

DEVELOPMENT OF A SPATIAL PLANNING SUPPORT SYSTEM FOR AGRICULTURAL POLICY ANALYSIS - CASE STUDY: BORKHAR DISTRICT, IRAN

B. Farhadi Bansouleh^{a, b}, M.A. Sharifi^a, H. Van Keulen^{c, d}

^aInternational Institute for Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, P.O. Box 6, 7500 AA Enschede, The Netherlands - farhadibansoule@itc.nl

b) Water engineering department, Faculty of agriculture, Razi University, Kermanshah, Iran

^cPlant Production Systems Group, Wageningen University, P.O. Box 430, 6700 AK, Wageningen, The Netherlands

^dPlant Research International, Wageningen University and Research Centre, P.O. Box 16, 6700 AA Wageningen, The Netherlands

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ABSTRACT:

This study aims developing a model to simulate the reaction of different farm-types to various policy instruments in order to support agricultural planning at regional levels. In this context a linear programming model developed to integrate the socio-economic and the biophysical resources of farmers to assess the immediate effects and the long-term impacts of various policy instruments. This distributed model includes variety of sub-models (Farm-type land unit, farm-type, village, and integrated model). Biophysical input-output coefficients of the model (yield, nutrient and water requirement) have been generated spatially by application of crop growth simulation model "CGMS" and GIS techniques for the crops in the district.

1. INTRODUCTION

Agriculture is one of the most important sectors of the Iranian economy, as it is the major land user and provides employment for the majority of the population. One of the challenges for the agricultural sector is better use of existing resources, e.g., land, water, fertilizers, pesticides, etc for increasing the production and prosperity of farmers.

Anticipation of the effects and impacts of agrarian policies on natural environment, agricultural sector and objectives of different stakeholders are important for decision makers and agricultural planners. The objectives of various stakeholders are often different and sometimes they are conflicting. Some policy instruments may have positive effects on the objectives of some stakeholders; while having negative effects on the objectives of some other stakeholders or no effects on others. For example, increasing the price of products may increase farmers' income and increase the use of fertilizers and pesticides, and as a result increase environmental hazards. Therefore, simulation of the behaviour of the farmers who are the final decision makers in land use planning in response to different policy instruments is very important. The aim of this study is to develop a model for simulation of the reaction of different farmers (with different socio-economic and biophysical conditions) to different policy instruments in order to support agricultural planning at regional levels.

Evaluation of the reaction of individual farmers to policies would be ideal, but is impossible because of time and investment limitations. Classification of farmers to homogenous groups of farm-types (Kruseman and Bade, 1998; Bouman et al., 1999; Mohamed et al., 2000; Laborte, 2006) and evaluation of the reaction of each farm-type instead of individual farmers is a way which can be used for solving this problem. Aggregation bias (Day, 1963) is an important issue which should be considered in the classification of farmers. Following criterion

has been mentioned by Day (1963) for homogeneity of planning units in linear programming: Technological homogeneity, Pecunious proportionality and Institutional proportionality.

In this study a spatial planning support system for agricultural policy analysis is developed and implemented in one of the districts of Esfahan province in Iran. For this purpose a combination of crop growth simulation models, linear programming, GIS and multi-criteria evaluation techniques has been used.

The study area is Borkhar district in Esfahan province, Iran. One of the most important arguments for selection of this area is availability of data and information from previous studies. From total area of 762500 ha in this district, about 65000 ha is suitable for agriculture and in average, about 35000 hectares are used for agriculture. Mean annual precipitation in the region varies between 50 and 200 mm and mean annual evapotranspiration is about 2000 mm. Groundwater quality in the region is low. Therefore, water is one of the most limiting factors for agricultural development. Most of the farmers have less than 2 hectares of land.

