INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES

ITC

MID-TERM REPORT

DEVELOPMENT OF CROP INVENTORY AND FORECASTING SYSTEM FOR THE MAJOR AGRICULTURAL COMMODITIES IN HAMADAN PROVINCE, ISLAMIC REPUBLIC OF IRAN

COOPERATION AND CONTRACT AGREEMENT
BETWEEN
THE AGRICULTURAL STATISTICS AND INFORMATION DEPARTMENT (ASID), MINISTRY OF AGRICULTURE, ISLAMIC REPUBLIC OF IRAN, TEHRAN
AND
THE INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES (ITC), ENSCHEDE, THE NETHERLANDS

(January 1997)

MID-TERM REPORT

(January 1997)

DEVELOPMENT OF CROP INVENTORY AND FORECASTING SYSTEM FOR THE MAJOR AGRICULTURAL COMMODITIES IN HAMADAN PROVINCE, ISLAMIC REPUBLIC OF IRAN

COOPERATION AND CONTRACT AGREEMENT

BETWEEN

THE AGRICULTURAL STATISTICS AND INFORMATION DEPARTMENT (ASID), MINISTRY OF AGRICULTURE, ISLAMIC REPUBLIC OF IRAN, TEHRAN

AND

THE INTERNATIONAL INSTITUTE FOR AEROSPACE SURVEY AND EARTH SCIENCES (ITC), ENSCHEDE, THE NETHERLANDS

M. A. Sharifi, Ph.D,
Prof. P.M. Driessen
Prof. H. Van Keulen
Ir. M.C. Bronsveld
Ir. M.B.W. Clavaux
Ir. J. Lenaars

TABLE OF CONTENT

1. SUMMARY

1.1 Objectives and Development Approach
1.2 Expected Products
1.3 Progress
1.4 Experienced problems

2. INTRODUCTION TO THE STUDY AREA

2.1 Hamadan Province
2.2 Selection of the pilot area

3. REVIEW AND ANALYSIS OF THE EXISTING METHOD

3.1 Current crop forecasting method in the Ministry of Agriculture Iran
3.2 Operational crop forecasting method using advanced technologies

4. DESIGN AND DEVELOPMENT OF CROP FORECASTING METHOD FOR THE PILOT AREA

4.1 Design and development of the crop inventory method
4.1.1 General description of the selected approach
4.1.2 Area Frame Sampling design
4.1.3 Stratification
4.1.4 Allocation of samples in each strata
4.1.5 Representations taken into the field
4.1.6 Remote sensing application
4.1.6.1 Identification of the required data and images
4.1.6.2 Pre-processing of images
4.1.6.3 Processing of images
4.1.6.4 Post processing of results
4.2 Design and development of the yield estimate method
4.2.1 The Concept
4.2.2 The Procedure (point analysis)
4.2.3 Implementation steps and corresponding information requirements for Yield estimate
4.2.4 Development/modification of the crop growth simulation model appropriate for the major crops in the study area
4.2.4.1 Objectives
4.2.4.2 Methods
4.2.4.3 Calibration of the simulation model
4.2.4.3.1 Analysis and preparation of available data for calibration purposes
4.2.4.3.2 Calibration exercises
4.2.4.3.2.1 Development/adaptation of the algorithm of PS123
4.2.4.3.2.2 Foreseen model adaptations for estimation of the yield potential at PS-3
4.2.4.3.2.3 Crop physiology parameters
4.2.4.3.3 Calibration results

4.2.4.4	Validation of the simulation model
4.2.4.4.1	Analysis and preparation of available data for validation purposes
4.2.4.4.2	Validation exercise
4.2.4.4.2.1	Adaptation of the simulation model; standardization of the timing of irrigation; Mana.exe
4.2.4.4.2.2	Adaptation of crop physiology parameters
4.2.4.4.3	Validation results
4.2.4.4.3.1	Verification at PS-2 with available experiment data
4.2.4.4.3.2	Generalisation
4.2.4.4.3.3	Validation results at PS-3
4.2.4.5	Conclusions on model calibration and -validation
4.2.5	Design of a conceptual data model for crop forecasting system
4.2.5.1	Main subsystems of Crop Forecasting System
4.2.5.2	Conceptual Data Model- Global Representation
4.2.5.3	Crop Area Estimation Subsystem
4.2.5.3.1	Detailed processes of Crop Area Estimation and Landcover Mapping
4.2.5.3.2	Conceptual Data Model of Subsystem 1 - Detailed Level Data Model
4.2.5.4	Yield Forecasting Subsystem
4.2.5.4.1	Detailed Process Model of Yield Forecasting
4.2.5.4.2	Conceptual Data Model of Subsystem 2
4.2.5.5	Crop production/Forecasting Subsystem
4.2.5.5.1	Detailed level Process Modelling
4.2.5.5.2	Conceptual data Model of Subsystem 3
4.2.5.6	Summary

5. IMPLEMENTATION OF THE CROP FORECASTING METHOD IN THE PILOT AREA

5.1	Implementation of crop inventory
5.1.1	Data collection during the field trip
5.1.2	Calculation of estimated crop areas (AFS)
5.1.2.1	Methodology
5.1.2.2	The Results
5.1.2.3	The variation found in the samples and those expected in the future
5.1.2.4	Comparison of calculated areas (AFS) with agricultural statistics
5.1.3	Number of fields in the segments
5.1.4	Distribution of crops
5.1.5	Analysis of stratification
5.1.6	Analysis of quality of data collection in the field
5.1.7	Alternative sampling methods
5.1.8	Classification of satellite imagery
5.1.8.1	Supervised classification
5.1.8.2	Knowledge based classification
5.1.9	Improvement of AFS with the classification result
5.2.2	Derivation of yield estimates of wheat and barley on various soil materials in the Razan township under defined management, using 10 years of weather data
5.2.2.1	Methods
5.2.2	Results

5.2.2.1 Results at PS-2
5.2.2 Results at PS-3
5.2.2.4 Conclusions
5.2.3 Implementation and evaluation of the yield estimate method
5.2.4 Overall conclusions

6. TRAINING AND DOCUMENTATION

6.1 Training activities
6.2 Documentation

7. PROJECT TIME TABLE AND WORKING PLAN

7.1 Project initation phase March 1995 (March 1996)
7.2 Design of a prototype crop forecasting method for the pilot area (March - May 1996)
7.3 Training of the Iranian counterparts
7.4 Design of a crop forecasting method for the entire province at ITC (January - April 1997)
7.5 Implementation of the crop forecasting method at the province level
7.6 Evaluation of the results (ITC, Iran) (September 1997)

1. INTRODUCTION

Reliable estimates of areas allocated to certain crops and of (anticipated) crop production are needed for proper planning, monitoring and improving the development process and policy decisions. Reliable and timely estimation of agricultural production can improve, import/export policy, allocation policy for various resources and inputs, such as seed, fertiliser, pesticides, fuel, storage, etc. Information on changes of land cover or land use is of particular importance when such a changes may lead to the progressive degradation of the land on the long run.

Derivation of land cover/use and production estimate of different agricultural commodities through the classical methods and techniques are costly, time consuming (causing generation of overdue information), and subject to variety of error of different types and sources. Among all classical methods, objective measurement of area and yield on the ground is the only one which is considered to provide reliable information. This is especially true in the places where farmers either are not able or for some reasons do not provide the reliable information. This method is time-consuming, and require well trained enumerators, adequate equipment; and therefore the most expensive of all.

Recent developments in aerospace survey technology, digital image processing, modelling of crop production process, and geographic information systems have created promising opportunities for upgrading the agriculture statistical systems. The technology in the related disciplines is well developed, many experimental project have demonstrated the efficiency and effectiveness of crop inventory programs that are based on the application of remotely sensed data. For yield assessment, several agro-ecological models have been developed and proved their potential in simulating the behaviour of various agricultural production systems. Geographic information systems which have emerged as a results of development in information technology, remote sensing, photogrammetry, graphics and many other related disciplines, have created a great potential to bring various forms of information from many different sources together and relate them through a common spatial basis.

All these techniques are available and have worked well, when applied individually in many pilot and some operational projects. In a few crop inventory and crop monitoring programs considerable efforts have been put on integrating all these elements as a system. In the framework of the agreement between the Agricultural Statistics and Information Department (ASID), Ministry of Agriculture, Islamic Republic of Iran, and the International Institute for Aerospace Survey and Earth Sciences (ITC), the related methods and techniques will be utilised to design and develop a proper method which can generate timely and reliable information on the acreage and production of the major agricultural commodity in the selected province (Hamadan). Such method could be later upgraded to cover the entire national territory.

The agreement covering this contract has been signed by ITC and ASID on January 1995, and the project activities has started from March 1995 and should be completed by December 1997.

This report summarises the results of activities that have been carried out during March 1995 to January 1997.

1.1 Objectives And Development Approach

The final goal of this project is to develop an integrated method and procedure that can be used by ASID to derive reliable, cost-effective, timely, and repeatable information on agricultural production of the major commodities at regional level prior to the harvesting date. This method will be first developed for a selected province and hopefully at the later stage will be upgraded to cover other provinces and finally the entire Iranian territory. Therefore, the objective of this project is to develop a crop forecasting methodology for major agricultural commodities in Hamadan province which has been selected as the study area. Wheat and barley which cover over 80% of the area are considered as the major agricultural commodities in the region. Since potato is strategically a very important crop it has been included in the project as well. This mainly includes the following main activities:

1 - ***Development of crop inventory method and procedures:*** To distinguish, identify, measure and map the area of crops of significant importance in the study area (crop inventory).

2 - ***Development of Yield forecasting method:*** To derive a reliable estimate of yields (production per hectare) of the major agricultural commodities that are growing in the study area.

3 - ***Development of crop forecasting method:*** To derive a reliable estimate on the production of major agricultural commodities prior to the harvesting date of each crop.

4 - ***Development of a conceptual model for the crop forecasting system:*** To integrate all the required processes and their respective thematic and spatial data in an operational method.

In the course of phase 1 and 2, the relevant methodologies and procedures for crop inventory and crop yield will be developed and evaluated. In the third phase, the results of area estimate and yield estimates are combined to derive production estimates. In the fourth phase all the developed procedures and models will be conceptually integrated in to a crop forecasting system. As it is mentioned in the contract, derivation of a reliable and timely and cost-effective estimates on crop area and their related productions does not concern a simple transfer of an established operational method or techniques especially for yield forecasting portion. Such methods and techniques are still at experimental stage and includes a number of research questions which will be addressed in the course of the project. On this basis in the development process it has been tried to select and apply operational methods based on the existing developments in the related fields, and for further development, in parallel the application of some experimental approaches which have proved to be promising has also been examined.

Development of a crop forecasting system for a large area such as this is certainly a complex process which includes development, calibration, validation and experimentation with a number of models of different principles. Basically, development of these models involves extensive development, realization and experimentation activities which need to be concentrated on a smaller area. Therefore, the following approach was taken for development of the method:

- Develop an operational crop forecasting method based on existing technology
- Apply it in a pilot area
- Evaluate and modify the original method
- Apply it at the provincial level
- Evaluate, modify and document the final method

1.2 Expected Products

In the framework of the contract agreement and as a results of study the following products will be produced and delivered:

- Distinct method/procedure for crop inventory and crop forecasting using satellite data and agro-ecological modelling for the major agricultural commodities.
- Development of a conceptual information model to integrate the crop inventory and yield forecasting method and derive production estimate on major agricultural commodities.
- Implementation of the method at provincial level and produce an estimate of the major agricultural commodities in Hamadan province (provided the relevant data and the required facilities are made available)
- Plan for the extension and implementation of the developed crop forecasting method at the national level. This shall include recommendation for development of the required infrastructure to support crop forecasting method at the national level.

1.3 Progress

In spite of many administration and technical problems which will be briefly mentioned later, the project has made considerable progress towards its objectives which can be summarised as follows:

- **Development of proper crop forecasting concepts:**
  During the period of March 1995 to February 1996 in which the project team could not travel to Iran (due to some administration problems)and collect the required data, the activities of the project continued based on some minimal scattered information gathered by the project team. Fortunately there were 2 Landsat coverage's of the study area were available in house. Those were used to develop the conceptual approach to crop forecasting and familiarisation and initial experimentation with the data-sets of the project area. The results of the initial experimentation is reflected in the first progress report (Sharifi, et. al., 1995).

- **Creation of a project set-up in Iran:**
  To create a project set-up and initiate implementation, the Project Initiation Trip as was foreseen in the contract agreement was carried out during February 1996, with the following objectives:
  - Study of the current situation of crop forecasting and crop inventory
  - Preliminary study of existing data and their corresponding sources

- Assessment of the selected approach
- Selection of a pilot area
- Initiation of the required local set-up to carry out the project
- Finalisation of the work plan

The finding of this trip is reflected in the PIT report (Sharifi and Driessen, 1996).

- **Design and development of crop forecasting method for the pilot area.** The results of this activity is summarised in Section 4 of this report.

- **Data collection and field work**:
  The field work was carried out during May June 1996 with the following main objectives:
  - Data collection and training related to the crop inventory sub-system, including:
    - Training of the field crews on data collection for area frame sampling
    - Data collection for area frame sampling and satellite data processing
    - Evaluation and upgrading of ASID's remote sensing capabilities on processing of remote sensing data for land cover mapping
  - Data collection for yield forecasting sub-system, including:
    - Discussion on the preliminary results of the crop growth simulation model
    - Data collection for development of yield forecasting system
    - Identification of the data requirements of the yield forecasting sub-system
    - Making the necessary provisions for collection of the required data
  - Creation of the required local set-up to start management and organisation of the data which is used in the frame work of the crop forecasting system. This includes:
    - Data analysis and overall design of the required information system
    - Detail design and development of all the required sub-systems
    - Realisation and implementation of the information system

  The finding of this trip is reflected in the field work report (Sharifi, et.al, 1996).

- **Implementation and evaluation of the crop forecasting method in the pilot area**:
  Based on the information collected during the field work and its follow-up activities a simplified version of the method is implemented and its procedure evaluated. In the course of evaluation some comparisons are made between the results of experimentation and the relevant estimates from the field. These comparisons are only made to check the order of the results not their absolute valuse and performances, as the data is not complete and the method not optimised for the pilot area.
  The implementation/evaluation included the following main activities:
  - Implementation of the crop inventory method
  - Implementation of the yield estimation method
  - Design of a conceptual data model for crop forecasting system

  The results of this activity is summarised in Section 5 of this report.

- **Training of Iranian Counterparts:**
  - Part of on the job training related to the crop inventory, yield estimation and remote sensing have been accomplished during the field work of summer 1996.
  - The long term professional training has started from September 1996.
  - Preparation for the short term training on three area of remote sensing, yield estimation and system development is made so that these training are carried out early 1997.

1.4 Experienced problems:

In the course of the project initiation and implementation the following main problems were experienced.

- **Administration and contractual problems including:**
  The agreement covering this contract was signed by ITC and ASID on January 1995. According to the contract the activities of the project should have started shortly after (2 weeks) Finalisation of the Contract agreement by carrying out the Project Initiation Trip "PIT". This was not possible because of some contractual, legal and administrative barrier which resulted delay in the advance payment till February 1996. The PIT only materialised on March 1995, mainly due to the persistence and ability of the project management team to solve the administration problems based on mutual trust and understanding. This delay caused financial problem for ITC, because the team which was mobilised for the project as of March 1995 could not effectively work on the project and could only carryout a preliminary study based on very scattered data from the project area.
- **Technical problems:** the crop forecasting method is designed in a way that makes use of very detailed information which are collected by different disciplines for other applications, it includes detailed daily weather data, soil data, crop management and historical data as well as the collection of data from a number of pre-specified fields and interpretation of satellite data. Although "ASID" staff proved to be very effective and active in data collection and support of the project activities, there were some problems which were out of their control and had some effect on the project. The main problems in this area were:
  - Unavailability of recent aerial photography, photomaps and maps of the project area for locating the sample segments. This was alleviated by using enlargement of Spot Pan images at various scale.
  - Unavailability of proper and timely Satellite data of the project area and pilot area. Originally multi-temporal Landsat TM data (2 coverage's at 2 dates) was foreseen to be used for image classification and derivation of land cover map of the pilot area. According to the plan the satellite data was supposed to be available right after the field work. In spite of all the effort which was put in timely acquisition of satellite data only one coverage of Spot-XS data could be made available on late November 1996. This created a serious delay in implementation and evaluation of crop inventory method.
  - Collection of crop phenological and crop management data of the pilot area is not yet completed. Only crop phenological information of irrigated wheat, and alfalfa and potato could be collected. For the rest mainly, rainfed wheat and barley and irrigated

barley very little useful information could be collected. This resulted in not being able to completely calibrate and validate the related crop growth simulation models.

- Collection of the required soil and weather data for the pilot area. Although very effective steps towards collection of these data have been taken, still the complete data set of the pilot area is not yet available.
- Design of crop forecasting method is based on the state of the arts technology, which naturally calls for more trained staff, unavailability of enough trained staff created delay in performing some of the tasks.

2. INTRODUCTION TO THE STUDY AREA

2.1 Hamadan Province

The study area will be the province of Hamadan, Islamic Republic of Iran. It is located in the western part of the country and covers 1,902,500 hectares, of which 561,000 ha. is agricultural land. The area consists of high (3500m.) mountains, hilly areas and plains. In the plains irrigated agriculture is predominant, though there are substantial salinised areas. In the hilly areas dry farming (mainly wheat and barley) is practised and also grassland and natural vegetation. The mountains are mainly covered by natural vegetation and grassland with (small) valleys where agriculture is practised (mostly irrigated). The major crops in the area are: wheat, barley, alfalfa, potato and beans (tables 2.1).

*table 2.1, Crop area data of Hamadan province, Iran (year*1994-1995

crop category	crop type	area in (ha)		
		irrigated	dry	total
cereals	wheat	98763	248984	347747
	barley	42483	27034	69517
	total	141246	276018	417264
pulses	total beans	9329	24833	34162
	potatoes	7790	-	7790
vegetables	onion	382	-	382
	tomato	1324	-	1324
	other	994	-	994
	Sub-total	10490	-	10490
melons	total	2329	3468	5797
forage	alfalfa	41484	1074	42558
	total	48081	5999	54080
other	crops	490	-	490
total	crops	217618	310371	527989
orchard	fruits	33747	-	33747
total		555088	310371	561736

According to the latest information from Provincial Plan and Budget Organisation (1995) the province contains 8 townships (Shahrestan) as follows:

-Hamadan Township with an area of	367,500 ha
-Razan Township with an area of	272,100 ha
-Bahar Township with an area of	132,900 ha
-Kaboudarahang Township with an area of	402,400 ha
-Asadabad Township with an area of	114,400 ha
-Malayer Township with an area of	320,800 ha
-Towiserkan Township with an area of	146,300 ha
-Nahavand Township with an area of	146,100 ha
Total area	1,902,500 ha

The administration map of the province is given on figure 2.1 and the available spot satellite data of the region is given in figure 2.2.

2.2 Selection of the pilot area

To develop, test and evaluate the proposed approach for crop inventory and crop forecasting, a suitable test area was to be selected in the province. After a preliminary study of the existing information and 3 days of visits to the region in the course of project initiation trip (Sharifi and Driessen 1996), the Hamadan, Bahar, Kabodaruhang, and Razan sub-districts (Shahrestans) seemed to be suitable, provided that satellite data of the area could be obtained. The locations of the test areas can be seen on the administration map. The total area of each township "Shahrestan" is given in the following table.

-Hamadan sub-district367,500 ha
-Bahar subdistrict132,900 ha
-Kabodarahang sub-district402,400 ha
-Razan sub-district272,100 ha
==
Total1,174,900 ha

These four Shahrestans are located in four main plains viz. Dashte Bahar-Hamadan covering an area of 930 square kilometres, Dashte Kaboudrahang covering an area of 570 square kilometers, Dashte Razan covering an area of 1500 square kilometres, and Dashte Ghahavand covering an area of 500 square kilometres. All together cover an area of about 4000 Km^2.

