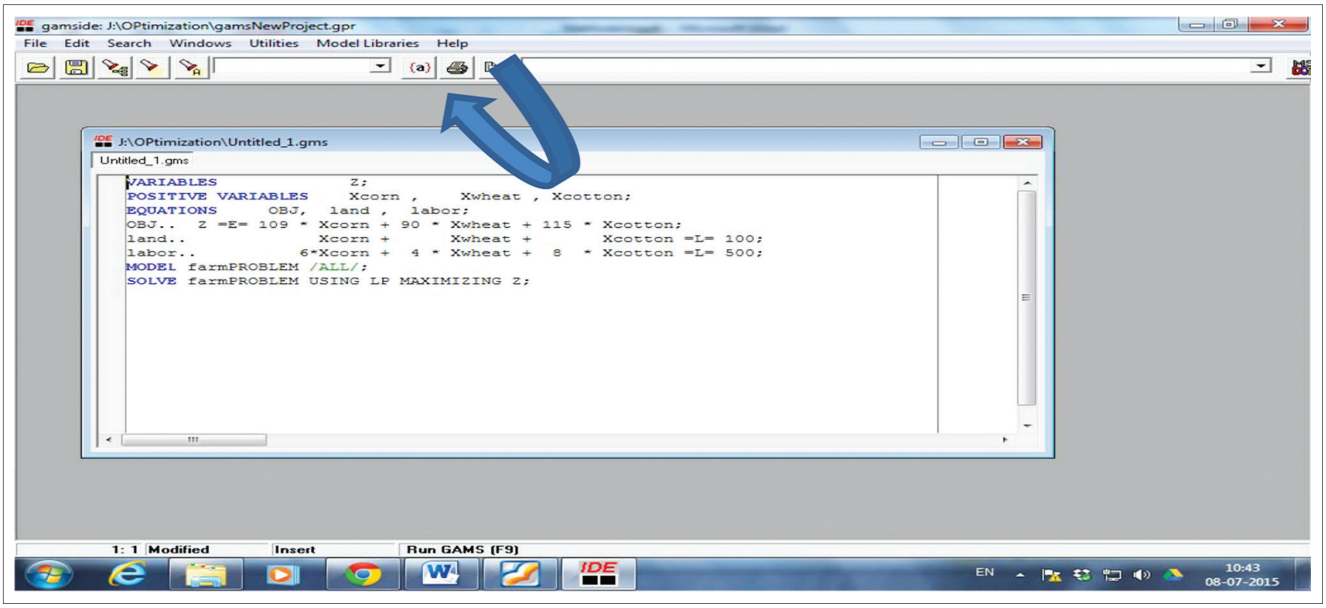


Figure A2.6: Running the GAMS code

A2.6 UNDERSTANDING GAMS OUTPUT

When a GAMS file is run then GAMS in turn creates a LST file of problems and results. The various components of LST file are:

1. Echo print
2. Symbol list and cross reference maps
3. Execution output
4. Generation listing
5. Solver report

A2.6.1 Echo print

The echo print is simply a numbered copy of the instructions GAMS received in the GMS input file. For the given example, a portion of the LST file is as follows:

```
1   VARIABLES Z; v
2   POSITIVE VARIABLES Xcorn, Xwheat, Xcotton;
3   EQUATIONS OBJ, land, labor;
4   OBJ.. Z =E= 109 * Xcorn + 90 * Xwheat + 115 * Xcotton;
5   land..Xcorn + Xwheat + Xcotton =L= 100;
6   labor.. 6*Xcorn + 4 * Xwheat + 8 * Xcotton =L= 500;
7   MODEL farm PROBLEM /ALL/;
8   SOLVE farm PROBLEM USING LP MAXIMIZING Z;
```

The numbered echo print as above serves as an important reference guide because GAMS reports the line numbers in the LST file where solves or displays were located as well as a the position of any errors that have been encountered.

A2.6.2 Symbol List and Cross Reference Maps

These items may or may not be present in the GAMS output depending on the default settings. The symbol list contains all the variables, equations, models and some other categories of GAMS language classifications in alphabetical order. More details can be referred in the GAMS user manual.

A2.6.3 Execution output

Execution output involves the following:

1. A report of the time it takes GAMS to execute any statements between the beginning of the program and the first solve (or in general between solves),

2. Any user generated displays of data; and

3. If present, a list of numerical execution errors that arose.

A2.6.4 Generation listing

Once GAMS has successfully compiled and executed then any solve statements that are present will be implemented. In particular, the GAMS main program generates a computer readable version of the equations in the problem that it in turn passes on to whatever third party solver is going to be used on the model. During this so called model generation phase GAMS creates output

1. Listing the specific form of a set of equations and variables,

2. Providing a summary of the total model structure, and

3. If encountered, detailing any numerical execution errors that occurred in model generation.

Listing the specific form of a set of equations and variables

When GAMS generates the model by default the first three equations for each named equation will be generated. A portion of the output (just that for the first two named equations) for the given example is

Equation Listing SOLVE farm PROBLEM Using LP From line 10

—— OBJ =E=

OBJ.. Z - 109*Xcorn - 90*Xwheat - 115*Xcotton =E= 0 ; (LHS = 0)

—— land =L=

land.. Xcorn + Xwheat + Xcotton =L= 100 ; (LHS = 0)

1. In first part, the model being solved and the line number in the echo print file where the solve associated with this model generation appears.