2. MATERIAL AND METHODS

General framework of agricultural policy analysis has been presented in Figure 1. Policy makers have some objectives which may be different and sometimes in conflict with the objectives of farmers and/or other stakeholders. Policy instruments are tools which are used for stimulation of farmers to change their behaviours for achieving the objectives of policy makers. By changing the behaviour of farmers, changes in land use (systems) can be expected. Changes in land use (systems) can be predicted using simulation models by optimizing the objectives of farmers considering their

constraints. In this study a linear programming model has been developed for prediction of changes in land use (systems) as a result of policy instruments. Objectives of other stakeholders including policy makers, and social and environmental impacts of these changes in land use system will be calculated as post calculation. Overall assessment of the policy instrument will be done using multi-criteria evaluation techniques. Policy makers can use the results of this overall assessment to accept (recommend) or change policy instrument.

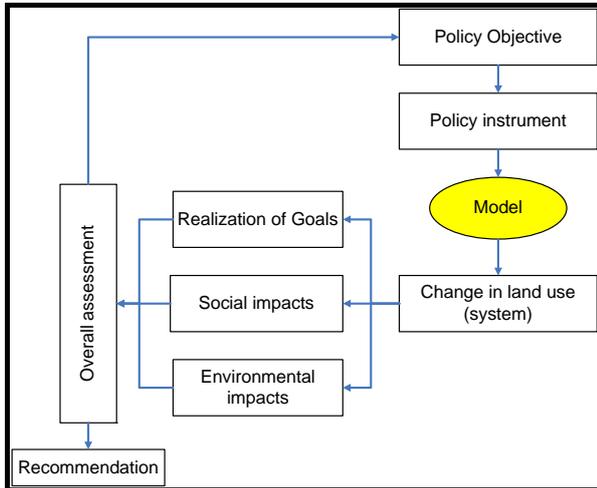


Figure 1- Flowchart of land use policy planning (Sharifi, 2003)

2.1 Model structure

A linear programming model has been developed for each farm-type land-unit. Farm-type land-units (FTLU) are homogenous units in terms of biophysical and socio-economic information. As the farmers of this area are economical oriented, objective function of maximizing net income has been considered for this model. Optimization has been applied considering the water, land, rotation, labour, and machinery constraints. Decision variables of this model are cultivation of 22 crops (10 single crop & 12 double crops in one year) with two irrigation systems (Surface and sprinkler), and three levels of irrigation (Fully irrigation, 20% deficit irrigation and 40 % deficit irrigation). GAMS (Brooke et al., 1998) has been used for programming and solving the linear programming model. Several indicators such as net income, cultivated land, nitrogen loss, employment generated by agricultural activities, total nutrient requirements, production of different commodities and etc. as well as objectives of other stakeholders have been calculated in post calculation after the optimization of the model.

Overall structure of the model is presented in Figure 2. The model integrates variety of sub-models (farm-type land-unit, farm-type, village, and sub-district model). The basic model is farm-type land-unit that is integrated into a regional model. Each of the constraints represents the limitation of activities at a specific level. For example, water constraint has been considered at farm-type and village level however, machinery constraint is considered at sub-district level. Integration of the agricultural cooperatives and agro industrial farms with the village models has been done in sub district model (It is not presented in this paper).

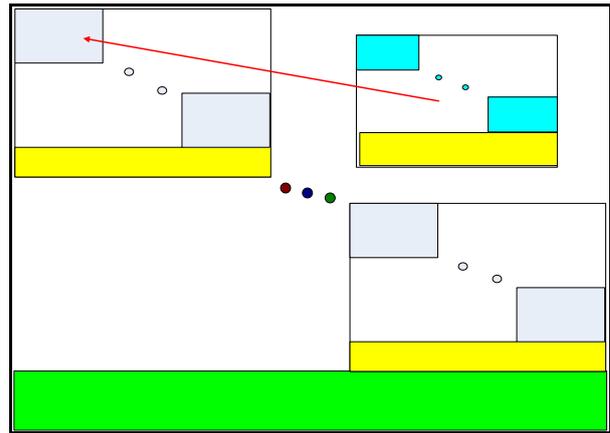


Figure 2-Overall structure of the model (smallest unit is FTLU)

2.2 Model development and implementation

2.2.1 Determination of planning units

Farm-type land-unit is the basic planning unit that are assumed to be homogenous in terms of socio-economic and bio-physical characteristics.