In the course of field work it was realised that satellite data for the selected pilot area can not be provided and therefore the size was reduced to the area of Razan township of which satellite data could be obtained. According to the general information given by the related authority in the Iranian

Ministry of Agriculture (Sharifi, et. al. 1996) Razan township covers an area of 267, 400 ha, with total population of about 140, 372. The township includes 3 "Bakhsh" with 7 "Dehestan" (figure 2.3). The main agricultural commodities are: wheat, barley, beans and alfalfa. With the following acreage's:

-Wheat (Irrigated) 20,000 ha (out of which 12000 ha are under the government support)

-Wheat (rainfed) 30,000 ha (out of which 20,000 ha are under the government support)

-Barley (irrigated) 8700 ha

-Alfalfa 6400 ha

-Potatoes 400 ha

-Maize 100 ha

Figure 2.1. The fieldwork area within Hamadan province.

Crop	cultivation	harvesting
wheat	½ Sept. - ¾ Dec.	¼ July - ½ Sept.
barley	½ Sept. - end Nov.	begin July - end Aug.
alfalfa	¾ April - ¾ Sept.	begin June - ½ Sept.
potato	begin April - end June	begin Sept. - end Nov.
beans	½ march - end June	½ June - end Oct.

Table 2.2 General crop calendar of the major crops in the province

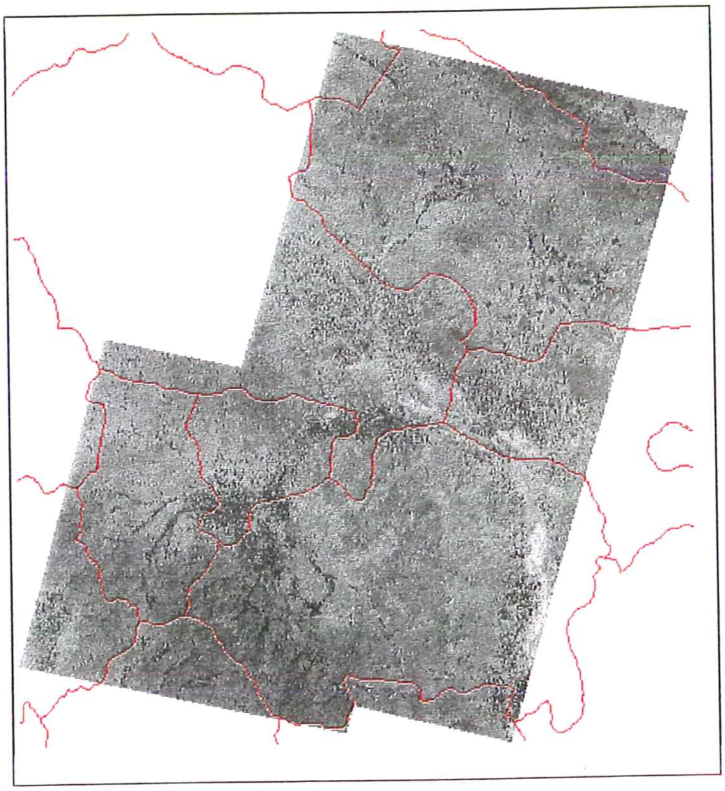


Figure 2.2, Available SPOT-PAN coverage.

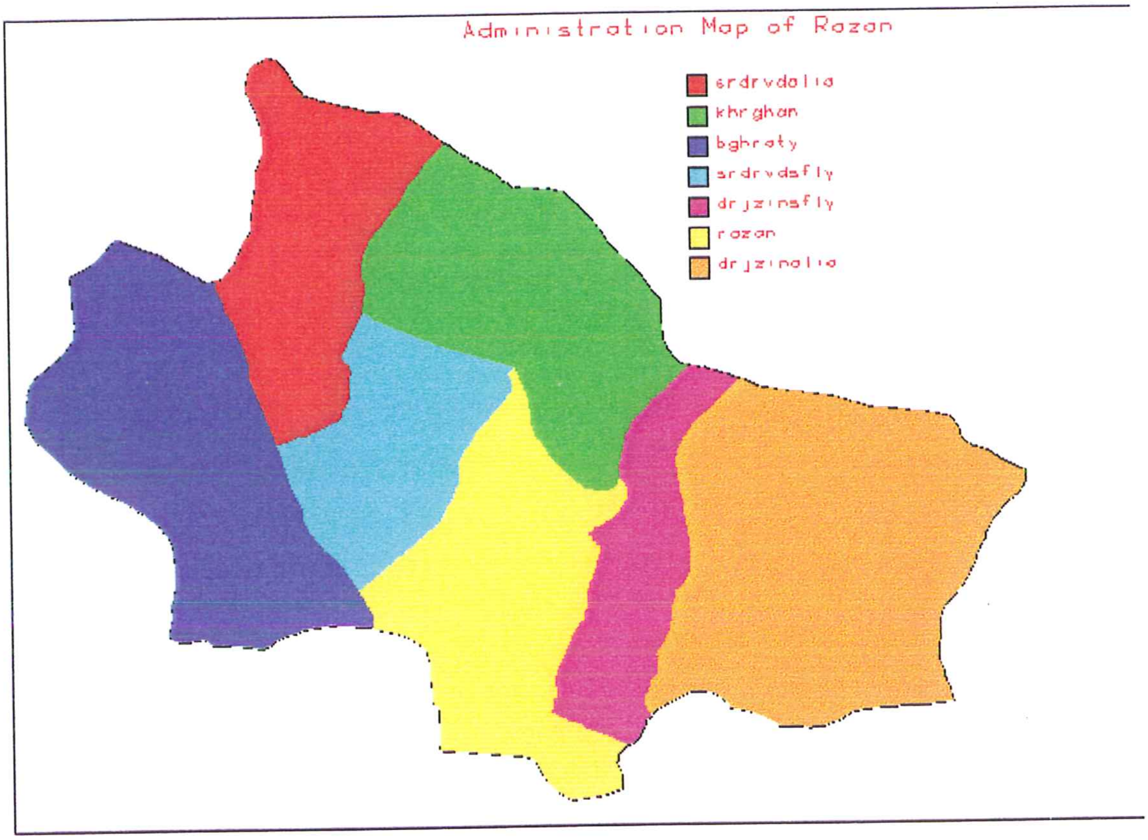


Figure 2.3 Administration map of the pilot area

During the 1994-1995 growing period the yield of irrigated wheat has been between 3200 - 5000 kg/ha, the same figure for rainfed has been between 1800-3800 kg/ha, and irrigated barley has yielded between 3000 - 4000 kg ha.

3. REVIEW AND ANALYSIS OF THE EXISTING METHOD

3.1 Current crop forecasting method in the Ministry of Agriculture Iran[1]

Ministry of agriculture obtains it's primary data on crop areas and yields through three major activities;

a- Production forecasts
b- Agriculture data assessments
c- Crop monitoring and direct measurements

[1] This part has been prepared by A. Denghan

Every year through the above activities Ministry forecasts crops and fruit production levels early spring. Later, on fall the actual production levels are assessed and if more accurate data is needed direct measurements and remote sensing techniques are applied.

Production Forecasts

By mid spring the Ministry reports it's forecasts on production levels for decisions to be taken on food-balance ,import-export policies , guarantined price polices and etc. .

The forecasting is done mainly through time Seri analysis and expert's observations through out the country at provincial level . Observational reports on areas planted, weather reports and input distribution reports are main sources of information on these forecasts.There is no standard procedure and guideline for provincial Agricultural Departments to carry out this task. Each province reaches to a conclusion upon it's experts and managerial perceptions.

By the end of march, all the provinces send their reports to the event organization or deputy in the Ministry of Agriculture in Tehran for deriving the final national results. All the provincial forecasts are then aggregeted in collaboration of the relevant experts to derive the national figures.

Since there is no coherent procedure written and implemented for deriving this forecast, the figures reflects more compromise rather than reality, therefore the figures are not reliable and usually are highly misleading. There is no specific budget allocated for this forecasting and it does not involve any kind of formal data acquisition: this process takes between two to three month each year.

Agriculture Data Assessment

Detail agricultural statistics are produced through sampling surveys every year after harvest in fall . Four data collection projects are carried out all through the country in this respect . Each project has its information system with well defined procedures and manuals.

Three projects are designed to assess productions and the fourth one for detail farming system data.These projects are:

1-Wheat and barley sampling project called " Khosheh " system.

2-Rice sampling project called "Zeraat "system.

3-Other crops sampling project called" Tarheh Jarieh Amar "system.

4-Details farming system sampling project called "Cost of Production" System.

Enumerators are given special training every year to fill questionnaires at farmers level using formal producers. All the projects start almost in mid September and priority is given to the project number one to assess the strategic wheat and barley figures as early as possible in January.

Each year samples are selected from census frame of 1993 national agricultural census. Survey is based on two level classification and random sampling method .

In crop year 1995-94 for three first production assessment projects, approximately 80000 questionnaires were filled in 7000 villages through out the country , and data was optimized and generated at township (shahrestan) level in 28 provinces and regions.

Final results are reached in seven month time , it takes one month for sample selection, four month for training and field work data collection , and two month for data processing.

For each sample village approximately 120'000 Rials were spent. The total work was done by approximately 28000 man / day of enumerators , drivers , editors and knowledge workers.

Crop monitoring and direct measurement

When ever there is special concern or disagreement on production or area data of a region or a plain, short term temporary data collection projects are designed and implemented.These kind of projects are usually very costly and require high expertise to be carried out .

The data generated through these specific projects are incorporated latter into official figures. Methodologically these projects could be categorized in three groups:

1_Remote sensing techniques . Crop-hectarage assessment using Land_sat TM and Spot images.For each TM and spot image scene it takes 4-5 month to be processed, after the receiving of the images. Hardware software and expertise needed is very expensive.

2-Large scale mapping to measure exact areas of some crops. In these cases, sample farms are mapped using aerial photos and teodoliets and etc. The results of this method is very accurate ,but it is expensive and not timely.

3-Weighting the production. To get more precise figures on yield, production of some sample areas of sample farms are weighted .The results of this method is very accurate , but it is expensive and not timely.

3.2 Operational crop forecasting method using advanced technologies

One of the very significant and recent efforts in applying remote sensing at large and operational scale for monitoring agriculture and developing methods to improve agricultural statistics has been the "MARS" (Monitoring Agriculture with Remote Sensing) project. MARS is a 10 year research and development program initiated by E.C's Directorate General for Agriculture and European Statistical Office (EROSTAT) and established based on the decision of the 26th September 1998 of the Councils of the Ministers of the E.U to apply remote sensing to agricultural statistics in European Community.

The first phase of the Project which was carried out during 1988-1993, concentrated mainly on the quantitative estimation of the acrages occupied by the various crops in a given region or country, vegetation and crop state monitoring, timely yield forecasting of mean crop yield per country, and the rapid and timely estimation of the E.C.'s total production of the most important crops. During the first 5 years, the various activities of the project were conceived, developed and implemented on the basis of inputs from approximately 100 institutions from 17 European Countries (Meyer-Roux & Vossen, 1993). As a result of the first phase, the methodology developed for regional crop inventories and rapid estimates of acreages and potential yields became operational and were being transferred to the member states.

The main objectives of the regional inventory was to meet the need for accurate and objective annual information on acreage at regional level covering the main crops. the method established was based on establishing close link between satellite data and observed ground data. Development and evaluation focused on the so-called regression estimator method which includes the following main steps:

- Stratification of the area on the basis of satellite data and existing maps
- Design of an area frame sampling (segments of 25 - 100 ha)
- Survey on the ground on the basis of aerial photographs

- Simultanous acquisition of full coverage of the region by Spot and Land_sat TM
- Automatic classification of the satellite data in order to improve the estimate generated through Area Frame sampling
- Analysis of results

Results of the study proved that stratification is very economical and it reduced the cost of the ground survey by factor of two for the same precision. Satellite data proved to be an ideal means of detecting homogenous area of land use and physical boundaries. The results of area frame sampling was promising and considered operational and was transferred to central and eastern European countries. The regression estimator was applied in all regions. Although the method works well but it was subjected to technical and financial problems regarding the acquisition of the timely images and their timely processing proved to be difficult.

The methodology used for yield estimate was based on deterministic agrometerological models for predicting annual crop yield. Such models are based on the basic understanding of crop behavior under various climatic, soil and management conditions. On this basis a Crop Growth Monitoring System "CGMS" was developed and tested. As of mid-1994 this system including all its relevant statistical modules are completed and is operational for all major annual crops. The results are published in the monthly MARS Bulletin, which is provided to the EU Directorate General of Agriculture and to EUROSTAT within 10 days after data acquisition.

The principal objective of the rapid estimation of acreage and potential yield was to provide early information at community level on changes in crop acreage each year with respect to previous year, as well as indicators of potential yields. The method which was developed for this action is based on defining limited sample representative sites (53 sites of 40 x 40 km for the European Community), obtaining and interpreting high resolution satellite images (3 to 4 coverages per year) to extract the required information. The interpretation is based on computer assisted photointerpretation supplemented by ground observation. In each site ground survey of 16 segments of 50 ha each is carried out annually and is used to support the photointerpretation. In each site 30 randomly selected segments are interpreted by specialized photinterpreters (including the 16 ground surveyed segments), then the whole site is classified using automatic classification. Based on this information the variation of the area and yields of different crops in year n/n-1 is calculated and applied to the statistics of year n-1 to derive the estimate for year n.

The full scale operational application of the method started in 1992; the deadlines for obtaining the images were kept down to about 4-5 days and 3 -4 days for analysis. All data acquired are incorporated into an information bulletin which is send to EU's Directorate General for Agriculture within 10 days after image acquisition. A detailed analysis of the results of this action has demonstrated a good agreement between the forecasts and the final official figures of the crops that are not localized.

4. DESIGN AND DEVELOPMENT OF CROP FORECASTING METHOD FOR THE PILOT AREA

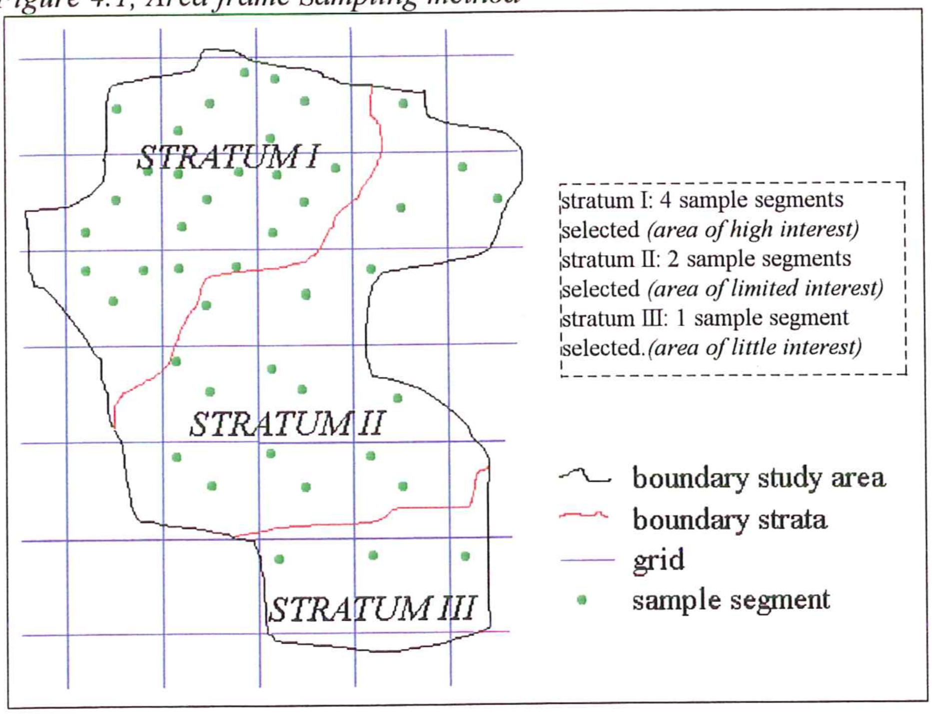
4.1 Design and development of the crop inventory method

4.1.1 General description of the selected approach

The full description of the selected method of Area Frame Sampling, modified aligned sampling (figure 4.1.3), is given in progress report I (Sharifi et al, 1995). A short overview is given in this paragraph. The method entails three stages:

1. design of a grid network
2. stratification of the region
3. identification of sampling segments

Figure 4.1, Area frame Sampling method



1. A grid is created to distribute the randomly chosen segments more evenly in the study area to increase the performance of the method (Cochran 1963).
Each grid cell consists of a certain amount of segments of which some are randomly selected for sampling. Within each grid cell in the study area the same segments are selected (random selection of segments done for one cell only and the selected segments are transferred to all other cells).

2. The second stage includes a stratification. The purpose of a stratification is to divide an area into sub-parts in which the distribution of the research object(s) is/are as homogenous as possible. In this project the research objects are the major crops in the area. Thus the stratification used must reflect the distribution of crop types and will include strata like: irrigated area, dry-land farming and high mountains. Each of the strata defined will have a different importance concerning the research object(s) and thus will be assigned different sample rates.

3. In each strata a number of small blocks called "segment" are identified. Within the segments selected for sampling, the fields will be measured, drawn on overlays and the crop types identified.

Steps for design & development of area frame sampling is given in appendix 1 and the fieldwork guide is given in appendix 2 of the report.

4.1.2 Area Frame Sampling design

As described in paragraph 4.1.1.2 of progress report I, the most practical method of locating the sample segments is to locate the maximum number of segments (maximum sample rate) needed in any of the strata. Later, those segments are discarded that are not needed due to the different (lower) sample rates per stratum. In this report these segments will be called the '*possible sample segments*'.

The calculation of the location of these possible sample segments is done in two steps: firstly, the selection of the segments within one grid cell and secondly the calculation of the actual position (co-ordinates) of these segments.

As possible sample segments, 6 were chosen randomly out of the 256 segments available within each grid cell. For random selection the random generator of Exell was used. A constrained was introduced to increase the geographical 'spread' of the sample segments. This consisted of a simple distance rule: distance > 25. The result is given in figure 4.2. Each of the possible segments within any grid cell has a certain fixed number from 1 to 6 (in the order of being selected), this is called the *segment code*.

The co-ordinates of these possible sample segments were calculated by spreadsheet. The starting point of the grid was: 365000 (x), 3690000 (y) within a UTM grid. With the position of the selected possible sample segments known it is quite easy to calculate the co-ordinates of all the possible segments (figure 4.3). It should be noted that the co-ordinates of the starting point of the grid is in the upper right corner of the province. This is done because a UTM zone cuts through the western part of the province. For ease of calculation, because only a small part of the province is party of a different UTM zone, The co-ordinates of the most western segments are fake. They are calculated like there were within an extension of UTM zone 39.

Figure 4.2, The location of the possible sample segments within each grid cell

edges of grid

256	*241*	*242*	*243*	*244*	*245*	*246*	*247*	*248*	*249*	*250*	*251*	*252*	*253*	*254*	*255*	*256*	*241*
16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	*1*
32	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	*17*
48	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	*33*
64	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	*49*
80	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	*65*
96	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	*81*
112	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	*97*
128	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	*113*
144	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	*129*
160	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	*145*
176	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	*161*
192	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	*177*
208	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	*193*
224	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	*209*
240	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	*225*
256	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	*241*
16	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*1*

16 km.