2. The second part of this output consists of the marker —— followed by the name of the equation with the relationship type (=L=, =G=, =E= etc). When one wishes to find this LST file component, one can search for the marker —— or the string Equation Listing. Users will quickly find —— marks other types of output like that from display statements.

3. The third part of this output contains the equation name followed by a ..and then a listing of the equation algebraic structure. In preparing this output, GAMS collects all terms involving variables on the left hand side and all constants on the right hand side. This output component portrays the equation in linear format giving the names of the variables that are associated with non zero equation terms and their associated coefficients.

4. The algebraic structure portrayal is trailed by a term which is labelled LHS and gives at evaluation of the terms involving endogenous variables evaluated at their starting points (typically zero unless the .L levels were preset). A marker INFEAS will also appear if the initial values do not constitute a feasible solution.

Model statistics

GAMS software also creates an output summarizing the size of the model, how many variables of equations and some additional information. For the given example the result is as follows:

MODEL STATISTICS

BLOCKS OF EQUATIONS	3	SINGLE EQUATIONS	3
BLOCKS OF VARIABLES	4	SINGLE VARIABLES	4
NON ZERO ELEMENTS	10		

A2.6.5 Solver Report

The final major component of the LST file is the solution output and consists of a summary and then a report of the solutions for variables and equations, followed by report summary. Each of these components for the given example are explained sequentially.

Solve Summary:

SOLVE SUMMARY

MODEL farm PROBLEM OBJECTIVE Z

TYPE LP DIRECTION MAXIMIZE

SOLVER CPLEX FROM LINE 8

**** SOLVER STATUS 1 Normal Completion

**** MODEL STATUS 1 Optimal

**** OBJECTIVE VALUE 9950.0000

RESOURCE USAGE, LIMIT 0.272 1000.000

ITERATION COUNT, LIMIT 2 2000000000

ILOG CPLEX Nov 1, 2009 23.3.3 WEX 13908.15043 WEI x86_64/MS Windows

Cplex 12.1.0, GAMS Link 34

LP status(1): optimal

Optimal solution found.

Objective : 9950.000000

The solution summary contains

- the marker S O L V E S U M M A R Y;
- the model name, objective variable name (if present), optimization type (if present), and location of the solve (in the echo print);
- the solver name;
- the solve status in terms of solver termination condition;
- the objective value (if present);
- somecpu time expended reports;
- a count of solver execution errors; and
- some solver specific output.

Equation solution report

The next section of the LST file is an equation by equation listing of the solution returned to GAMS by the solver. Each individual equation case is listed. For our example the reports are as follows:

	LOWER	LEVEL	UPPER	MARGINAL
— — EQU OBJ	.	.	.	1.000
— — EQU land	-INF	100.000	100.000	52.000
— — EQU labor	-INF	500.000	500.000	9.500

The columns associated with each entry have the following meaning,

- Equation marker — —
- EQU - Equation identifier
- Lower bound (.lo) – RHS on =G= or =E= equations
- Level value (.l) – value of Left hand side variables. Note this is not a slack variable but inclusion of such information is discussed in the Standard Output chapter.

- Upper bound (.up) – RHS on =L= or =E= equations
- Marginal (.m) – dual variable, shadow price or in MCPs only complementary variable value

Variable solution report

The next section of the LST file is a variable by variable listing of the solution returned to GAMS by the solver. Each individual variable case is listed.

	LOWER	LEVEL	UPPER	MARGINAL
— — VAR Z	-INF	9950.000	+INF	.
— — VAR Xcorn	.	50.000	+INF	.
— — VAR Xwheat	.	50.000	+INF	.
— — VAR Xcotton	.	.	+INF	-13.000

The columns associated with each entry have the following meaning,

- Variable marker — —
- VAR - Variable identifier
- Lower bound (.lo) – often zero or minus infinity
- Level value (.l) – solution value.
- Upper bound (.up) – often plus infinity
- Margninal (.m) – reduced cost or in MCPs only slack in complementary equations

Report Summary:

Report summary of the given example is given below which is self-explanatory.

****** REPORT SUMMARY : 0 NONOPT**
0 INFEASIBLE
0 UNBOUNDED

EXECUTION TIME = 0.016 SECONDS 2 Mb WEX233-233 Dec 15, 2009
USER: NAIP-DSSACMO G100201:1520CP-WIN
NCAP DC8171

****** FILE SUMMARY**
Input RCPModel1Untitled_2.gms
Output I:RCPModel1Untitled_2.lst

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किसानों का हमसफर
भारतीय कृषि अनुसंधान परिषद

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