Land units are spatial units, which have been established by overlaying soil map with weather grids (village polygons in this study) over the agricultural lands in the study area. This assumes that weather parameters have not significant changes over a village. By this assumption one or more land units can exist in one village. Borders of each village in the sub-district have been determined based on Thiessen polygon, as these borders were not determined in the available maps.

Farmers were classified (Methodology of farm type classification explained in the next section of this paper) in the whole district based on the variables which have been selected for this purpose. Number of farm types in each village has been determined in farm type classification. In each village percentage of each farm-type in terms of number, area and water has been calculated. Area of each land unit has been distributed between farm types based on the percentage of the area of each farm type in the village.

2.2.2 Farming systems and farm-type classification

Several types of agricultural system are existing in the study area (APERI, 1997). These systems are different in terms of ownership, management and objectives. List of existing farming systems in Borkhar district are presented in Table 1.

There are differences between agricultural activities, efficiencies and objectives of different farming systems, as there was no information on the number and percentages of sub-systems in the study area, only traditional farmers have been modelled at this stage.

Farm classification is mainly subjective. Farmers can be classified based on their objectives, their resource endowments and their technologies and institutions. For determination of farm types, an extensive analysis has been done on the characteristics of more than 7000 agricultural holders. In this study traditional farmers are classified based on Day's (1963) principle and data availability. Following variables which has

been given or calculated from agricultural census in year 2003 have been used for farm-type classification:

- Total land
- Available water
- Average production efficiency
- Average income per ha

| Main system | Sub system |
|-----------------|-------------------------------|
| Traditional | Sharing system |
| | Leasing (Rent) system |
| | Hired labour |
| | Family type |
| Cooperative | Rural production cooperatives |
| | Agricultural cooperatives |
| Agro industrial | Agro industrial units |

Table 1- List of existing farming systems in Borkhar district, Iran (APERI, 1997)

Available water of each holder estimated based on the area under cultivation of different crops and water requirement of the crops. Production efficiency of each holder per commodity is defined as the ratio of the crop yield of the holder over the maximum yield of that crop in the sub-district (Dehestan). Overall production efficiency of each farmer has been calculated by weighted average of production efficiency and area under cultivation of that commodity. Average net income per ha of each commodity in the provincial level has been used as bench mark for calculation of the net income of farmers.

Average net income of each farmer (holder) calculated by weighted average of net income per ha of each commodity and area under cultivation of that commodity (the same as overall production efficiency).

Farmers are classified to eight farm-types by doing hierarchical cluster analysis in SPSS (SPSS Inc., 2007). Table 2 shows average of the total land, water availability, cropped area, net income and overall production efficiency of all farm types in year 2003.

| Farm Type | FT1 | FT2 | FT3 | FT4 | FT5 | FT6 | FT7 | FT8 |
|-----------------------------------|------|------|------|------|------|-------|-------|-------|
| Total land (ha) | 0.19 | 0.8 | 0.9 | 1.14 | 2.07 | 31.72 | 62.2 | 173.9 |
| Water availability (L/s) | 0.27 | 0.64 | 0.67 | 0.94 | 1.58 | 19.8 | 80.32 | 46.72 |
| Cropped area (ha) | 0.12 | 0.42 | 0.47 | 0.62 | 1.08 | 15.23 | 50.39 | 42.63 |
| Average Income (Million Rials/ha) | 9.32 | 4.20 | 3.09 | 1.24 | 2.18 | 2.47 | 2.70 | 2.36 |
| production efficiency (%) | 67 | 56 | 45 | 24 | 36 | 43 | 49 | 46 |

Table 2 - Average of the total land, water availability, cropped area, net income and overall production efficiency of farm types in year 2003

2.2.3 Estimation of bio-physical input/outputs for the model

Biophysical input-output coefficients (crop yield, water requirement, and nutrient requirement) of the model have been generated spatially by application of crop growth simulation models and GIS techniques. In this process, WOFOST (Boogaard et al., 1998) crop growth model has been calibrated

for winter wheat, winter barley, silage maize, sunflower, sugar beet, and potato in the district (Vazifedoust et al., 2008; Farhadi Bansouleh et al., in prep.). Calibrated crops are then used in the same model which has been regionalized (CGMS) to simulate crop growth on each land unit.