16 km.

number of segment within grid cell	*segment code*
28	*1*
105	*2*
215	*3*
190	*4*
3	*5*
128	*6*

Figure 4.3. the calculation of the co-ordinates of the possible sample segments.

random-	selected					segment	segment	segments (upper right)			(ilwis coordinates for	
numbers	(with dist)		UTM:	X	Y	number	code	A(X)	A(Y)		X	Y
28	*		start grid	365000	3960000	1	1	361000	3959000		360500	3958500
53			(upp.right)	349000	3944000	2	2	358000	3954000		357500	3953500
105	*			333000	3928000	3	3	356000	3947000		355500	3946500
113				317000	3912000	4	4	363000	3949000		362500	3948500
215	*			301000	3896000	5	5	352000	3960000		351500	3959500
190				285000	3880000	6	6	365000	3953000		364500	3952500
190	*			269000	3864000	7	1	361000	3943000		360500	3942500
216				253000	3848000	8	2	358000	3938000		357500	3937500
3	*			237000	3832000	9	3	356000	3931000		355500	3930500
92				221000	3816000	10	4	363000	3933000		362500	3932500
128	*			205000	3800000	11	5	352000	3944000		351500	3943500
					3784000	12	6	365000	3937000		364500	3936500
note:					3768000	13	1	361000	3927000		360500	3926500
dist>25					3752000	14	2	358000	3922000		357500	3921500
						15	3	356000	3915000		355500	3914500
(y)	seg.size	X	Y			16	4	363000	3917000		362500	3916500
1	1000	4000	1000			17	5	352000	3928000		351500	3927500
6	1000	7000	6000			18	6	365000	3921000		364500	3920500
13	1000	9000	13000			19	1	361000	3911000		360500	3910500
11	1000	2000	11000			20	2	358000	3906000		357500	3905500
0	1000	13000	0			21	3	356000	3899000		355500	3898500
7	1000	0	7000			22	4	363000	3901000		362500	3900500
						23	5	352000	3912000		351500	3911500
		number of pixels in segment				24	6	365000	3905000		364500	3904500
30	meter	33.33333				25	1	361000	3895000		360500	3894500
50	meter	20				26	2	358000	3890000		357500	3889500
						27	3	356000	3883000		355500	3882500
						28	4	363000	3885000		362500	3884500
						29	5	352000	3896000		351500	3895500
						30	6	365000	3889000		364500	3888500
						31	1	361000	3879000		360500	3878500
						32	2	358000	3874000		357500	3873500
						33	3	356000	3867000		355500	3866500
						34	4	363000	3869000		362500	3868500
						35	5	352000	3880000		351500	3879500
						36	6	365000	3873000		364500	3872500
						37	1	361000	3863000		360500	3862500

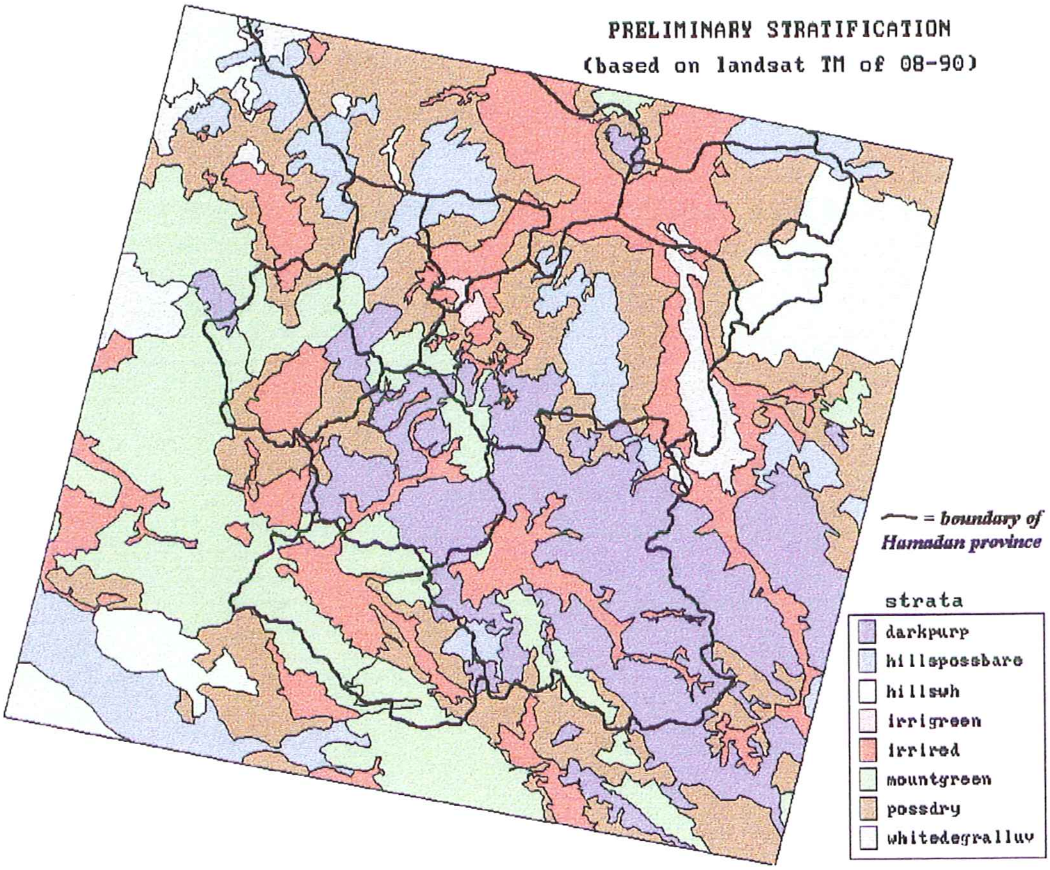
In the complete table the total number of records is 924

For calculation in ILWIS (GIS) it proved to be easier to use the center of the segments thus these were calculated as well.

4.1.3 Stratification

To create a stratification of the province according to importance for agriculture a visual interpretation of a Landsat TM image was performed. The image used date from 30-8-90 but it was reasonable to assume that major agricultural patterns to remain constant over a period like that. The area was divided into 8 strata (figure 4.4). Some cover types were difficult to trace but a workable interpretation can be created without major field work. After the first sampling enough data will be available to modify the stratification to suit the needs of operational data collection.

Figure 4.4. preliminary stratification based on visual interpretation of Landsat TM

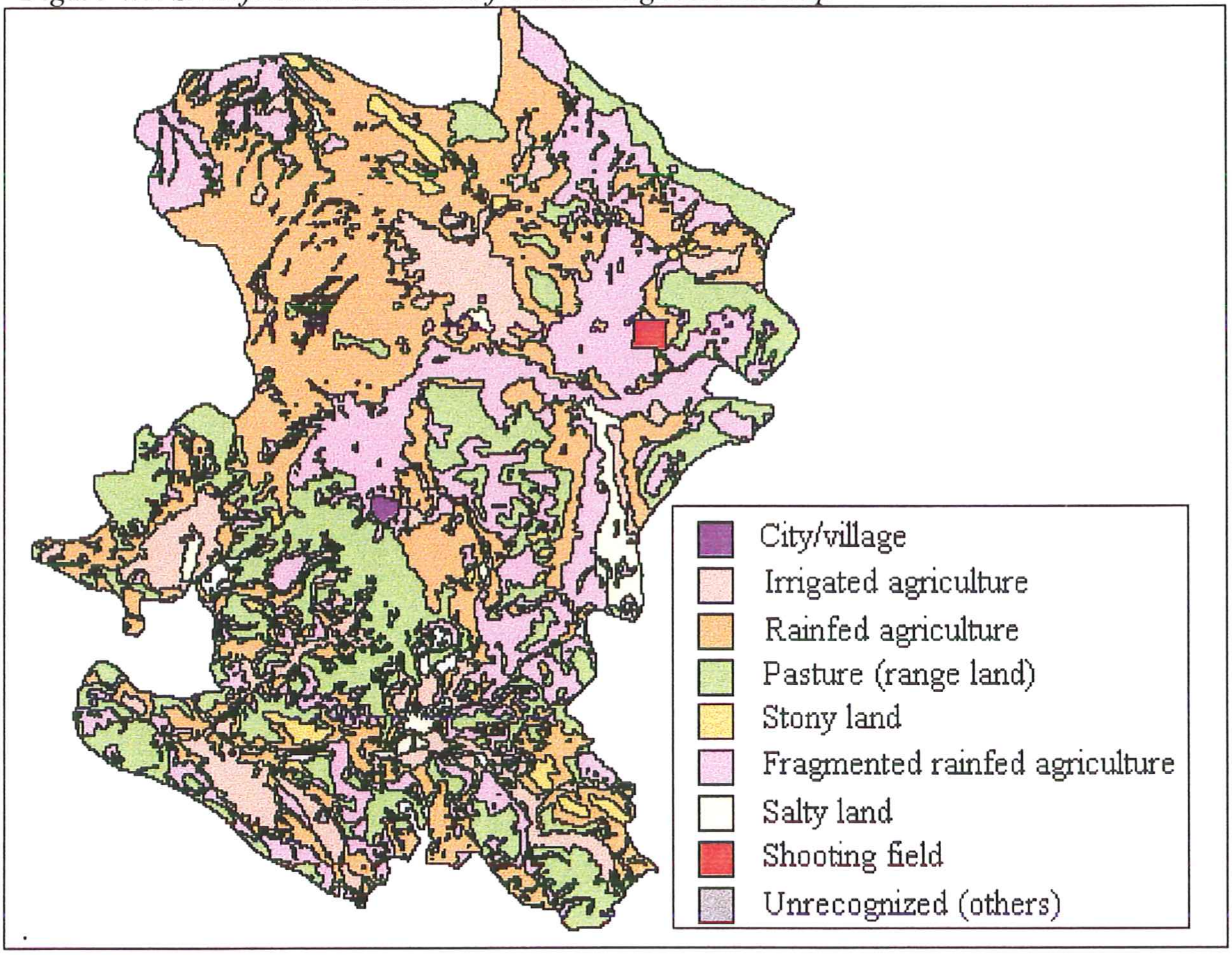


darkpurp	= hill/mountains, no field pattern
hillspossbare	= hills, no field pattern
hillswh	= dissected hills, no field pattern
irrigreen	= irrigated small fields (potato/tomato)
irrired	= irrigated fields (wheat/barley/alfalfa)
mountgreen	= high mountains, little cover
possdry	= some field patterns, high probability of dryland agriculture
whitedegralluv	= degraded irrigation & young alluvial soils

Just before the field trip an existing land use map became available (created by a consultant firm in Iran). It was decided to use this map instead of the visual classification as a basis for stratification because a land use map incorporates all knowledge needed for a useful stratification. A second advantage in this case was that the TM image did not cover the northern part of the province and the land use map did. The Land use map showed much more detail than could be accomplished by visual classification at this stage, which is to be expected because of the amount of effort and (field work) data.

It was decided not to group any of the land use classes into one stratum because at this stage of the project the gathering of knowledge was deemed more important. It is very useful to know what the landuse classes exactly mean in the field. Combinations of preliminary strata into new strata can always be made at a later stage while subdivision is much harder.
This method for stratification resulted thus in nine strata as displayed in figure 4.5.

Figure 4.5. Stratification as derived from existing land use map



4.1.4 Allocation of samples in each strata

Figure 4.6. Sample rates per stratum .

Segment -code

luse50	seg4code	Nix	Area	crusecod	avgseg(2)	smp.sen.1	smp.sen.2	smp.sen.3
0	1	29108	72770000	2	72.77			
0	2	25556	63890000	4	63.89			
0	3	21752	54380000	12	54.38			
0	4	20145	50362500	8	50.3625	(0 till 0)	(0 till 0)	(0 till 0)
0	5	22942	57355000	1	57.355	0.00	0.00	0.00
0	6	19047	47617500	6	47.6175	0	0	0
10	6	24	60000	35	0.06	(0)	(0)	(0)
20	1	5081	12702500	20	12.7025			
20	2	4512	11280000	22	11.28			
20	3	4804	12010000	28	12.01			
20	4	2637	6592500	26	6.5925	(1 till 4)	(1 till 3)	(1 till 4)
20	5	3890	9725000	29	9.725	42.59	35.99	42.59
20	6	5137	12842500	25	12.8425	1.660873	1.403757	1.660873
30	1	11885	29712500	3	29.7125			
30	2	9664	24160000	21	24.16			
30	3	9548	23870000	15	23.87			
30	4	10651	26627500	9	26.6275	(1 till 3)	(1 till 4)	(1 till 3)
30	5	10468	26170000	17	26.17	77.74	104.37	77.74
30	6	10246	25615000	7	25.615	1.131848	1.519516	1.131848
40	1	4137	10342500	32	10.3425			
40	2	8018	20045000	23	20.045			
40	3	6773	16932500	14	16.9325			
40	4	7563	18907500	11	18.9075	(1 till 1)	(0 till 0)	(1 till 1)
40	5	6406	16015000	18	16.015	10.34	0.00	10.34
40	6	5093	12732500	31	12.7325	0.246958	0	0.246958
50	2	492	1230000	38	1.23			
50	3	388	970000	46	0.97	(0 till 0)	(0 till 0)	(0 till 0)
50	4	646	1615000	27	1.615	0.00	0.00	0.00
50	5	271	677500	30	0.6775	0	0	0
60	1	6926	17315000	19	17.315			
60	2	7126	17815000	5	17.815			
60	3	8445	21112500	13	21.1125			
60	4	8460	21150000	10	21.15	(1 till 4)	(1 till 3)	(1 till 3)
60	5	6759	16897500	16	16.8975	77.39	56.24	56.24
60	6	8552	21380000	24	21.38	1.601411	1.163774	1.163774
70	1	63	157500	41	0.1575			
70	2	1399	3497500	42	3.4975			
70	3	1043	2607500	40	2.6075			
70	4	214	535000	45	0.535	(0 till 0)	(0 till 0)	(1 till 4)
70	5	963	2407500	37	2.4075	0.00	0.00	6.26
70	6	597	1492500	36	1.4925	0	0	1.670691
80	6	400	1000000	33	1	(0)	(0)	(0)
100	2	433	1082500	44	1.0825			
100	3	47	117500	47	0.1175			
100	4	324	810000	34	0.81	(1till4)	(0 till 0)	(1till4)
100	5	301	752500	43	0.7525	2.01	0.00	2.01
100	6	104	260000	39	0.26	2.741127	0	2.741127
			451225000		451.225			
	area province (km2):				sum, withou	(tot sampl(	(tot sampl(	(tot sampl(
	(derived from progress report I)					210.07	196.61	195.19
	19445					(tot rate)	(tot rate)	(tot rate)
	area strata (Npix=50*50m.)					1.080342	1.011083	1.00378
	(derived from hsb (luse50))							
	stratum	npix						
	0	5771390						
	10	15463						
	20	1025605						
	30	2747454						
	40	1675187						
	50	129142						
	60	1933108						
	70	149938						
	80	17858						
	100	29331						

which segment codes within a stratum are used.

absolute number of segments selected within a stratum.

sample rate within a stratum (not the overall sample rate)

The columns Nix, Area and Crusecod are used to calculate the sample rates only.

luse50 = strata:
10: city\village
20: irrigated agriculture
30: rainfed agriculture
40: pasture
50: stony land
60: fragmented rainfed agriculture
70: salty land
80 shooting field
100: unrecognized

The sample rates for each stratum as derived from figure 4.6 are given in table 4.1.

Table 4.1. the sample rates per stratum as used for the fieldwork in the Razan area.

STRATUM	SAMPLE RATE
- (10) City/village:	0.00 %
- (20) Irrigated agriculture:	1.66 %
- (30) Rainfed agriculture:	1.13 %
- (40) Pasture/range land:	0.25 %
- (50) Stony land:	0.00 %
- (60) Fragmented rainfed agriculture:	1.16 %
- (70) Salty land:	1.67 %
- (80) Shooting field:	0.00 %
- (100) Unrecognised:	2.74 %

For this introductionary fieldwork the sample rates were chosen quite conservatively. Even strata of limited interest for crop area estimation were included. This was done for two reasons: the first was that information is needed for classifying satellite images and thus all cover types had to be sampled. The second reason was that the quality of the stratification needed to be tested.

Some of the strata (salty land & unrecognised) have a very high sampling rate. These rates were chosen because these strata cover a relatively small area, though interesting for image classification and testing of stratification. To have a small number of sample segments within these strata high rates are needed. Only six segments were in fact selected to be sampled within the stratum of 'salty land' and 2 in 'unrecognised'.

The actual location of the sample segments within Razan (the fieldwork area) is given in table 4.2, with the co-ordinates and the unique identification numbers. Figure 4.7 gives a spatial representation of the segments (from table 4.2) with the stratification as background and figure 4.1.10 gives the same segments with a colour composite as background.

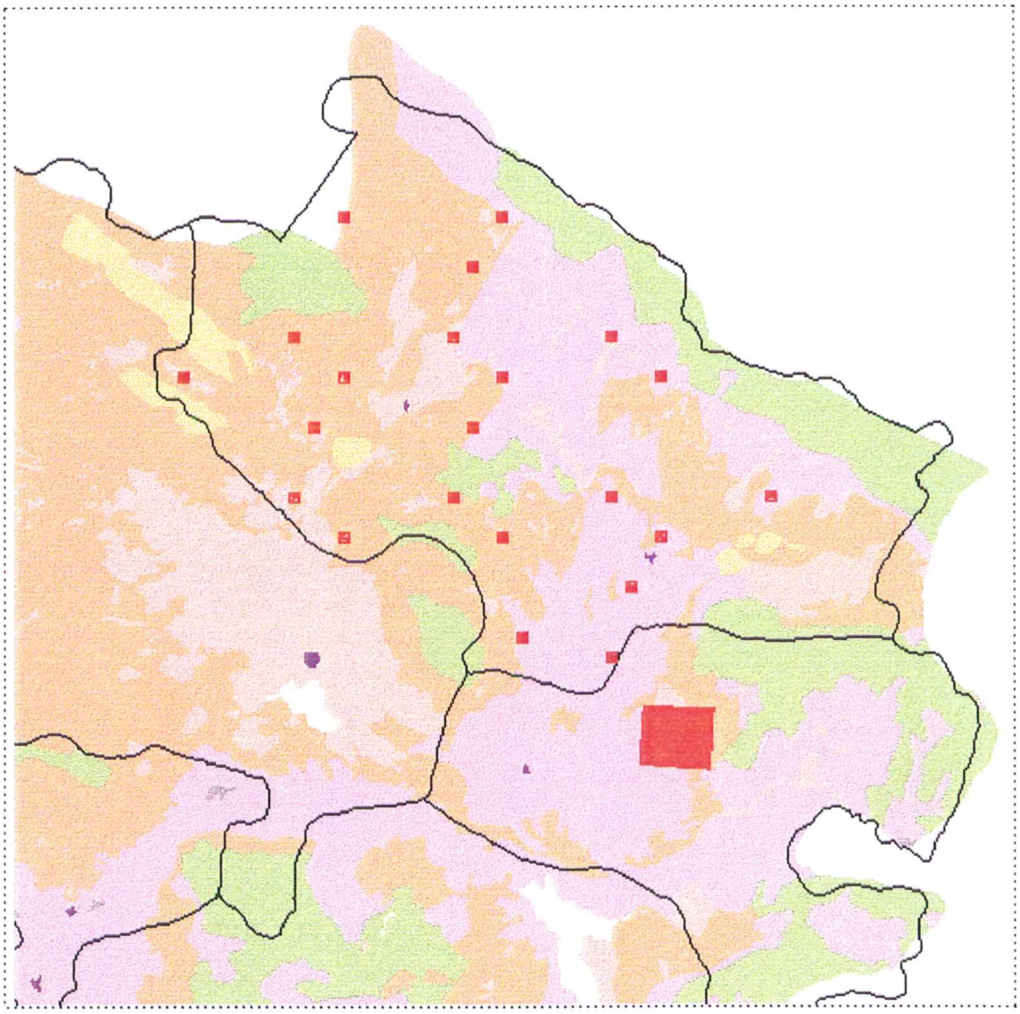
Note: As can be seen in figure 4.7 and 4.8, many versions of the administrative boundaries exist. This is partly due to the fact that the boundaries of Razan (and Hamadan) have been changed in recent years and partly by inaccurate maps. In a later stage all maps will be overlayed with the most recent map of administrative boundaries.

Table 4.2. The co-ordinates of the segments selected for sampling during the field trip.

UNIQUE NUMBER	STRATUM NUMBER	NPIX	Y	X	SEGMENT CODE
99	60	400	3914500	339500	3
177	60	353	3930500	323500	3
181	60	400	3926500	328500	1
183	30	256	3914500	323500	3
187	60	386	3910500	328500	1
188	60	400	3905500	325500	2
189	60	400	3898500	323500	3
259	60	319	3942500	312500	1
260	30	400	3937500	309500	2
261	20	400	3930500	307500	3
265	60	396	3926500	312500	1
266	30	308	3921500	309500	2
267	30	400	3914500	307500	3
271	30	299	3910500	312500	1
343	30	201	3942500	296500	1
345	30	400	3930500	291500	3
349	30	400	3926500	296500	1
350	20	293	3921500	293500	2
351	30	234	3914500	291500	3
355	30	400	3910500	296500	1
433	20	321	3926500	280500	1

The column 'npix' shows how much of a segment (1*1 km) falls in a certain stratum. If Npix=400, then segment completely in that stratum.