Growth of different crops has been simulated using CGMS 2.3 and for 20 years (1985-2004) using daily weather data of the weather stations in and around the district. Some of the outputs of this model which are used for generation of biophysical input/outputs of the model are:

- a) Crop yield (Total weight of storage organ and total above ground products) at potential and water-limited situations
- b) Potential and water-limited transpiration per decade
- c) Potential and water-limited leaf area index (LAI)

Simulated crop yield used for estimation of gross income and also nutrient requirement. Average of simulated potential yield of winter wheat (grain) and silage maize (Total above-ground) over the period of 1985-2004 in each land unit have been presented in the Figures 3 and 4 respectively.

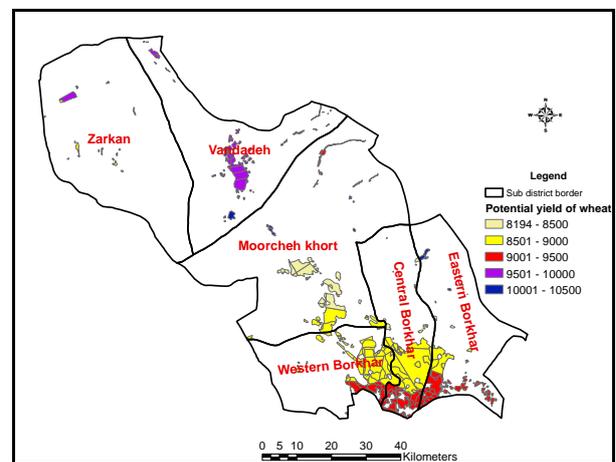


Figure 3 – Average of simulated potential yield (grain) of winter wheat in the district (1985-2004)

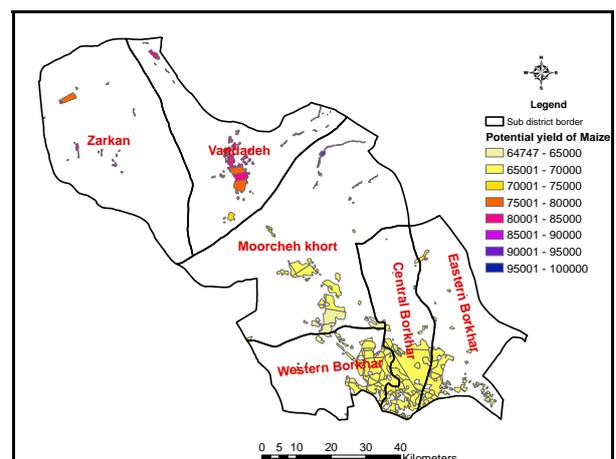


Figure 4- Average of simulated potential yield (total above-ground) of silage maize in the district (1985-2004)

Water requirement for evapotranspiration calculated based on potential transpiration and leaf area index. Daily potential evapotranspiration (ET) of each crop in each grid has been

calculated based on CGMS results. Minimum, average and maximum potential ET of winter wheat in different villages of Borkhar district based on 20 years daily weather data (1985-2004) presented in the Figure 5.

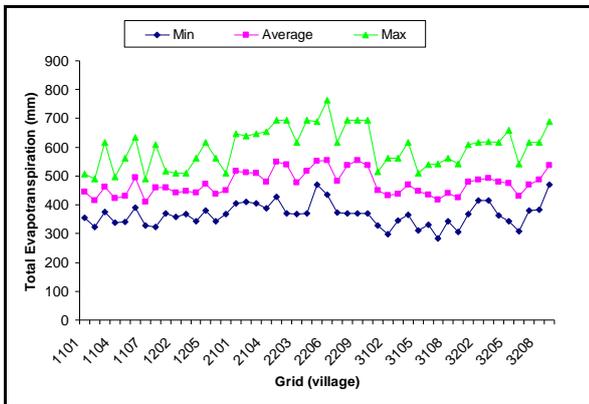


Figure 5- Minimum, average and maximum of simulated potential ET of winter wheat in the period 1985-2004

CGMS model does not directly calculate irrigation application. The model has been modified to carry out this function. Results of the CGMS model in the water-limited situation indicate the simulation of crop growth under the specified irrigation management. CGMS model has been run under three different irrigation managements (Fully irrigation, 20% deficit irrigation and 40% deficit irrigation) for all crops and 20 years weather data. However the average yield of winter wheat in the village presented in Figure 6, but results per land unit are available.

CGMS results are assuming perfect management. Therefore, the simulated yield is converted to expected yield of farm type per land unit by considering a management coefficient (Equation 1) for each farm type per crop and land unit.

$$M_Coeff_{FT,LU,Crop} = PE_{FT,crop} * \frac{Max\ Yield_{Crop,Dehestan}}{Yield_{Crop,LU}} \quad (1)$$

Where:

$M_Coeff_{FT,LU,Crop}$: management coefficient of FT in land unit per crop

$PE_{FT,Crop}$: production efficiency of farm type for each commodity (crop)

$Yield_{crop,LU}$: simulated yield of crop in the land unit

$Max\ yield_{crop, Dehestan}$: Maximum simulated yield in the Dehestan (Sub-district)

Ratio of maximum yield in Dehestan to yield in land unit is an indicator of differences in bio-physical potentials. For crops which we did not use CGMS, the ratio of another crop with the same growing period has been used.

Nutrient requirement for production of each crop has been estimated based on the crop yield and nutrient contents of crops in storage organ and residues.

2.2.4 Estimation of socio-economical input/outputs

Different sources have been used for estimation of socio-economic input/outputs of each farm-type. Labour requirement for production of each commodity and farm size has been estimated based on the data of on-going project (Estimation of production costs of agricultural commodities) of Iranian

ministry of Agriculture. Machinery requirement has been related to farm size and it has been given from other on-going project (National project for development of agricultural mechanization) in the Esfahanian agricultural organization. Prices are considered based on the average prices in the year 2002. Complementary required data has been found by interview with farmers, local experts, use of questionnaire, and literature.

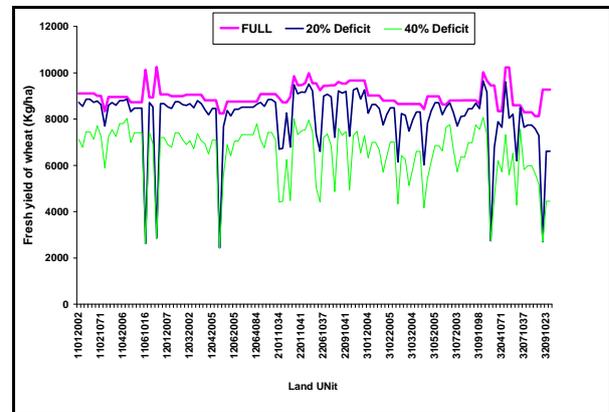


Figure 6- Average of grain yield of winter wheat with three different irrigation managements over 20 years (1985-2004)

2.2.5 Objectives of farmers and other stakeholders

Farmers are the owners of their land and water resources. They are the final decision makers in agricultural sector. They have some objectives and also some constraints. Objectives of the farmers may be varied among different farmers. Farmers are trying to optimize their objectives considering their constraints.