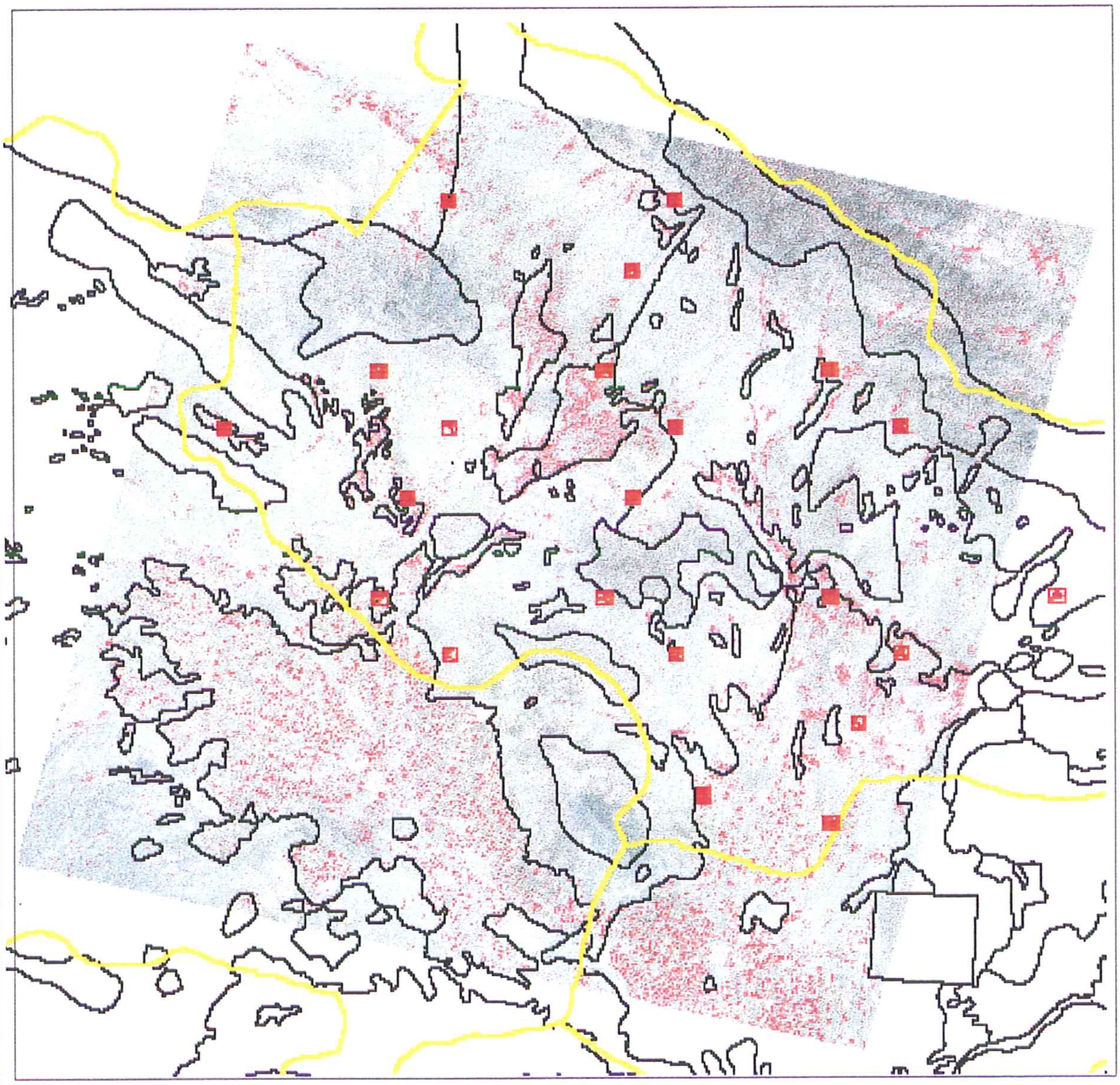
Figure 4.7. Stratification of Razan (study area) with the location of the sampled segments.



Black lines = administrative boundaries
red squares = segments sampled in the field work of June 1996
background = stratification

- City/village
- Irrigated agriculture
- Rainfed agriculture
- Pasture (range land)
- Stony land
- Fragmented rainfed agriculture
- Salty land
- Shooting field
- Unrecognized (others)

Figure 4.8. A representation on the sampling scheme in the study area.



Yellow lines = boundary of study area
black lines = boundaries of strata (polygons)
red squares = segments sampled
background = SPOT-XS colour composite (bands 3,2,1) of 96-07-15

4.1.5 Representations taken into the field.

To reduce the time needed to actually sample segments in the field, which entails the drawing of all field/tract boundaries, a representation is used of the segments is used. In the case of the field trip the representation was based on SPOT-PAN images. These black and white pictures have a resolution of 10*10 meters which should make it possible to recognise field boundaries (figure 4.1.11). The advantage of using these images is clear; when most of the boundaries of the fields are already known, only changes have to be recognised in the field.

The creation of the representations is relatively simple when:

* the SPOT-PAN images are geocorrected (figure 2.2)
* the co-ordinates of the sample segments are known (table 4.2)

For the field trip the SPOT-PAN images were geocorrected with a 1:250000 topographic map. The result of this can not be perfect but no other map was available at that time. In a later stage the images will be geocorrected more accurately, but for the field trip the level of precision was acceptable.

For use in the field two representations were made of each segment. One was on a scale of 1:5000 (figure 4.9), covering only the sample segment, and the other on a scale of 1:10.000, covering 2*2 kilometres (4.10). The latter representation was made to aid orientation in the field. The segment to be sampled is located in the centre of this representation.

Figure 4.9. Representation of a segment (NR. 189) as taken in the field, with a scale of 1:5000

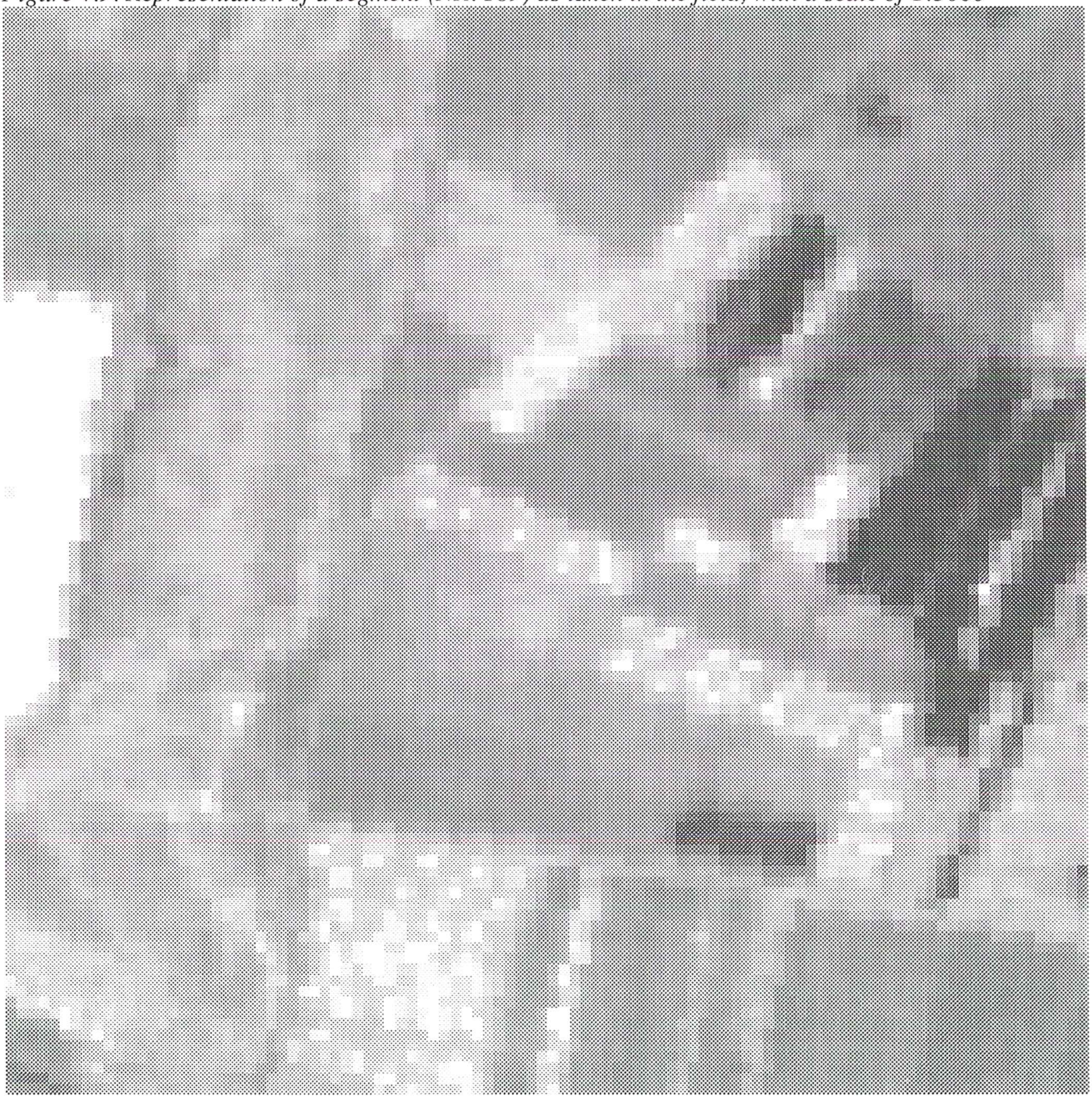


Figure 4.10. A representation taken into the field as an aid for orientation (scale 1:10000).

The blue line represents the segments to be sampled

4.1.6 Remote sensing application

4.1.6.1 Identification of the required data and images

Ideally, multi-temporal imagery of high resolution satellite imagery is needed. The possible satellites include: Landsat-TM, Spot-XS and IRS-1. The images should be acquired during flowering of the major crops (grains) and after their harvest. The costs of using multi-temporal imagery are relatively high especially regarding the republic of Iran because Landsat-TM is not available. SPOT-XS is quite expensive because of its small swap size, only 60 km compared to the 180 km. of Landsat-TM. The Indian IRS-1 satellite is becoming a viable alternative, because its properties are quite close to those of Landsat-TM. If no multi-temporal imagery can be acquired the single cover must be taken as close to the date of the fieldwork as possible (maximum of 1 month earlier or later). This imagery is still useful but the classification will be more difficult.

A new possibility regarding this project is the Russian Resurs-01 satellite. Especially because of the large area which has to be covered by the crop forecasting system; first one complete province (Hamadan) with the possibility of extending it to the whole country). The Resurs-01 satellite is a kind of hybrid system because its properties fall between the high resolution satellites like Landsat and SPOT and the low resolution satellites like NOAA.

The Resurs-01 satellite carries the MSU-SK conical scanner. The pixel size is 160*160 meters with a swap size of 600 km. The high swap size means that the complete province might fall into one image. The use of multi-temporal image classification thus becomes an viable option again (Resurs gives a discount of 50% on 5 images of the same area).

The possibilities of the use of this imagery will be checked by re-sampling the SPOT-XS image to look like a Resurs image provided the Resurs data is made available. This entails the combination of 8*8 SPOT-XS pixels into one. This re-sampled image will be classified with the same field work data and the results will be compared to those obtained from classifying the SPOT-XS image.
It is not possible to simulate multi-temporal Resurs imagery.

4.1.6.2 Pre-processing of images

It is the view of the Vegetation and Agricultural Science "VAS" Division at ITC that pre-processing of imagery should be kept at a minimum reducing labour inputs and keeping as close to the original reflectance values as possible. Thus every step in this process has to be looked at very carefully.

Geocorrection is one step that cannot be excluded. One set of images will have to be geocorrected very carefully with help of detailed topographic maps and, if possible, GPS measurements. This set of images will become the base map on which all other digital data can be fitted. For the pilot area the base map will be the SPOT-XS imagery.

4.1.6.3 Processing of images

Supervised classification

This classification method is based on a direct relation between reality on the ground and reflectance values in an image. The relation is formalised by a so called training's set. A training set is created by locating ground truth points/areas on the image and determining a range of (multi-spectral) pixel values for each class which has to be identified. The range of values can be displayed in a multidimensional feature space where the axis depict the reflectance values in different bands. Ideally all classes which have to be identified form separate clouds within the feature space. When the training's set has been created each pixel of an image has to be assigned to a certain class. One method to do this is by a maximum likelihood algorithm, other possibilities are e.g. minimum distance to means, k-nearest neighbour and box algorithms (Lillesand & Kiefer, 1987; Buiten & Clevers, 1990; Sabins, 1987; Mather, 1987)). Supervised classification has three distinct disadvantages. One is that it can only identify classes which have a distinct spectral reflectance. The second is that a pixel is always assigned to one class only, the one which is the most likely according to the algorithm, other possibilities are discarded. Therefore the results of supervised classification with a maximum likelihood algorithm are usually not satisfactory in large complex areas (Heinzman & Zollinger, 1995) and when cover types have similar refection characteristics. The third is that for building the training set all classes will have to be incorporated otherwise the results will be, statistically, incorrect. This becomes a problem when large areas, like in this project, have to be analysed. The extent of the problem differ from software package to package but the fact remains that many (sub)classes will be generated.

Because the Maximum likelihood algorithm is widely used and present in most software packages, this algorithm will most likely be used in this project. It should be noted that the use of other algorithms in supervised classification only change the decision rule which assigns pixels to pre-defined classes not the method itself.

When supervised classification does not give the required results it may be needed to use some additional information like: soil maps, Digital Terrain Model or prior probabilities (Gorte 1995).

Knowledge based classification.

With the "during-classification knowledge processing" (DCK) method a likelihood for each label (land use or cover type) is assigned to each source of evidence. Instead of using likelihood's and classical set theory, plausibility theory and fuzzy logic can also be used Srinivasan & Richards (1990).
Having assigned likelihood's to classifications from different sources of evidence (*e.g.*, two different satellite images), they then have to be combined. The method of assigning likelihood's has consequences for further processing (see Srinivasan & Richards, 1990, Bronsveld et al., 1992, Strahler, 1980, Maselli et al., 1992). In this case an adoption of the Dempster and Shafer rule is used (Srinivasan & Richards, 1990).

4.1.6.4 Post processing of results.

Improving the area estimates of AFS with satellite imagery
It is important to note that by this method the (non spatial) area frame estimates are improved while the maps are not.

Crop areas in the classified image can be calculated simply by taking the sum of the number of pixels which are assigned to each cover class ($x_{ijh}=PI_{ij}/Pi_j$). A correction factor may have to be introduced when the total area of the classified image is not exactly the same as the total area used in other digital/non-digital data. These differences result from inaccuracies in digital (GIS) processing and/or standard map making.

The estimated areas as calculated with area frame sampling are compared linearly with the area estimates as calculated from the classified image. The resulting graph should ideally be a straight line with an angle of 45 degrees. This will probably not be the case because inaccuracies will be present in all data.

With the following method based on linear regression the area estimates can be improved:
(Amitai, 1992) & (Gallego, 1995).

In this project linear regression will be applied separately for every cover type in order to modify its area estimate (from AFS) by x_i (areas derived from the classified imagery).

In stratified sampling, *b* is assumed to vary substantially from stratum to stratum. The mean value of the regression estimate in the region ($\bar{y}_{reg}$) may be calculated in two steps. First, the regression estimate of the sub-population mean $\bar{y}_{reg_h}$ Of y_i in stratum *h* is calculated:

$$\bar{y}_{reg_{ih}} = \bar{y}_{i_h} + b_{i_h}(\bar{x}_{ih} - x_{i_{jh}})$$

The area estimate for land cover type$_i$ in the region is:

$$T_{reg_i} = \sum_{h=1}^{h}(D_h * \bar{y}_{reg_{ih}})$$

To asses the improvement in area estimates by linear regression the regression efficiency parameter RE_i can be calculated:

$RE_i=@^2Tgr_i/@^2Treg_i$

If the RE_i is greater than 1 an improvement in area estimate accuracy is indicated.

RE_i=regression efficiency for crop i
$@^2Tgr_i$=variance of area estimate from area-frame sampling for crop i

$@^2 Treg_i$=variance of area estimate after linear regression for crop i
$\bar{y}_{reg_{ih}}$ =regression modified area estimate of crop i in stratum h
b_{ih}=linear regression coefficient for crop i in stratum h
$x_{ijh}=PI_{ij}/PI_j$
$\bar{x}_i$=mean value of x_{ijk}
PI_{ij}=number of pixels labelled crop i in classified segment j
PI_i=number of pixels in classified segment j
D_h=area of stratum h (real value)
D_{ij}=area of crop i in ground survey segment j
D_j=area of ground survey segment j
$y_{ij}=D_{ij}/D_j$
$\bar{y}_i$=mean value of y_{ij}
$Treg_i$=regression modified area of crop i

Gallego (1995) also presents some results of using a confusion matrix instead of linear regression for improving the area estimates. This technique makes in principle better use of the information contained in the difference between classified cover types and the ground truth (the confusion matrix) than the method using a regression estimate. But some fine tuning of this method is still needed.

4.2 Design and development of the yield estimate method

In this section the concept, procedure, data needs, and implementation steps for deriving forecast for yield is briefly described

4.2.1. The Concept

Crop production forecasting is a procedure to estimate future crop production on the basis of observed and/or expected land and landuse attributes.

4.2.2. The Procedure (point analysis)

Actual crop production is conditioned by many complex and interacting factors that are often unpredictable (e.g. the weather, incidence of pests/diseases). This complexity precludes modelling of **actual** crop production and yield as dependent variables.

Land-use systems in which possible constraints to crop production have been eliminated or blanketed (water constraints, nutrient constraints, weeds, pests/diseases, harvest losses, 'Acts of God') are less complex than **actual** land-use systems. Such simplified systems are called 'Production Situations'. Simple Production Systems can be modelled with adequate accuracy.

The simplest land-use system imaginable is a system in which **all** constraints that can be eliminated are assumed to be non-constraining (water shortage is eliminated through irrigation/drainage, there is optimum fertilization, weeds and pests/diseases are eradicated, and there are no harvest losses nor harmful external influences). In this **Production Situation 1 (PS-1)**, production and yield depend entirely on the only factors that a farmer cannot modify: solar irradiance, temperature(s) and crop physiological requirements.

The production calculated for Production Situation PS-1 is the highest that a farmer could obtain; it is the **bio-physical production potential**. It may be regarded as a reference value by which (observed) **actual production** can be judged.

Real-world farmers are confronted with a score of crop production limiting or crop production reducing factors that they cannot fully eliminate. As a consequence, observed **actual production and yield are (normally) less than the calculated potentials**. The discrepancy between calculated potential yield and observed actual yield is known as the **yield gap**.

The PS-1 production environment is vastly different from the actual production situation of real-world farmers. If production and yield are thought dependent on the actual solar irradiance, the actual temperature **and the actual availability of water to the crop**, a Production Situation **'PS-2'** would result that resembles closely the actual land-use conditions in **advanced** agriculture. Modelling this Production Situation 2 permits to calculate the **water-limited bio-physical production potential** that is equal to or less than the PS-1 bio-physical production potential.

Calculations of crop production potentials at the PS-2 level require good quality data. Calculated PS-2 potentials are normally less accurate than PS-1 potentials because of additional errors introduced in the additional data and functional relations used.

Crop growth and production under conditions of Production Situation PS-2 are largely conditioned by soil and weather conditions. The effects of soil and weather conditions are also of influence on the observed **actual** production and yield. This suggests that the correlation between PS-2 potential and actual yield is stronger than the correlation between PS-1 production and actual yield.

A thoroughly tested PS-2 model, fed with verified/screened basic data can reliably quantify the water-limited production potential (with, say, > 80% accuracy). Correlation of calculated water-limited production potentials with observed sample yields is expected to produce a workable description of the yield gap between PS-2 and actual yields. This relation is to be established **using soil, weather, and yield records of discrete years, collected at experiment stations.**

Calculated PS-2 potential minus calculated yield gap equals anticipated actual yield. The elusive actual yield can now be approximated by subtracting from a reliably calculated PS-2 production potential the statistically estimated yield gap. This yield gap embodies the result of all factors and interactions that could not be accommodated in a model that describes actual production as a dependent variable.

As a first approximation, the PS-2 potentials of selected sample sites are calculated using **long term average weather data and indicative soil parameter values**. These average data are substituted with actual measured **daily weather data** as the crop cycle goes on. **The calculated PS-2 potentials become ever more accurate, i.e. year- and site-specific.** It may therefore be expected that the correlation between calculated potential production and observed actual production becomes better as the crop cycle advances.