A list of objectives of different stakeholders has been prepared based on the literature (Sumpsi et al., 1996; Mohamed et al., 2000; Gomez-Limon and Riesgo, 2004; Laborde, 2006; Bartolini et al., 2007). These objectives have been used as a base for discussion with national, provincial and regional agricultural managers and experts. As the implementations of all the objectives need more time and investment, only the most important ones have been chosen for this study. Objectives of other stakeholders calculated as a post-calculation. Water productivity, total employment, total cultivated land and nitrogen loss will be calculated for each of the units (FTLU, FT, village, Dehestan (sub-district) and Shahrestan (district)) for assessment of the policy instrument using multi criteria evaluation technique.

2.2.6 Constraints

The following major constraints were considered:

Land constraint in FTLU level: Total land under different activities should not exceed the available land of the farm type per land unit.

Water constraint in FT level: Farmers have monthly and annual water constraints. Farmers which have well can save water in the months with low water demand. Maximum water extraction of each well has been limited by regional water organization. Total water used for the agricultural activities per farm type in the village should not exceed 1.2 times of the total water of farm type per month. We have let 20% water mobility

between farm types. The same constraint is also considered annually.

Water constraint in village level: All the available water in the village will be used in that village (no water mobility between villages). Monthly and annual water constraint has been considered at the village level.

Labour constraint in village level: Total labour requirement for agricultural activities should not exceed available labour per village and month. Available labour per village and month calculated by multiplying number of working days per month times number of workers in the village.

Tractor constraint in Dehestan level: In this model it is assumed that the tractors can move in the sub-district, however it is not true in some cases especially in the borders of sub-districts. Total tractor hour required for agricultural activities should not exceed tractor availability in the sub-district per month.

Rotation constraint in rotation unit level: Each rotation unit is included several land units. Common rotations in each rotation unit has been given from previous studies (APERI, 1997) in the study area. For each rotation unit one or more rotations have been defined.

3. PRELIMINARY RESULTS

As the model is under development and it needs validation, it has been run only in one sub-district (Eastern Borkhar sub-district) which is located in the south eastern part of the district. Eight villages are located in this sub-district. Table 3 shows the amount of available water in each village per water resource. Water can be pumped 6000 hours from the wells, but water is available in the canal only for 6 month in the year (March – September).

| Village | Canal | Ground water | |
|-------------|-------|--------------|-------|
| | | Well | Qanat |
| Ali Abad | 177 | 421 | |
| Ali Abadchi | | 377 | |
| Donbai | | | 15 |
| Habib Abad | 212 | 500 | |
| Komshech | 276 | 700 | |
| Margh | | | 28 |
| Parvaneh | | 238 | |
| Shoorch | | | 6 |

Table 3 - Available water in each village from canal and groundwater (L/s)

Validation of the model has been done by comparison of total cultivated land and area under cultivation of winter crops and summer crops in the year 2002 with agricultural census data in that year (Figure 7). In this year only 30% of water in Borkhar canal allocated. Results of this model showed that Komshech which is a village in the neighbourhood of Habib Abad with more land and water resources, has more agriculture than Habib Abad, while it is vice versa based on agricultural census data. This is one of the subjects which should be verified by local experts.

Table 4 shows net income of each holder in each farm type and village. Farm-type 4 which has the lowest production efficiency

with 0.94 l/s water, showed non economic activity. Also this table shows that net income of farm-types 2, 3 and 5 are less than 4 million Rials per year (Approximately 300 Euro/year).