At PS3 (production situation 3), simulated daily crop growth is function of the ratio of daily actual nutrient availability over daily PS2 crop nutrient requirements. However, rather than calculating production and yield under PS3, PS123 simulates seasonal (type specific!) fertiliser requirements on basis of soil (material) specific yield gap analysis between simulated seasonal PS2 potential crop production and input actual non-fertilised crop production. Rather than to derive unfertilised production from actual nutrient availability, actual nutrient availability (base uptake) is derived from actual and potential production figures. Fertiliser requirements to fill the yield gap between PS2 and PS3 will be called PS23 hereafter. With respect to simulation of daily crop growth at PS-3, some modelling efforts have been developed but these fall out of the scope of this report and are intended for follow-up research.

To obtain a regional image of (expected) actual crop production, the calculations of PS-2 production potentials and the estimation of the yield gap must be done at a number of **sites for which adequate data are available**. The individual point analyses must than be input in a **regionalisation procedure**.

4.2.3 Implementation steps and corresponding information requirements for Yield estimate

- **SOIL data requirement and preparation:** Land-Use Systems (and Production Situations) consider a **defined Land Utilisation Type that is practised on a defined Land Unit**. The Land Utilisation Type is described by **Crop Data** and **Management Attributes**. The Land Unit is defined by **Weather Data**, and **Soil/Land:** The thematic soil data requirements had been identified and given in the appendix 3 of the report. Such data should be prepared for each polygon of LMU. The spatial distribution of the soil series should be provide through digitisation and proper organisation of the soil series maps in GIS.

- **Preparation of the administration maps:** The location and the main thematic attributes of each village in the study area should be collected and properly organised in a GIS. If possible, information such as number of house holds, total agricultural land, crop calendar and cropping pattern will be helpful information. The main information should be the identifier which shows the administration hierarchy, e.g. village number, Dehestan, Bahksh, Shahrestan and Province.

- **Identification of mapping unit:** Mapping unit will be derived from overlay of soil series maps over the administration boundary maps. At this stage we suggest the Dehestan to be considered as the lowest administration area.

- **Collection and preparation of weather data:** The thematic and geographical information of all the existing weather stations in the region should be collected and properly stored in a GIS. This should include all the existing weather station of any kind and run by any organisation, mainly:
  - Synoptic stations
  - Climatological stations
  - Agroclimatological stations
  - Rain gauge station

  The station name, its latitude, longitude (in degrees and hundreds of degrees) and altitude of the station in meters above the sea level. Information of all relevant/neighboring stations should be used to derive the following set of weather data for each polygon in the study area:
  - Day number (Julienne number)
  - Tmax, maximum daily temperature in centigrade
  - Tmin, minimum daily temperature in centigrade
  - Prec, precipitation in cm per day
  - RHA relative air humidity, as a fraction (0-1)
  - E0, potential evaporation rate in cm per day
  - SUNH, number of sunny hours per day, in hour per day
  - ET0, potential evapotranspiration rate, in cm per day

  If E0 and/ or ET0 data are not available, these can be calculated according to Penman (1984) or Penman-Monteith.In that case, the extra information is required: average daily wind speed at 2 m height, in meter per second.

- **Collection and preparation of crop data:** The required crop information are given in the follwing. This information are related to the phenological and physiological characteristics of the crops. Therefore they are very specialised information which should be carefully derived and used.

  Crop Data are variety-specific; they are stored in a file. The PS123 model of Potential Crop Production uses sequential files in ASCII format. File structure and data items are as follows:
  - "Crop_label$"
  - "C3/C4$",T0,TSUM,TLEAF,TLOW,RDSroot,RDint,RDmax,PSIleaf
  - SLAmax,SLAmin,ke,TCM,r(leaf),r(root),r(stem),r(s.o.)
  - EC(leaf),EC(root),EC(stem),EC(s.o.),NY,NSTR,PY,PSTR
  - #interception_points
  - RDS0,RDS1,..............RDS#interception_points
  - fr(leaf)1,fr(leaf)2,............fr(leaf)#interception_points
  - fr(root)1,fr(root)2,............fr(root)#interception_points
  - fr(stem)1,fr(stem)2,............fr(stem)#interception_points
  - fr(s.o.)1,fr(s.o.)2,............fr(s.o.)#interception_points
  - These variables have the following descriptions and dimensions:
  - "Crop_label$" alphanumeric, no dimension
  - "C3/C4$"alphanumeric, indication of photosynthethic pathway, either "C3" or "C4".
  - T0 Threshold temperature for crop development, in °C

- TSUM Heat requirement for full crop development, in °C.d
- TLEAF Heat requirement for full leaf development, in °C.d
- TLOW Lowest temperature tolerated by the crop, in °C
- RDSroot Relative development stage at which root growth ceases, --
- RDint Rooting depth at germination, cm
- RDmax Maximum root depth at any time in the crop cycle, cm
- PSIleaf Critical leaf water head, hPa
- SLAmax Maximum Specific Leaf Area, m^2kg^{-1}
- SLAmin Minimum Specific Leaf Area, m^2kg^{-1}
- ke Extinction coefficient for visible light,

- **Collection of the required field data:** To establish a proper relationships between the production/yield potentials and their corresponding actual yields the following data sets should be collected and provided to the system:

- List of all the villages that each year have been selected as a sample for the current agricultural statistic project. This project have been running as of 1987 (1367). On each year based on the original questioners the following information should be derived for each selected villages:
    - Total agricultural land
    - Total area of each crop
    - Average yield of each crop at that particular year
    - The frequent crop calendar, and rotation

- List of all the production co-operatives in the region and on each administration units. The total agricultural land of each production co-operatives, area under each crop, their corresponding average yields, and the frequent crop calendar and crop rotation.

- Derivation of the average yield and total area and the total production estimate of each commodity in each administration units if possible at Dehrstan level if not at Shahrestan level. The same sorts of aggregation should be carried out to derive the following crop management data:
    - Crop calendar
    - Crop rotation
    - Average fertilizer, seeds and number and amount of irrigation for each crop

- **Calculation of the potential yields for existing sample points:** For each village which has been selected as a sample in the agricultural statistics project the constraint free yields , the water limited and possibly the nutrient limited yields of each crop will be simulated This simulation requires the weather data of the specified year, the soil data of the particular villages and the specialized crop phenological properties and management information of each crop. The results of all these calculation should be stored on a table with the following types of structure:

    - Village code
    - Village name

- Crop commodity
- Year
- Average yields of each crop based on field data
- Potential constraint free yields of each crop, based on simulation
- Water limited yields of each crop, based on simulation
- Total dry matter of each crop, based on simulation

- **Calculation of the potential yields for existing sample areas:** On the same basis as was explained on the previous step, the potential production and water limited production will be simulated for all the administration units in which their reliable historical production and weather data are available. These simulations require the weather data of the specified year, the soil data of the particular administration units and the specialised crop phenological properties and management information of each crop in the same administration units. The results of all these calculation should be stored on a table with the following types of structure:

    - Administration code
    - Administration name
    - Crop commodity
    - Year
    - Average yields of each crop based historical data
    - Production of each crop based on historical data
    - Potential constraint free yields of each crop, in the administration unit based on simulation
    - Water limited yields of each crop in the administration unit based on simulation
    - Total dry matter of each crop, in the administration unit based on simulation

- **Developed an statistical model for yield forecast:** To derive yield forecast a forecasting model is to be developed. Such a model will be developed on the basis of the assumptions that there is an strong relationships between the potential and actual yields of various crops. Such a relationships will be developed using the estimates of the potential productions and the estimated actual productions derived from point samples and area samples (historical production of each administration units). in each administration units (Dehestan, Bakhsh, Shahrestan, Province) based on the above tables.

- **Calculation of the potential yield:** At this stage the constraint free yield and water limited yields of each crop at each polygon (mapping unit) will be calculated. To this the corresponding weather data of each polygon should be provided through the application of a popper interpolation techniques. The soil data of each polygon should also be made assessable to the crop growth simulation program.

- **Calculation of the average yield:** The weighted average of the yield of each commodities in each administration units will be calculated and used as an average for further calculations.

- **Derivation of the estimates on the actual yields:** In each administration units use the relationship (derived in the previous steps) and derive the estimate of the actual yield of each commodity in that administration unit (using the potential yields)

- **Derivation of aggregated yield:** Aggregate the yield to the right level of hierarchy using the weighted average principles.

4.2.4 Development / modification of the crop growth simulation model appropriate for the major crops in the study area

4.2.4.1 Objectives

Calibration and validation of the PS123 crop growth simulation model was done for wheat and barley with experiment data that were kindly submitted by Ekbatan branch of the Iranian Meteorological Organization in Hamadan province, under the following regimes:

- properly irrigated potential yield (PS2) with optimum nutrient supply
- rain-fed potential yield (PS2) with optimum nutrient supply
- fertiliser requirements at PS2 (PS23).

4.2.4.2 Methods

As stated by Sharifi (1992), evaluation of model performance involves calibration, verification and validation. Calibration refers to selection of parameters and functional relations, so as to reach the best overall agreement between simulated and observed results (van Keulen, 1976). Verification is concerned with establishing whether a model is a true or correct representation of reality (absolute truth), whereas validation is the assessment of usefulness and effectiveness of a model for specific purposes (Dent and Anderson, 1971).
Calibration of the model matches model output with available (measured) experiment data on corresponding parameters. Output here is defined as simulated crop performance for a specified situation which served as input.
Validation of the model matches model output with available (measured) data on crop performance under a wider range of parameter variation. The main output parameter for validation purposes in this context is 'final grain yield', which is also the parameter to be sought in the pilot area.

Marginally lower agreement with measured (calibration) experiment data is accepted when validating. However, algorithms have been adapted when necessary.

4.2.4.3 Calibration of the simulation model

4.2.4.3.1 Analysis and preparation of available data for calibration purposes

Model input requirements include data on land and land use, which together make a land use system:

Land:
- weather characteristics
- soil characteristics

Land use:
- crop characteristics
- land- and crop management characteristics

Parameters description, parameter types and parameter structures were reported to facilitate data exchange for further system development (Leenaars, 1996).

Values of model input parameters as well as measured actual crop growth are derived from two consistent data sets on two agricultural experiments on irrigated wheat at Ekbatan research station. These data sets were explained by van Keulen (1996) and Young (1996) and contain the following information (parameters which are model input are marked with *):

Land:

Location data:
- longitude (48.32 °E) *
- latitude (34.51 °N) *
- elevation (1730 m.) *

Daily weather data for the years 1986 - 1995:
- maximum temperatures (°C) *
- minimum temperatures (°C) *
- precipitation (cm/d) *
- minimum and maximum relative humidity (0-1)
- sunshine hours (h/d)
- class A pan evaporation (cm/d)
- average wind speed (m/s)

From these data further required parameter values were derived
- potential evaporation according to Penman-Monteith (cm/d) *
- potential evapotranspiration according to Penman-Monteith (cm/d) *

Derivation took place by adapting and running the model FAOtoPS, kindly provided by ISRIC, and originally written to transform FAO weather data sets to PS123 format. Derivation results were compared with monthly averages as reported by the Iranian weather station Nowjeh (situated at only a few kms from Ekbatan) and with measured class A pan evaporation. As calculated and measured values on potential evaporation did not agree, and because data on potential evaporation were not measured during winter time, hybrid weather data files were constructed. For measured days, measured evaporation values (* 0.85; pers.comm. van Keulen) were maintained. For days not measured, substitutes values for potential daily evaporation were used. The calculated daily ratio of potential evapotranspiration over potential evaporation was used to derive daily values of evapotranspiration.

Soil data:
- texture (loam) *
- qualitative indication of soil humidity of the top 40 cm of soil
- chemical composition of the soil after harvesting: C(%), N(%), P(ppm), K(ppm)

The soil material of Ekbatan station is described by a default soil parameter set (loam), as established by Driessen.
The reported loamy texture is a field texture (with aggregation intact) and is 'lighter' than would be concluded from laboratory analysis after dispersion of the soil material (Driessen, pers.comm.); soils of Hamadan province are predominantly of clayey texture. According to Dewal and Famouri (1964), the geology of Hamadan province is dominated by calcareous schists, limestones etc., leading to variable- but mainly deep soils, deep phreatic levels and loamy to clayey soils (brown soils, chestnut soils, lithosols).
Despite the presence of a small stream, the phreatic level (*) is assumed to be present at great depth. Monitored soil humidity could serve to calibrate and validate model performance at PS2 but has not been used Soil chemical parameters are of little value for calibration and validation of (the present version of) PS123.

Land use:

Management data for the seasons of 1992/93, 1993/94 and 1994/95
- previous land cover (fallow yes or no) *
- date of cultivation
- date of sowing *
- quantity of seed *
- dates of irrigation *
- net irrigation gifts *
- dates of fertilisation
- types of fertiliser
- fertiliser gifts
- soil surface roughness

Management (e.g. ridging) and slope angle determine soil surface roughness which defines soil surface water storage capacity (*). Electrical conductivity of irrigation water (and of soil and phreatic water) (*) is assumed to be low (1 mS/cm). Depth (and fluctuation) of phreatic water level (*) can be managed by installing a drainage system but are assumed fixed at great depth.

Crop physiology data:

Navid wheat variety characteristics are derived from the data mentioned hereafter. Where needed, supplemental data on wheat characteristics are based on default values provided by Driessen and Konijn (1992), Russell and Wilson (1990) and van Keulen and Seligman (1987).

1. Experiment on irrigated wheat, c.v. Navid during the seasons of 1993/94 and 1994/95;
- crop (variety) phenology; percentages of stand of crop at stage of
  - germination *
  - emergence
  - tillering
  - stem extension (*)
  - heading (*)
  - flowering (*)
  - milk ripe
  - wax ripe
  - dead ripe; full maturity (*)
- duration of full crop development from 50% germination to 50% maturity (*)
- absence of vernalisation requirements
- grain production at full maturity (kg/ha).

2. Fertiliser experiment on irrigated wheat, c.v. Navid during the seasons of 1992/93 and 1993/94;
- crop (variety) phenology: dates of crop at stage of
  - emergence
  - tillering
  - jointing
  - heading (*)
  - maturity (*)
- duration of full crop development (from emergence to 100% maturity) (*)
- number of ears/m2
- number of grains/ear
- weight of 1000 grains (g) (*)
- chemical composition of leaves; N(%), P(%), K(%) (*)
- straw production at full maturity (kg/ha)
- grain production at full maturity (kg/ha)

Parameters indicated with (*) are required input. Weight of 1000 grains is required input in the present version of PS123 to describe grain filling as a function of sink dynamics alongside source dynamics, but is not processed at present. Chemical composition of leaves is no input parameter, though straw minimum N & P% are. Duration of full crop development in days is no input parameter but required duration of accumulation of daily temperature sum is (TSUM*; °C.d) and corresponds with relative development stage 1 (RDS*). Date of germination is defined as relative development stage 0. Dates of other phenological stages refer to relative development stages for which assimilates partitioning to the crop organs is specified.

Experiment 1. refers to farmers practices (Sharifi pers.comm.), whereas crop conditions in experiment 2. were more favourable (different irrigation regime, higher fertiliser doses; higher yields). In the season of 1993/94, Navid yielded 3100 kg grain/ha in the 'farmers' experiment (1, c.q. C) and more than double that in the fertiliser experiment (2, c.q. B) as can be seen in next table. Bold Julian day numbers indicate dates just after heading.

Navid	germinated at JDN	and received irrigation gifts of net 7 cm at JDN's	and yielded:
A. 1992/93 (2)	298	109,**144**,159	5600
B. 1993/94 (2)	307	104,**144**,158,175	6300
C. 1993/94 (1)	321	113,131,**141**,143,175	3100
D. 1994/95 (1)	298	99, 169	4000

4.2.4.3.2 Calibration exercises

Calibration of PS123 for irrigated wheat, c.v. Navid, involved some major activities:

- adaptation of the algorithm
- construction, adaptation and fine tuning of crop physiology parameter definition

4.2.4.3.2.1 Development / adaptation of the algorithm of PS123

PS123 or PS12S365 is adapted for Hamadan province; its latest version is called Mana. PS123 is a Simple Model for Calculation of Production Potentials of Annual Crops (Driessen, 1996). Mana refers to certain management decisions which have been standardised (germination day co-determined by soil moisture status and irrigation as a function of phenological development stage and water sufficiency factor). See § 4.2.2.3.3

Crop growth is fuelled by assimilation, the reduction of atmospheric CO_2 to carbohydrates. The potential assimilation rate is primarily governed by temperature and light intensity. The process is also known as photosynthesis. The actual assimilation rate is a function of canopy characteristics; the canopy functions as an active exchange surface (see crop physiology). Crop growth implies that the available carbohydrates (assimilated energy), partitioned to individual plant organs and corrected for losses due to maintenance respiration are converted to structural organ tissue. Respiration losses decrease with temperature and light intensity; 24 hours weather (and crop) dynamics determine the daily net energy balance and the daily increase (or decrease) in crop dry mass.

Ekbatan station is situated at an altitude of 1730 m. It is assumed that CO_2 and H_2O sources are not limiting. Absolute quantities decrease with altitude but concentrations are assumed to remain sufficient. Temperatures decrease with altitude, he amount of radiation increases with altitude. The fraction of radiation in the range of 400-700 nm (wave lengths) is 'photosynthetically active' (PAR) and this fraction could well decrease with altitude. However, as no exact data are available it is assumed that absolute amount of PAR at canopy level (PARCAN) for a given day in the year is irrespective of altitude; atmospheric light transmission fraction (TRANS) of extra terrestrial radiation (EXTRA) decreases towards sea level. This implies that the absolute amount of the shorter wave fraction (u.v.) increases with altitude. The greater amount of radiation reaching the canopy (CANRAD) at higher altitudes is thus assumed not to determine photosynthesis but it does influence the net intercepted radiation (INTER; function of CANRAD minus long wave losses (LWLOSS)) which influences the difference between air and canopy temperatures (TEMPDIFF). At higher altitudes, this difference will be greater and leads to shorter duration of full crop development (see Subroutines TEMPCALC and TEMPDIFF). Ångstrom coefficients A & B are set to 0.29 and 0.52, which might perhaps be somewhat too high for Iran (Frère and Popov, 1979) as the atmosphere might often become very dusty (what was observed for vicinity of Tehran at 1150 m. (Clavaux, pers.comm.)). Assessment of substitute values for A & B as done for the European Community (Supit et al., 1994) might be worthwhile.

EXTRA	= SC * RDN	[J/m2.d]
CANRAD0	= EXTRA * TRANS0	[J/m2.d]
TRANS0	= A + B(SUNH/DL)	[Ångstrom]
A	= 0.29 * COS(LAT*RAD)	
B	= 0.52	
PARFRAC	= PARFRAC0 - (ELEVATION/1000) * 0.07	
PARFRAC0	= 0.5	
PARCAN	= CANRAD0 * PARFRAC0 / (360*DL)	[J/m2.sec]
CANRAD	= CANRAD0 / PARFRAC	[J / m2.d]
TRANS	= CANRAD / EXTRA	
VAR0	= variable at sea level	
VAR	= variable at altitude x.	

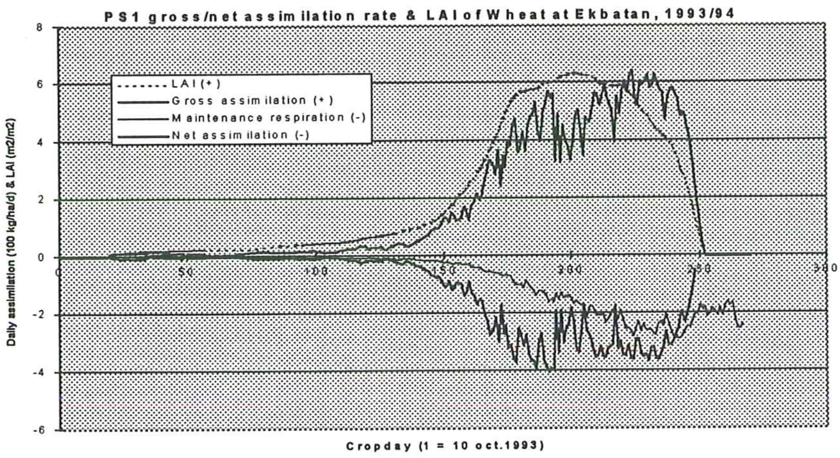
Calculations of potential evapo(transpi)ration take account of the altitude and need no adaptation in the algorithm. Calculation of specific leaf area (SLA), is related indirectly to altitude by decreasing maximum and minimum values with decreasing reference temperatures. Description of leaf mass dying because of mutual shading has been copied from van Keulen and Seligman (1987).

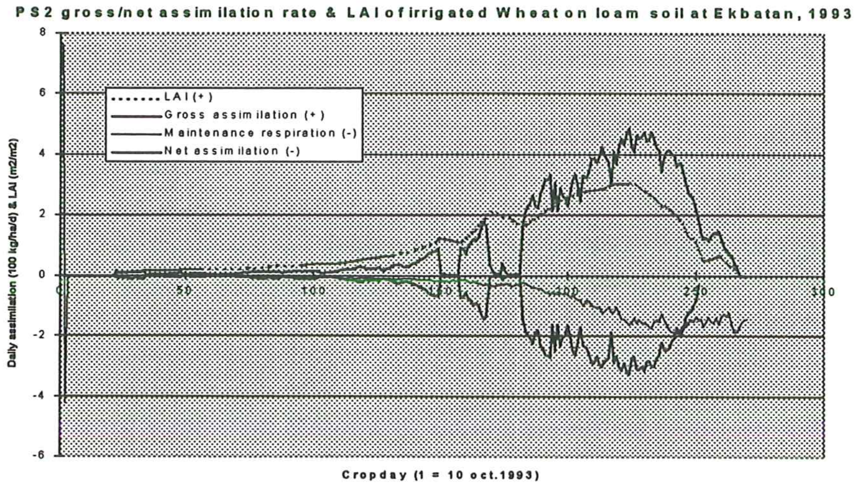
SLAMAXD	= SLAMAX - 0.45 * (TREF - TREFMAIN)	[m2/kg]
SLAMIND	= SLAMIN - 0.45 * (TREF - TREFMAIN)	[,,]
SLA	= SLAMIND - 0.5 * (SLAMAXD - SLAMIND) * LOG(RDS)	[,,]
LAI	= SLA * LIVSLEAF / 10000	[m2/m2]

TREF and TREFMAIN are last 10 days averages of respectively day time- and day- & night time temperatures. LIVSLEAF is living leafs dry mass (kg/ha).

MAXRLFDRATE = 0.3 [1/Dt]
RLFDRATE = MAXRLFDRATE * (LAI - 4) / 4
IF RLFDRATE > MAXRLFDRATE THEN RLFDRATE = MAXLFDRATE
LIVSLEAF = LIVSLEAF - (LIVSLEAF * RLFDRATE) [kg/ha]

The simulated development of the LAI of wheat at Ekbatan station is presented in fig.5, which illustrate clearly that LAI and gross assimilation rate (FGASS) are closely related. In the model, FGASS appears to depend solely on LAI, contrary to statements of other authors who consider FGASS as a function of LAI, green stem surface and ear structures. Ear structures are first intercepting layer of canopy during grain filling and stems remain green for a long time, but these effects are considered negligible.
For illustrative purposes are FGASS and LAI presented with positive values and the derived division into MRRT and NAAT with negative values. Conceptually it would however be correct to illustrate NAAT with positive values as well. The correct interpretation is FGASS = MRRT + NAAT.





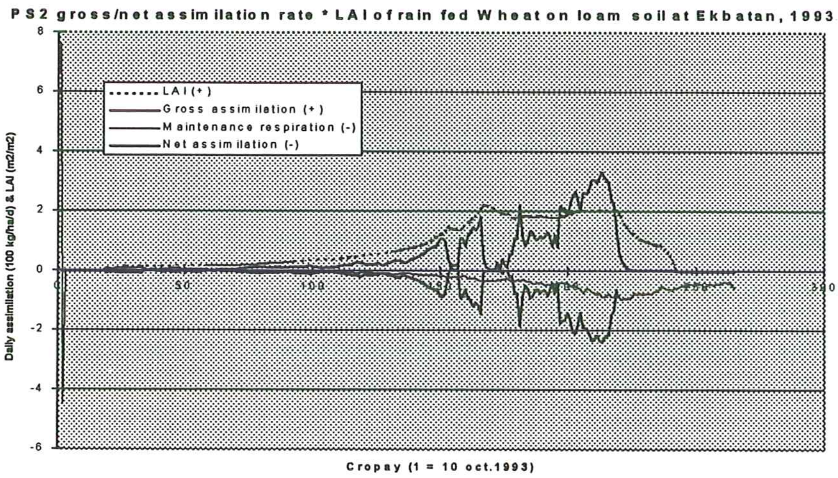


Figure 4.11. (a,b,c). Simulated LAI, gross- and net assimilation rates and maintenance respiration rate at PS-1 and PS-2 (irrigated and rain-fed) of wheat on a loamy soil, Ekbatan 1993/94. (Conceptually it would be correct to illustrate the net assimilation with positive values).

In PS123, daily gross assimilate production is partitioned (to the organs) as a function of RDS. Subsequently, assimilate requirements for respiration for tissue maintenance are quantified as a function of organ dry mass and TREFMAIN (MRRORG). The excess assimilate production denotes the net assimilation per organ (NAAORG), which can attain both positive- and negative values. According to van Keulen and Seligman (1987) and Goudriaan and van Laar (1994) gross assimilate production is used for overall maintenance respiration (MRRT) partitioned to the crop organs, what results in an overall net assimilation (NAAT) which is then again partitioned to crop organs as function of defined partitioning.

Consequences of these two different approaches might have considerable impact on grain filling. According to van Keulen and Seligman (1987) and Goudriaan and van Laar (1994) partitioning of (net) assimilates to vegetative tissue ceases at flowering. While vegetative tissue remains maintained, all net assimilates are used for grain filling. According to PS123 (Driessen and Konijn, 1992) vegetative tissue does not (!) cease to be maintained even if partitioning of FGASS to vegetative structures is defined zero after flowering. However, net assimilation becomes negative leading to accelerated dying of vegetative tissue which affects LAI and (next day) FGASS. Negative net assimilation of vegetative structures is theoretically incorrect according to van Keulen (pers.comm.) but the rate of dry mass decrease according to PS123 equals the rate of dry mass decrease according to SWHEAT (van Keulen and Seligman, 1987) and is, for leaves, about 1.5 - 2.5% of dry mass of LIVSLEAF, which corresponds with relative maintenance respiration rate (RLEAF; kg/kg.d). Rate of generative crop dry mass increase, at a certain gross assimilation rate, is thus relatively high as all of the gross assimilates are partitioned to the generative parts while the negative net assimilation in the vegetative structures functions virtually as a assimilate reserve pool. When one compares source dynamics, as a function of daily net partitioning to the generative structures, with sink dynamics, as a function of thousand grain weight (TGW), one observes at PS1 during only a few days immediately after flowering that source exceeds sink. Daily organ dry mass increases of wheat at PS-1 in 1993/94 are illustrated in fig.4.12.

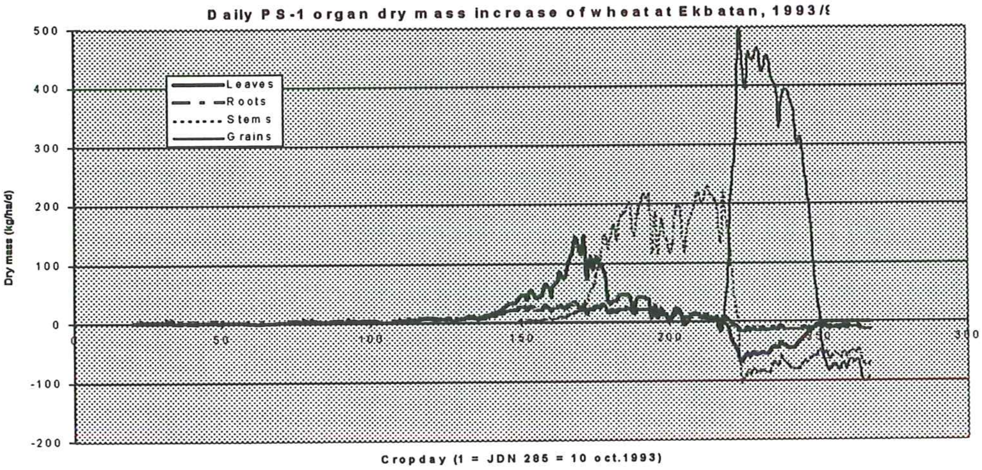


Figure 4.12. Simulated daily increases of organ dry mass at PS-1 of wheat, Ekbatan 1993/94.

After some adaptations of the algorithm and referring to the above mentioned observations was decided to maintain the original algorithm as much as possible for the time being. As stated by Russell and Wilson (1994), partitioning of assimilates is the crop growth process which is least well understood. The only model adaptation maintained is to assure gross assimilate partitioning to SSO (grain filling) for both maintenance respiration (MRRSO) and net assimilation (NAASO) when crop development has passed anthesis but not yet reached the start of senescence of leaves (TLEAF/TSUM) and when NAAT has negative value. Only if FGASS is less than MRRSO, can NAASO become negative. The remaining FGASS (i.e. NAAT, with an even more negative value) is partitioned as a function of organ specific maintenance requirements. TLEAF becomes a more significant parameter with respect to simulated final grain yield and allows simulation of longer remaining high LAI values.

```
CC          = EFF * ke * PARCAN    (= 0.5)                                  [kg/ha.d]
Fgc         = DL * (AMAX / ke) * LOG((AMAX + CC)  /  (CC * EXP(-LAI * ke)
               + AMAX)))                                                   [kg/ha.d]
FGASS       = Fgc * 30/44 * CFWATER                                         [kg/ha.d]

MRRT        = SUM(RORG * SORG * CFTEMP                                      [kg/ha.d]
NAAT        = FGASS - MRRT                                                  [kg/ha.d]

IF INTFRSO >= 0.5 AND RDS < TLEAF/TSUM AND NAAT <= 0 THEN
        NAASO        = GAASO - MRRSO
        NAAT         = FGASS - (MRRT - MRRSO) - NAASO
        NAALEAF      = NAAT * RLEAF / RVEG
        NAASTEM      = NAAT * RSTEM / RVEG
        NAAROOT      = NAAT * RROOT / RVEG
ELSE
        NAAORG       = GAAORG - MRRORG
END IF
```

The description of the dynamics of non-structural carbohydrates by incorporating a reserve pool in the algorithm has been copied from van Keulen and Seligman (1987). Though functioning well, this exercise has subsequently been replaced by a highly simplified approach in order to assure compatibility with original PS123 versions.
The reserve pool of non-structural carbohydrates in wheat is reported to reach values of about 5 - 35% of the dry mass of stems and leaves (van Keulen and Seligman, 1987, Fischer, 1983, Russell and Wilson, 1994). This suggests that wheat at anthesis tastes very much like sugarcane if these carbohydrates are saccharose. The reserve pool might function as an assimilate source for grain filling. According to Kiniry, cited by Russell and Wilson (1994) stems and leaf sheaths of wheat that was severely shaded from 10 days after anthesis till maturity lost up to 29% of their dry mass compared to unshaded controls. Unfortunately the effect on grain yield is not mentioned though the same authors report that removing the entire wheat flag leafs at anthesis resulted in a grain yield decline of only 15%. Resuming, organ specific negative net assimilation appears a reasonable assumption to occur. Translocation of the reserves is reported highly stress dependent, assuring grain filling even when stress occurs. A.o. stress due to severe shading and due to water shortage are reported, both implying reduction of gross assimilation (FGASS).

Van Keulen and Seligman (1987) and Goudriaan and van Laar (1994) made the partitioning of assimilates to a reserve-pool a function of RDS. In MANA, the maximum amount of reserves is input as a fraction of stems and leaves (RESFR). From anthesis till the start of leaf senescence and while NAASO has negative value (what in the present version very rarely occurs), then the daily translocation of reserves to grains is a linear function of the source of reserves and the time factor (TCTR) used by van Keulen and Seligman (1987). As such reserve translocation is defined as stress depending.

```
RESVEG      = RESFR * (LIVSLEAF + SSTEM)                          [kg/ha]
RES         = RESVEG                                              [kg/ha]

IF INTFRSO  >= 0.5 AND RDS < TLEAF / TSUM THEN
IF NAASO    <= 0 THEN
       RESSO = RES * TCTR                                         [kg/ha.d]
ELSE
       RESSO = 0
END IF
RES         = RES - RESSO                                         [kg/ha]
IF RES      <= RESRES THEN RES = RES
RESVEG      = RES                                                 [kg/ha]

NAASO       = NAASO + RESSO                                       [kg/ha.d]
NAALEAF     = NAALEAF -  0.33 * RESSO                             [  ,,   ]
NAASTEM     = NAASTEM -  0.67 * RESSO                             [  ,,   ]

ELSEIF (INTFRSO < 0.5 OR RDS > TLEAF / TSUM OR NAASO > 0) THEN
       RESVEG= RESVEG                                             [kg/ha]
END IF
```

RESFR is a constant defined in the crop physiology file and arbitrarily se to reach a maximum of 20%. RESRES are residual reserves (to avoid negative reserve pool values) and TCTR is time factor for reserve translocation for what a value of 0.5 (for wheat?) is suggested by van Keulen and Seligman (1987).

Resuming, it might be worthwhile to consider to define partitioning to vegetative structures during grain filling as being higher than zero and equal to maintenance respiration requirements and before grain filling partitioning (between roots and shoots) could be defined dynamically as a function of occurring stress. If so, reserve pool dynamics (and partitioning) should be incorporated. If maintenance of vegetative structures during grain filling remains defined as it is, negative net assimilation is allowed to occur and description of the reserve pool dynamics should not be incorporated in the algorithm. At present, the reserve pool dynamics are not functionally incorporated in the model.

FGASS at PS1 depends solely on FGC (CFWATER = 1). At PS2, a water sufficiency coefficient (CFWATER) is calculated which influences FGASS directly. The water balance subroutine is complicated and no adaptations have been made except for the incorporation of residual (fallow) water. Fallow is common practice in Hamadan province.
Estimated upper and lower depths of residual water (respectively FALLUP & FALLOW) are input from file to calculate a quantity of residual water (FALLW; cm). The dynamics of fallow water are simplified; fallow water is incorporated in the water balance calculations from the moment that the root system front (RDTAP) penetrates the storage layer. Water balance calculations consider one equivalent rooting depth (RD); the surface soil is considered as one homogeneous compartment. Daily soil matric suction (PSI; cm) is calculated as well as the corresponding volume fraction of moisture in

the rooted soil (SMPSI; cm3/cm3). The daily growth (RDTAPGRWTH: cm/d) of the volume fraction of residual moisture of the storage (soil) layer (SMFALLOW) is integrated over RD and added to SMPSI. The contribution of SMFALLOW to the water balance is made a function of the crop specific root distribution factor (RDISTR). The rooting pattern of wheat is reported to have a relatively homogeneous distribution with depth (rooting distribution of most crops shows an exponential decrease with depth) and RDISTR has been set at 0.85. The remaining 15% are incorporated when RDTAP extends deeper than FALLOW. The effect of only 5 cm. of residual fallow water stored between a depth of 60 cm. till 120 cm. on the simulated (rain fed) wheat grain yield at Ekbatan station is considerable because the maximum rooting depth of 125 cm is reached at flowering. Most of the stored water becomes available just before grain filling.

As mentioned, the PS123 water balance is of a complicated nature. It is difficult to foresee the consequences of adaptations. The soil is defined to have 4 compartments:

1. a possible present soil surface mulch layer with suction of PSIMUL (cm.)
2. the equivalent depth of an uniformly rooted compartment with matric suction PSI (RD)
3. the phreatic level at depth ZT (cm.) with suction PSI = 0
4. the zone between RD and ZT with matric suction ranging from 0 till PSI (cm.)

Both upper and lower boundaries of compartments 1 and 2 are open to net downward or upward water flows. Actual infiltration rate (cm/d) is a.o. function of texture determined default infiltration capacity values (reference sorptivity (SO; cm/d^2) and hydraulic permeability of transmission zone (KTR; cm/d). Actual capillary rise (CR; cm/d) is according to Rijtema's texture determined default functions (1969). When SMPSI exceeds the pore volume fraction during one time step (Dt), the excess in compartment 2 drains to compartment 3.

The actual transpiration rate (TR; cm/d) is zero when the rooted soil is excessively wet (SMPSI > SM0 - 0.04). Else TR is function of SMPSI and the transpiration rate possible (TRM; cm/d). However, when rooted soil is drier than SM0 - 0.08 cm^3/cm^3 then TR is equal to the maximum uptake rate of water by the crop (MUR cm/d) with a maximum of TRM cm/d. MUR is a function of the crop specific leaf suction (PSILEAF; cm), the rooted soil's matric suction (PSI) and the plant- and root resistance to flow (RPLANT & RROOT; d).

$$CFWATER = TR / TRM \qquad [\ -\ ]$$

As mentioned in § 2.2.2.1, the hydraulic characteristics of the soil material, associated with the Ekbatan experiments, are generic default parameters for the texture class LOAM. In situ measurements might improve the explanatory- and deterministic value of PS-2 model runs. However, when data quality is not fully guaranteed, default values are accurate and valuable substitutes.

Full integration of the dynamics of salt (ECET; mS/cm) leading to an increase of PSI, cannot be omitted. FAO (1972) estimates reduction of crop yield as a function of the salt concentration of irrigation water (ECEW) and Mahler (1970) suggests ratings. According to Sharifi and van Keulen et al. (1996), ECEW has a low value at Ekbatan research station

4.2.4.3.2.2 Foreseen model adaptations for estimation of the yield potential at PS-3

First model adaptations with respect to simulation at PS3 are based on the model CPBKF (Verberne et al., 1995) though not finalised. Calibration of the nitrogen balance and crop performance of CPBKF are based on fertiliser experiment data reported by Leenaars (1993) as part of the research framework as described by Leenaars et. al. (1992). The nitrogen balance itself is based on extensive work on wheat (Groot, 1987).

Analysis of PS123 or MANA in its present version confirms the practical and general applicability of the model for evaluation of nitrogen- and phosphorus fertilizers requirements. Parameter requirements are limited to the soil (material) class and no-fertilized yield. In this §, a first step will be described to allow potential yield estimation at PS-3. The procedure is to combine an empirically established relationship between fertiliser application and experimental yield figures, with the dynamically simulated yield potential at PS-2. The average response of irrigated wheat to fertiliser application- and the associated deviation from the average values, are illustrated in fig. 4.13. and fig. 4.14. The original experiment data from Ekbatan- and Ghareh Gol research stations, are listed in annex 1. The relation between grain dry mass and fertilisation dose has been established by linear multiple regression:

dependent variable: Y; averaged measured irrigated grain dry mass [kg/ha]
independent variables: N, N^2, P, P^2, (N+P), $(N+P)^2$, (N*P), $(N*P)^2$ [kg/ha]

$Y = 3666 - 0.0436 * N^2 + 14.563 * (N+P)$ $\qquad$ $R^2 = 0.88$, std.err. = 208

The predicting equation was built by stepwise selection of the independent variables. Stepwise selection implies that at each step a variable is entered as a function of descending correlation coefficient and that variables with too low significance are eliminated from the equation. The degree of fit (the intercept included) is represented by $R^2 = 0.88$ (adjusted $R^2 = 0.86$). The significance of the predictor variables is represented by the student's T values, which were -3.96, 6.60 and 28.05 for N^2, (N+P) and the constant (unfertilised yield) respectively). The other evaluated variables had student's T values ranging from -0.32 to +0.82.
The experiment data without the unfertilised yield included, were best described with an accuracy of $R^2 = 0.92$ (adjusted $R^2 = 0.90$), while the equation goes through the origin (0):

$Y = 78.369 * (N+P) - 0.2665 * (N+P)^2$ $\qquad$ $R^2 = 0.92$, std.err. = 1485

The applicability of this empirical relationship when integrated into the dynamic simulation model, is restricted to attain maximum values of grain dry mass as simulated at PS-2 and minimum values of 0 and is further limited to irrigated wheat and -barley. For Land Use Systems with simulated grain yields at PS-2 lower than the intercept of 3666 kg/ha (unfertilised irrigated yield), is assumed that production is best described by the equation through the origin, which implies that it is assumed that production is limited by nutrient (N and P) shortage and that differentiation according to fertilisation regime thus will result in differentiated simulated yield values.