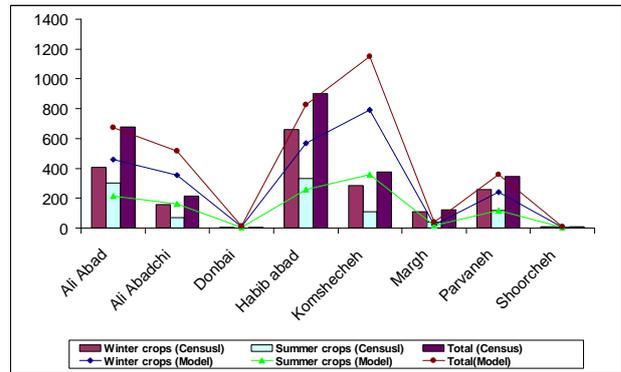


Figure 7- Simulated and reported cropped area (total, winter crops and summer crops)

Following indicators have been calculated after optimization, for evaluation of the current situation and also assessment of new policy instruments by policy makers. Some of these indicators which are calculated in different levels (FTLU, FT, village and Dehestan) are cultivated area under different crops, production of different commodities, production costs, net income, water productivity, nitrogen loss, direct labour used (employment), fertilizer requirement and etc. Water productivity of different farm-types per village based on the situations in year 2002 is presented in Figure 8.

| Village | FT2 | FT3 | FT4 | FT5 | FT6 | FT7 | FT8 |
|-------------|------|------|-----|------|--------|---------|--------|
| Ali Abad | 3659 | 3002 | | 3405 | 84166 | 404883 | |
| Ali Abadchi | | | | | 193002 | 1042915 | |
| Donbai | | | 168 | 1196 | | | |
| Habib Abad | | 2216 | | 1929 | 64135 | 330408 | 272320 |
| Komshech | 3360 | 2617 | | 2950 | 73642 | 375175 | |
| Margh | | 1215 | 3 | 2174 | 36663 | | |
| Parvaneh | | | | | 88792 | 507649 | 416694 |
| Shoorch | | | 89 | 502 | | | |

Table 4- Net income of each holder of each farm type per village (1000 Rials)

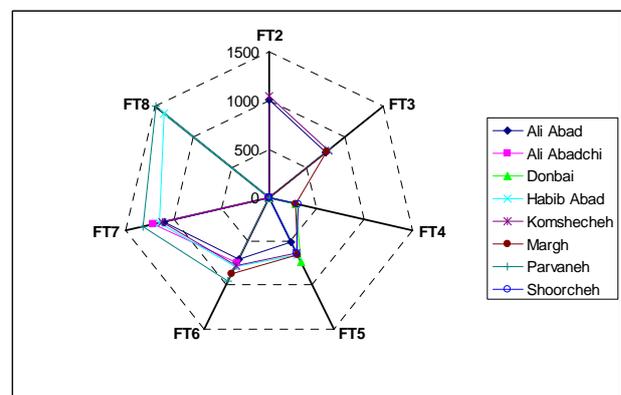


Figure 8- Water productivity of farm-types in each village (Rials.m⁻³)

Results of this analysis showed that water in months April, May, June and July are binding constraints. However, by allocation all the water from canal, tractor in months June and October also become binding constraint.

4. DISCUSSION

A model based plan formulation approach has been applied in this study to support policy formulation process. In the first step crop growth simulation model have been applied to explore the potential biophysical resources "resource analysis". In this process the potential capacity of each land unit has been assessed and combined with the socio-economic information of various farm-types. The combination of farm-type-land-units is then used as a smallest planning unit for modelling. Next the farm-type-land-unites are aggregated to form the village model, and villages are aggregated to create district model. In this context a distributed linear programming model is developed to simulate the reaction of the farmers with respect to various policy instruments. Such model is expected to the aggregation errors inherent to this type of models. It tries to make use of the biophysical potential of land as well as the behaviour of various farm-types.

Use of crop growth model for determination of the biophysical input/outputs of the model is one of the strengths of the proposed model. Crop yield and water requirement are very important for agricultural planning which has been determined spatially. Also, results of crop growth model showed variation of these parameters in different years. This is also useful for scenario analysis and also risk analysis. The farm-types are derived through farm classification which showed existence of several farm-types in each village.

Preliminary results of the model showed a reasonable match with the historical data. As there were quite different data sets with different values coming from different organizations, was quite difficult to choose the right type of data sets and as a result difficult to assess the quality of the model results.

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