The use of empirical relationships between yield and other variables for yield estimation might improve the fit between simulated yields and actual yields, but applicability will be limited to circumstances which are comparable with the experimental conditions. Incorporation of the relationships however permits to gradually be replaced by process based descriptions, implying generalisation of model applicability.

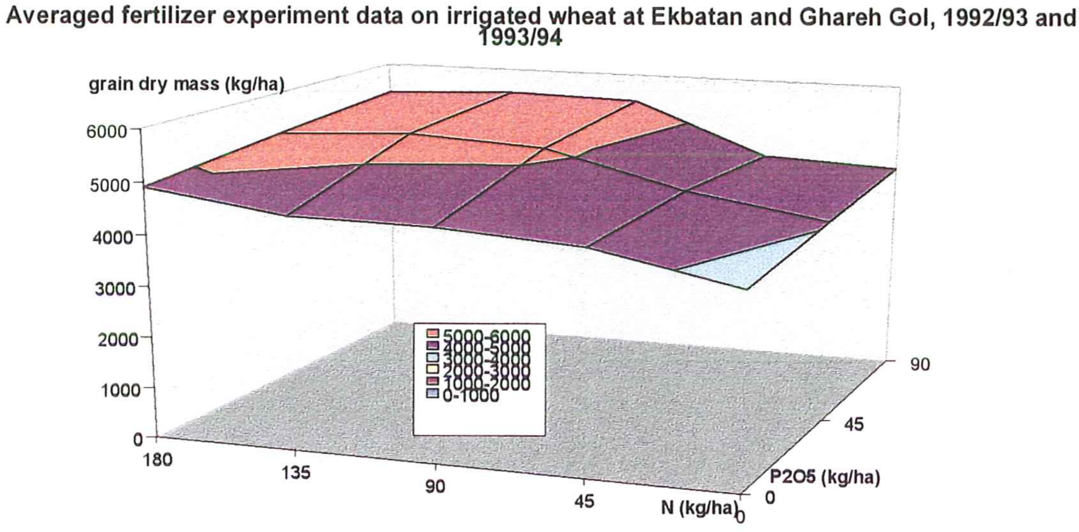


Figure 4.13. Averaged response of irrigated wheat to application of nitrogen (N) and phosphorus (P2O5) in the form of urea and di-ammonium phosphate as observed in experiments at Ekbatan and Ghareh Gol, 1992/93 and 1993/94.

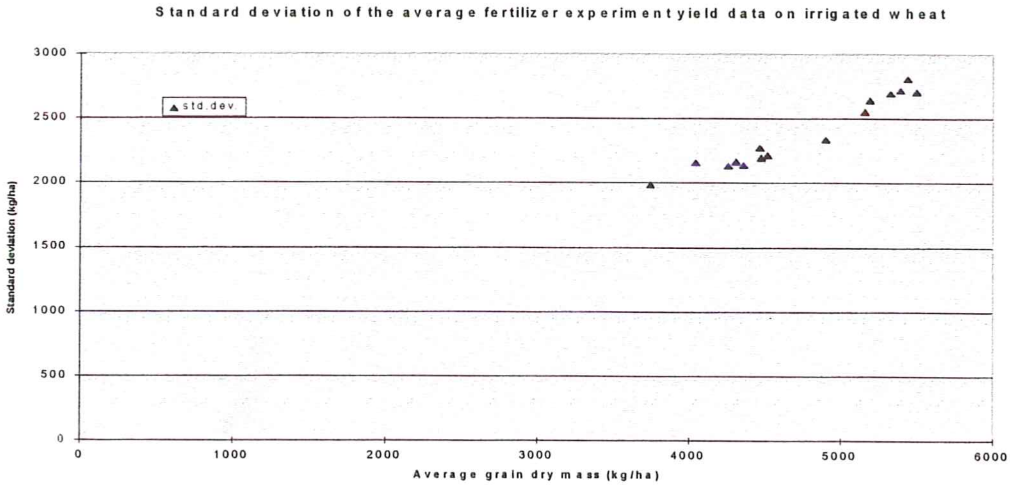


Figure 4.14. Standard deviation of the averaged response of irrigated wheat to fertilisation as observed in experiments in Ekbatan and Ghareh Gol.

The above empirical relationships between fertiliser application and yield, as derived from Ekbatan- and Ghareh Gol experiments, show unfertilised yields of 3666 kg/ha on average. Associated base uptakes are about 295 kg N/ha and 40 kg P/ha respectively. Calculation of these figures is presented in annex 2. As well presented in annex 2 are measured nutrient contents of soil and crop of unfertilised experiment sites. These soils have on average 0.7% of organic carbon and 0.08% of nitrogen (in the assumed topsoil of 25 cm with a bulk density of 1.5 kg/dm^3), which implies that nitrogen must have been mineralised at a yearly rate of 10%. If this would be true, the organic matter of the soil would drop from 0.7% to below 0.07% within 8 years of continuous cultivation. Whatever, k = 10% is very high as well as the nutrient base uptakes as derived from the nutrient contents, which in their turn are high as well. The measured contents of N, P and K are respectively 4, 5 and 2.5 times as high as reported minimum contents. This seems to imply that unfertilised irrigated wheat production of these experiments was not limited by nutrient shortage but by water shortage.

4.2.4.3.2.3 Crop physiology parameters

The physiology of wheat is well researched (van Keulen and Seligman, 1987, Fischer, 1983, Russell and Wilson, 1994, Ritchie et al., 1988). The crop file is based on parameter definition and default- and generic values as presented by Driessen and Konijn (1992) which are partly derived from van Keulen and Wolf (1986).

The structure of the crop (variety) files is as follows (see list of acronyms for explanation):

```
CROPLABEL$
C3C4$, T0, TSUM, TLEAF, TLOW, RDSROOT, RDM, RDINT, PSILEAF
SLAMAX, SLAMIN, KE, TCM, RLEAF, RROOT, RSTEM, RSO
AERENCHYM, WTG, RESFR, RDISTR
ECLEAF, ECROOT, ECSTEM, ECSO, NSO, NSTRW, PSO, PSTRW
NRPTS
RDS (PT1)       RDS (PT2)   RDS (PT3)   ....   RDS (NRPTS)
FRLEAF (PT1)    ....        ....        ....   FRLEAF (NRPTS)
FRROOT (PT1)    ....        ....        ....   FRROOT (NRPTS)
FRSTEM (PT1)    ....        ....        ....   FRSTEM (NRPTS)
FRSO (PT1)      ....        ....        ....   FRSO (NRPTS)
```

The physiological characteristics of wheat cultivar Navid are annexed. Navid, like all other wheat varieties grown in Hamadan province has no vernalisation requirements (Akbarian, cited by Sharifi and van Keulen et al. 1996). Wheat (both irrigated and rain fed) is sown in autumn (JDN 285 - 315) and harvested in summer (JDN 190 - 210). The earlier harvesting date refers to rain fed wheat (c.v. Sardari a.o.). The growing period from sowing to harvest is thus some 265 days on average.
Russell and Wilson (1994) summarise TSUM (°C.d) values for full wheat crop development and report 1700, 3400 and 5100 °C.d for latitudes of 60, 50, and 40 °N in the European Community. For

every 100 m. above sea level they suggest to subtract 150 °C.d for winter wheat and 100 °C.d for spring sown wheat. The same authors cite Azzi (1956) and Nuttonson (1957) who contend that wheat requires 2200, 1955 and 1750 °C.d and 3360, 2760 and 2260 °C.d to complete its growing cycle at European latitudes of 30, 45 and 60 °N respectively. A base temperature for development (T0) of 0 °C was used in all cases.
According to the above figures, Navid, grown at Ekbatan station at a latitude of 35 °N and an altitude of 1730 m. would require a TSUM of about 2750 minus 125 * 17.3 = 600 °C.d for a growing cycle from 50% germination to 50% full maturity (dead ripe). A full cycle until dead ripe (grain moisture content of 12-15%) lasts about 250 days, which corresponds with about 2050 °C.d at a T0 of 2 °C. The value of T0 gave the best fit with observed experiment data from 3 seasons and best simulated dates of 50% heading and flowering in the 3 years. The moment halfway between 50% heading and 50% flowering (which differ by about 5 - 7 days) is defined as the start of assimilate partitioning to generative structures (FRSO or INTFRSO > 0). This moment (anthesis) occurs between about JDN 138 and 142, which corresponds with RDS = 0.50. Other partitioning data during the complete growing cycle were derived from van Keulen and Seligman (1987). By and large these agree with data used in WOFOST by van Diepen et al. (1989), cited by Russell and Wilson (1994). Before stem extension, some 2/3 of all assimilates go to the leaves and 1/3 to the roots. At ¼ and ½ between stem extension and anthesis (the latter defined as end of flag leaf expansion), respectively 50% and 30% are partitioned to the leafs and 50% and 70 % to the stems and roots. At anthesis newly formed assimilates are allocated to stems and roots. For Navid is was arbitrarily assumed that some 10-15% of all gross assimilates are partitioned to the leaves at the onset generative growth (SSO). Later this becomes 0%, alike partitioning to stems and roots, when 100% is partitioned to SSO.

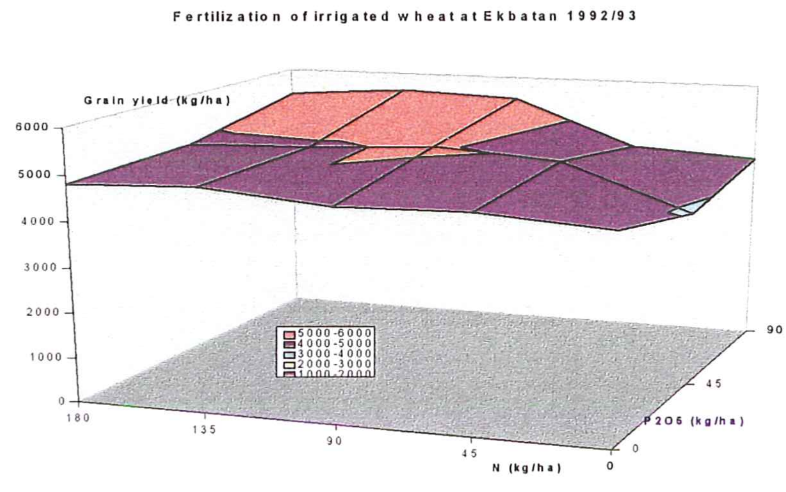
The length of the leaf life span (TLEAF; °C.d) strongly influences simulated grain yield. TLEAF is set such that LAI approaches zero about 10 days before full maturity. SLAMAX and SLAMIN agree with the values as mentioned by Russell and Wilson (1994) viz. 24 and 18 m2/kg respectively. SLA decreases with RDS and is secondary made a function of reference temperatures.
The extinction coefficient (KE) for wheat canopies varies from 0.44 to 0.55 according to Russell and Wilson (1994). KE for Navid was set slightly higher than the default value 0.5 (0.52) which distinguishes it from the default value for barley (0.44).

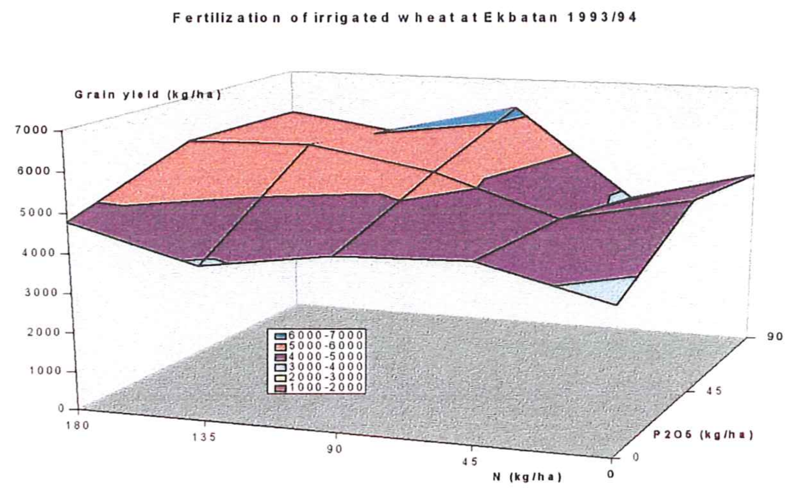
The thousand grains weight (WTG) is calculated from number of grains set according to Fischer (1983) and PS-1 production. The results agree with data from Ekbatan fertiliser experiments (35-40 g.). The root distribution index (RDISTR) was arbitrarily set to a value of 0.85.

4.2.4.3.3 Calibration results

Model calibration with respect to variety Navid specific phenology took place using crop physiology data from experiment 1 (C and D). Data from experiment 2. (A and B) became available during the month of October and were more valuable- and used to calibrate the model for dry mass production at PS2 and corresponding fertiliser requirements (PS23).

Observed dates of occurrence of phenological stages during 1993/94 and 1994/95 are presented in table 4.3. Observed grain yields at several fertiliser applications are presented in fig.15a and fig.15b. According to Sharifi et. al. (1996), wheat in Hamadan province yields up to around 10 tons of grain/ha. It is assumed that this also holds for Ekbatan.





3750 ± 2000

Figure 4.15. (a & b) Fertiliser experiment data on irrigated wheat, c.v. Navid, at Ekbatan 1992/93 and 1993/94. Applied fertilisers were urea (46% N) and di-ammonium phosphate (16% N and 21% P).

Table 4.3. Observed and simulated irrigated wheat grain yields (kg/ha) and fertiliser gifts (kg/ha) at Ekbatan

Observed Navid	1992/93	1993/94	(1994/95)
PS1	(10000)	(10000)	(10000)
PS2 irrigated	5600	6300	-
PS3 irrigated	4000	3600	
PS23 N / P *	90 / 40	90 / 40	
Simulated Navid	**1992/93**	**1993/94**	**(1994/95)**
PS1	9150	9250	(8400)
PS2 irrigated	5550	6700	(5500)
PS3 irrigated **	3500	3500	(3500)
PS13 N / P ***	160 / 90	165 / 100	(140 / 80)
PS23 N / P ***	55 / 30	90 / 50	(55 / 35)

* are reported fertiliser experiment doses (kg /ha). According to Sharifi (pers.comm.) the experiment data refer to applied elements of N and P2O5 (P = P2O5 * 0.436)

** is assumed to have been 3500 kg/ha for all (!) seasons

*** are simulated N and P requirements (kg/ha) when applied in the form of urea (split application, 46% N) and mono-ammonium phosphate (11% N & 21% P) on a soil formed in calcareous slightly alkaline weathering material.

Simulated crop phenology indicators are conform observations and indicated in annex $. Indicators are duration of development and the moments of stem extension and anthesis. The latter is evident from the dates of simulated (start of) daily increase of stem- and grain dry mass. Maximum LAI values at PS-1 remain within theoretical ranges.

Simulated constraint-free yield values (PS1) in the 3 years considered are somewhat lower than what was assumed to be attainable but as can be seen in fig. $, some 10 tons of grain yield at PS1 is attainable in about 1 out of 5 years. These values are comparable, though with caution, with wheat yield potentials in East Azarbijan as reported by Sharifi (1992). He reports simulated biophysical wheat yield potentials of about 9000 kg/ha on the best soils.

Simulated and measured irrigated wheat yield agrees very well. Crop parameter values used are the result of both this calibration exercise as well as the performed validation exercise. Simulated irrigated wheat growth in 1993/94 after calibration and validation is illustrated in fig.4.16. which presents daily Leaf Area Index (LAI) and daily grain growth at PS-1 and PS-2. (The graphed yields differ slightly from above tabulated yields on account of slightly different management (see § 2.2.3).

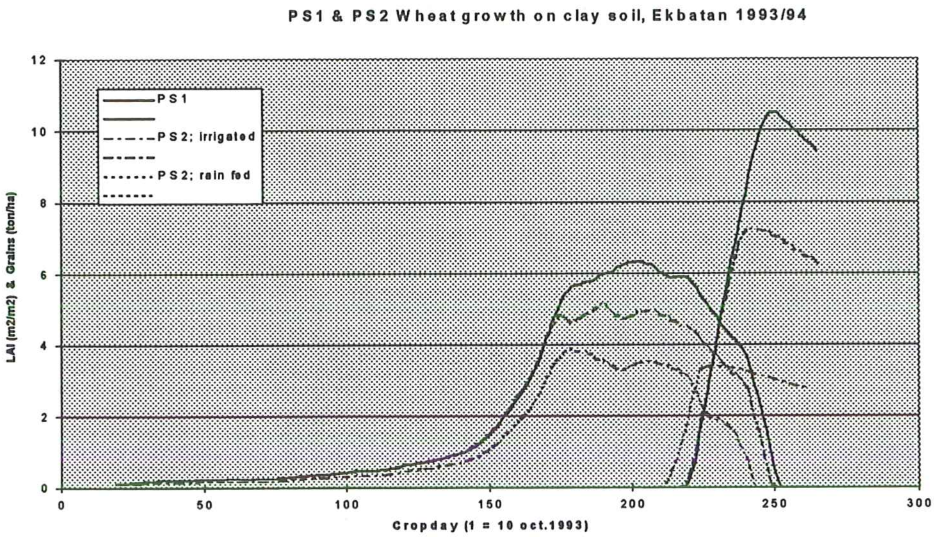


Figure 4.16. Simulated growth at PS-1 and PS-2 of wheat (irrigated and rain-fed) on a clay soil, Ekbatan 1993/94. Early season growth is illustrated by LAI, late season growth by grain dry mass.

Application of fertilisation doses of 90 kg N/ha and 90 kg P/ha results in maximum yields as observed in the fertiliser experiments of both years. Higher P doses were not applied, higher N doses led only to a small decrease in observed grain yield. Agreement between these actually applied doses and the simulated fertilisation requirements for maximum yields, appears to be good for both elements, though best for P. In 1992/93, simulation underestimates N- and P requirements with a factor of about 1/3 - 1/4, while in 1993/94 simulation fits observations on N and overestimates P requirements with a factor of 1/4.

It should be stated that the simulation was performed with the settings according to mono-ammonium phosphate which contains 11% N and 21% P, while di-ammonium phosphates contain about 16% N according to Ahn (1970). The types of fertiliser experiment doses were not explicitly expressed in the data sets, but they referred to pure N and P2O5 according to Sharifi.

Recommended fertiliser doses are 200 kg urea/ha and 150 kg di-ammonium phosphate/ha. Corresponding element doses are 200*0.46 + 150*0.16 = 115 kg N/ha and 150*0.21 = 30 kg P/ha. This recommendation seems rather good when compared with the fertiliser experimental data which show a slight over estimation for N and a slight under estimation for P. Probably it would be worthwhile to consider to apply less urea and more di-ammonium phosphate.

Measured leaf nutrient concentrations and derived absolute amounts of adsorbed nutrients in the experiments (targets) have not (yet) been taken in account.

4.2.4.4 Validation of the simulation model

Validation of the model serves to evaluate- and possibly ameliorate model performance under a wider range of circumstances. These (changing) circumstances are associated with changing crop physiology and changing management practices at Ekbatan. Model performance is tested by evaluating simulation for 10 years (9 seasons) under different weather specifications. Different crop physiology and different management practices tested are:

Wheat
PS2 irrigated (c.v. Navid)
rain-fed (c.v. Sardari)
PS23* irrigated (c.v. Navid)
rain-fed (c.v. Sardari)
(* refers to fertiliser requirements at PS2)

Barley
PS2 irrigated (c.v. Joh!)
rain-fed (c.v. Zarjo)
PS23 * irrigated (c.v. Joh!)
rain-fed (c.v. Zarjo)

4.2.4.4.1 Analysis and preparation of available data for validation purposes

The following data were available (for irrigated wheat see § 4.2.2.3.1):

Experiment data from Ekbatan station (for land characteristics see § 4.2.2.3.1) and from Tajarak potato research station. Data on land characteristics (location, weather, soil) of Tajarak station are missing though the Crop Inventory Group however can provide the exact location. Tajarak station has recently installed a weather station which measures all parameters required for crop growth simulation according to PS123. Data are not available as yet. Sharifi recommends to substitute weather data from Ekbatan. Both stations are located on weakly sloping piedmont plains. According to the project initiation mission report (Sharifi and Driessen, 1996) these soils of these plains are presumably cambisols in limestone weathering, deep, neutral or slightly alkaline and clayey throughout, what agrees with the soil map of Iran (Dewan and Famouri, 1964). The hydraulic characteristics of these soils are not known; PS123 default values were used as suggested for texture class "clay".

Rain-fed wheat:

Management and crop data for Ekbatan 1993/94
- cultivation date
- fertiliser doses
- variety (Navid)
- grain production at full maturity (kg/ha)

Management and crop data for Ekbatan 1994/95 and 1995/96
- cultivation data
- seed rate (kg/ha)
- fertiliser doses (kg/ha)
- variety (Sardari)
- grain production at full maturity (kg/ha)

Management and crop data for Tajarak 1994/95 and 1995/96
- seed rate (kg/ha)
- fertiliser doses (kg/ha)
- varieties (Sardari)
- grain production at full maturity (kg/ha)

Irrigated barley:

No experiment data were available. Substitute data were derived from mission reports, from the barley knowledge base elaborated for the European Community (Russell, 1990) and from de Ruiter et al. (1993).

Rain-fed barley:

Management and crop data for Tajarak 1994/95:
- seed rate (kg/ha)
- variety (Zarjo)
- grain production at full maturity (kg/ha)

More (substitute) data on management practices and associated yields of rain fed- and irrigated barley and wheat are derived from general information sources as mission reports, pilot area Razan figures and Iranian agricultural statistics. Crop characteristics of barley were derived from default values provided by Driessen and Konijn (1992) and values suggested by Russell (1990).

Data from experiments with rain-fed wheat at Ekbatan (varieties Navid and Sardari) were evaluated; grain yields were reported to vary between about 6000-7000 kg/ha. It seemed prudent not to use these data (Sharifi, personal comment).

4.2.4.4.2 Validation exercise

Validation resulted in:
- adaptation of the algorithm
- construction, adaptation and fine-tuning of crop physiology parameters

4.2.4.4.2.1 Adaptation of the simulation model; standardization of the timing of irrigation; Mana.exe

Adaptation of the model for effects of elevation has been reported in § 2.2.2.2.2. Further, assumptions with respect to timing of germination and irrigation will be discussed hereafter. Originally, the day of germination and the various irrigation inputs and the soil humidity at germination were exogenous inputs. This was done for calibration purposes (with dates documented and available) with initial soil

matric water suction at germination set to a value of 1000 cm). For multi-year applications, a standard SOWDAY has been defined with an initial soil matric water suction (PSIINT) of 16000 cm. Germination takes place when PSI reaches a value of less than GERPSI (set to 1000 cm. for all land uses). Germination implies (re-)start of crop growth at RDS = 0. When a crop dies due to fatal drought within SOWPERIOD (pre-defined allowed period of sowing according to crop calendars) then re-sowing is simulated.
The timing of irrigation is tentatively defined as a function of crop phenology. No irrigation is applied before stem extension. This does not always correspond with practice but has been chosen to avoid excessive accumulation of salt within the rooted depth upon early irrigation, what leads to soil matric water suctions in excess of PSILEAF. The first irrigation application is given at the moment of stem extension (SEXTENSION), the second at ANTHESIS (early heading), the third at flowering, corresponding with the moment at which 100% of all assimilates are allocated to the grains (GRAINFILL) and the fourth when the first leaves die (RDS = TLEAF/TSUM). Between stem extension and early heading, the crop is irrigated when CFREF (past 5-day average water sufficiency coefficient) is less than 0.15.

With regard to the validation results for wheat and barley (§ 2.2.3.2.1 where the sum of net irrigation gifts to barley was found to exceed irrigation needs of wheat), it can be concluded that CFREF of irrigated barley drops below 0.15 more often than CFREF for irrigated wheat.

The described standardisation will need further amelioration. CFREF, the arbitrary factor 0.15 and the identified phenological stages, are based on rather superficial analysis of calibration experiments. These experiments and the simulation results, show that irrigation is especially effective when applied during grain filling. Then, irrigation contributes directly to grain dry mass increase. Using CFREF as a drought indicator, permits to use SMPSI as done by Sharifi (1992) who postulates that irrigation in Azarbijan is applied if SMPSI is less than half of field capacity. Note that CFREF refers to crop stress rather than soil drought.

4.2.4.4.2.2 Adaptation of crop physiology parameters

All parameter values that define the physiology of the wheat- and barley varieties Navid, Sardari, Joh! and Zarjo are annexed. Rain-fed wheat (Sardari) has a somewhat shorter growing cycle (TSUM) than irrigated wheat (Navid) and a somewhat longer (relative) period of grain filling. The heat sum (°C.d) after anthesis however remains about equal. At RDS = 0.2, when partitioning to leaves peaks to a value of 75% for Navid, partitioning to leaves peaks to 70% for Sardari, implying a stronger start of stem elongation. The maximum % of leaf and stem dry mass at anthesis which is confiscated by non-structural carbohydrates (assimilate reserve pool) is raised from 20% to 30%.
Compared to wheat, barley has a shorter growing cycle in terms of °C.d (TSUM). The leaf life span (TLEAF) is only slightly more than half of TSUM, compared with 1/2 - 1/3 for wheat. The leaves of barley thus die sooner than those of wheat. The lowest permissible temperature is higher (leading to 2 seasons of crop failure out of 9 due to excessive cold (below -30 °C). Barley has higher SLA (27-17 m2/kg), a lower light extinction coefficient (0.44), deeper maximum rooting depth (150 cm.) and

stronger attainable leaf water suction capacity (16000 cm). The assimilate reserve pool defined is only 1%. At germination, about 2/3 of all assimilates are partitioned to the roots and 1/3 to the leaves (for wheat 1/2 and 1/2). Peak of assimilate partitioning to leafs (at RDS = 0.2) is less than for wheat varieties and all remaining assimilates are allocated to the roots. The root distribution factor (RDISTR) is slightly less (0.75) than for wheat, indicating a greater relative proportion of roots in the topsoil. Difference between the irrigated barley variety (Joh!) and the rain-fed barley variety (Zarjo) is limited exclusively to the difference in TSUM and TLEAF.

In summary, barley has a shorter duration for full crop development. Less is partitioned to leaf growth but favourable assimilation values can be attained due to relatively high SLA values and low light extinction. Water in soil can be transpired to a greater soil moisture suction at a greater depth.

4.2.4.4.3 Validation results

4.2.4.4.3.1 Verification at PS-2 with available experiment data

Reported grain yields of rain-fed wheat at Tajarak (c.v. Sardari) varied between 1350 and 1900 kg/ha for the seasons of 1994/95 and 1995/96. Corresponding weather data of 1995/96 could yet be obtained. Fertilization was limited to 15 kg N/ha and 30 kg P/ha. Simulated yield potentials amount to 5950 kg/ha on clayey soil and 2950 on loamy soil.

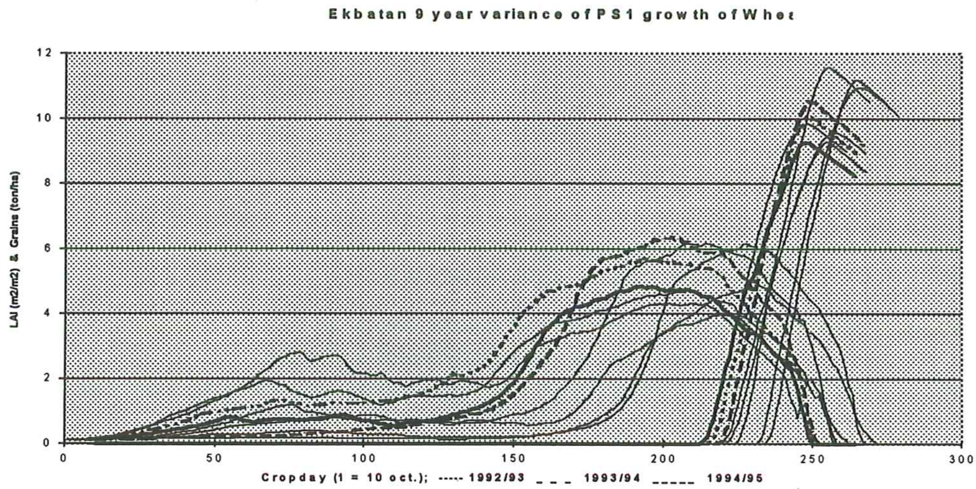
Yield figures of rain fed wheat, variety SXL/Glenson are available only for the 1995/96 season. The date of sowing is unknown. Yields at the highest fertiliser inputs varied between 2500 and 2800 kg/ha (80 kg N/ha and 60 kg P/ha), and between 2000 and 2300 kg/ha at lower gifts. With even lower applications (20/0 kg N/P /ha) yields fall to the range reported for Sardari (see above).

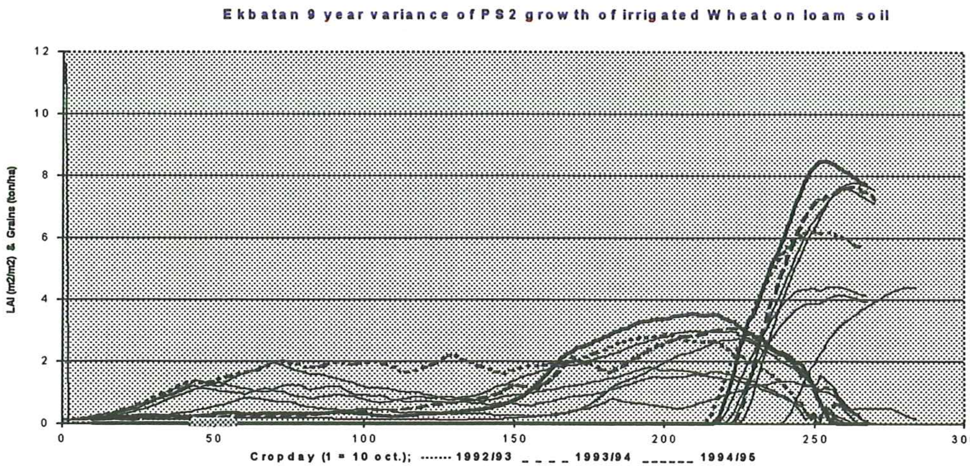
Actual grain yields of rain-fed barley (c.v. Zarjo) at Tajarak varied between 1400 and 1850 kg/ha for the season of 1994/95. Fertilisation is unknown. Contrary to cropping calendar of barley suggested by Sharifi and van Keulen et al. (1996), this rain-fed barley is not sown in spring but in autumn. Simulation on clayey soil resulted in a potential yield of 2600 kg/ha.

Data on (experiments on) irrigated barley are absent. According to the GIS-database of historical crop data of Razan pilot area, irrigated barley out-yields irrigated wheat with the exception of the 1993/94 season. Simulation of land-use systems with barley on clayey soil resulted in about 7400 in 1993/94 and 5400 in 1994/95.

Multi-year simulated potential crop growth and grain yields of wheat and barley varieties Navid, Sardari, Zarjo and Joh!, are presented in fig.7 and fig.8 respectively. Simulated phenological indicators and -yields for the 9 years on 3 soil texture classes are presented in tables . Sowing dates correspond with the first day of the sowing periods indicated in the crop calendars for the Razan pilot area (Sharifi and van Keulen et.al., 1996); the germination day is made a function of soil humidity, with presumed re-sowing if necessary. According to the cropping calendars, wheat is about 1-7 times irrigated and barley 5 times. The simulated results are based on irrigation timing (of net gifts of 7 cm.) as a function of phenological development and incidental periods of severe drought, (still) irrespective of the type of crop. In all situations, about 50 mm. of residual fallow water is assumed in the 60-120 cm. soil depth. Soils correspond with default texture classes as provided by Driessen with the exception of 'clay loams'. Clay loam parameter settings were adapted for preliminary calibration purposes. The phreatic level was set to a steady 555 cm. Soil surface water storage capacity is 4 cm. for both rain-fed and irrigated crops.

Fig. 4.17 and fig. 4.18 illustrate the multi-year variance of biophysical-, irrigated- and rain-fed wheat growth potentials at Ekbatan. The Leaf Area Index (LAI) increases slowly or decreases during winter time and increases then rapidly in spring. Dates of maximum LAI coincides closely with the date of onset of increase of grain dry mass increase. The growth reducing effect of shortage of water is illustrated by comparing the graphs in order.





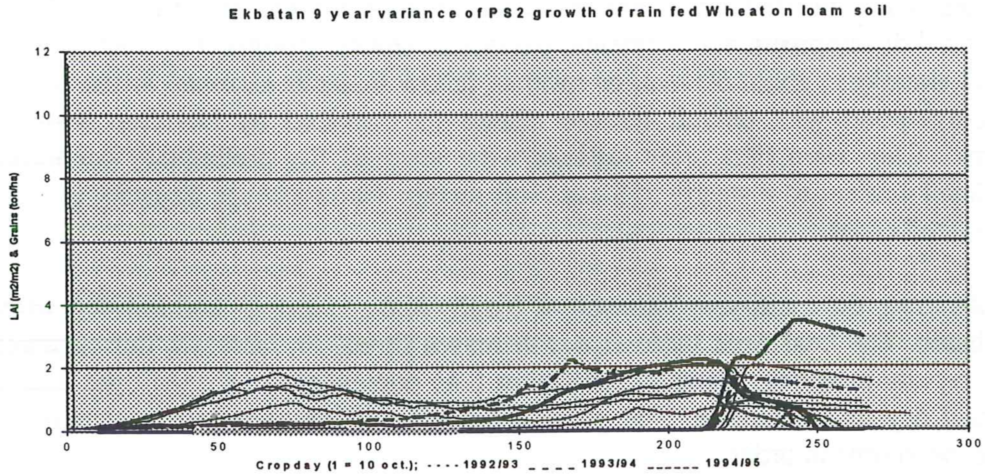
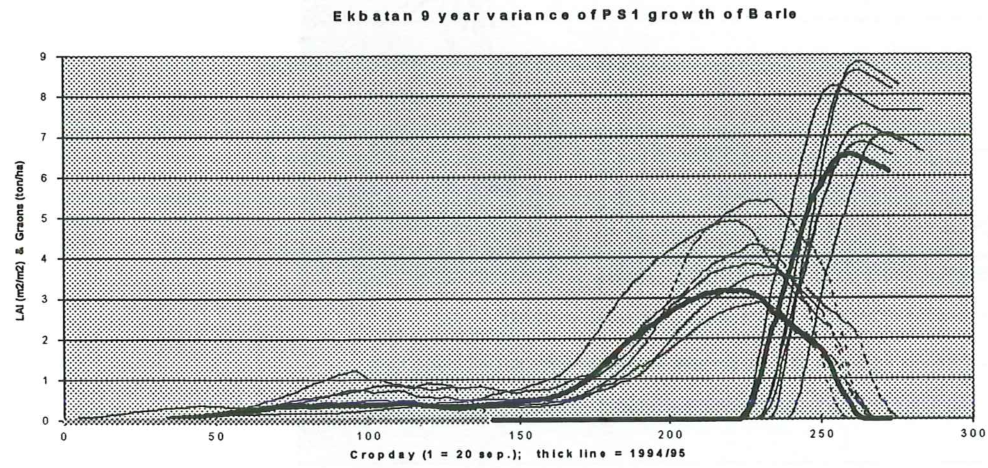
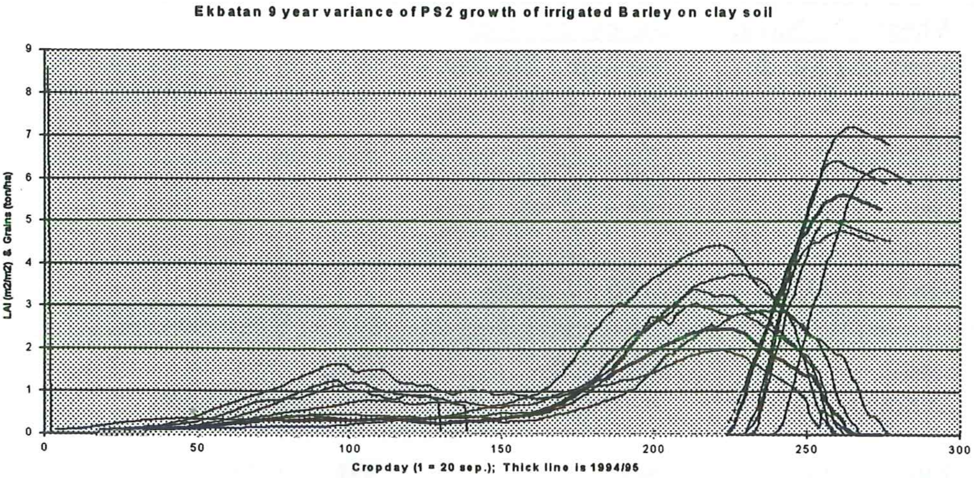


Figure 4.17. (a,b,c). Simulated multi-year (9) variance at PS-1 and PS-2 (irrigated and rain-fed) of wheat growth on a loamy soil, Ekbatan 1986/95. Early season is illustrated by LAI, late season by grain dry mass.





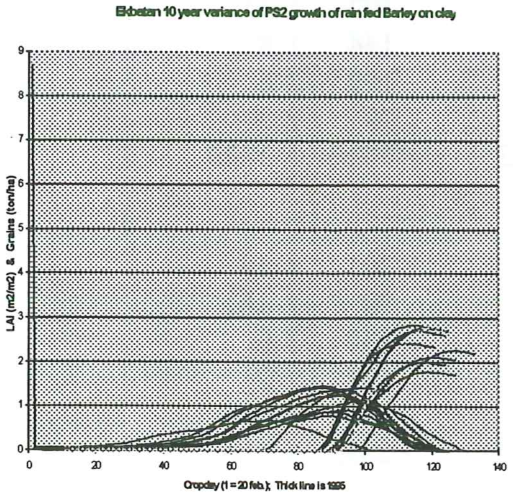


Figure 4.18 (a,b,c). Simulated multi-year (9) variance at PS-1 and PS-2 (irrigated and rain-fed) of barley growth on a clayey soil, Ekbatan 1986/95. Early season is illustrated by LAI, late season by grain dry mass.

Simulated crop growth with various settings for 'soils', 'crops' and 'management' and for 9 years of weather data:

PS1	Wheat, c.v. Navid	Barley, c.v. Joh!
	Average / Std.dev.	Average / Std.dev.
Germination	296 / 8	297 / 10
Stem extension	96 / 15	93 / 39
Anthesis	140 / 7	129 / 54
Maturity	189 / 5	185 / 59
Irrigation sum	/	/
Yield	9283 / 778	7166 / 3059

PS2	Loam	Clay loam	Clay
	Average / Std.dev.	Average / Std.dev.	Average / Std.dev.
Wheat, c.v. Navid			
Germination	296 / 13	299 / 11	301 / 14
Stem extension	79 / 32	101 / 13	102 / 14
Anthesis	125 / 45	144 / 8	144 / 8
Maturity	/	192 / 6	192 / 6
Irrigation sum	25 / 9	28 / 0	29 / 2
Yield	5310 / 2367	5602 / 1212	5826 / 1073
Wheat, c.v. Sardari			
Germination	305 / 17	299 / 11	301 / 14
Stem extension	66 / 39	98 / 15	99 / 16
Anthesis	106 / 57	138 / 8	138 / 9
Maturity	/ 69	188 / 6	188 / 7
Irrigation sum	0 / 0	0 / 0	0 / 0
Yield	924 / 863	2440 / 1547	2593 / 1645
Barley, c.v. Joh!			
Germination	302 / 15	293 / 11	293 / 11
Stem extension	97 / 41	89 / 38	89 / 38
Anthesis	132 / 55	128 / 53	127 / 53
Maturity	230 / 71	186 / 59	185 / 59
Irrigation sum	42 / 15	38 / 14	38 / 14
Yield	5733 / 2762	5177 / 2424	5773 / 2555
Barley, c.v. Zarjo			
Germination	51 / 0	54 / 3	54 / 3
Stem extension	110 / 34	112 / 8	111 / 7
Anthesis	136 / 41	137 / 7	137 / 7
Maturity	183 / 24	174 / 7	174 / 7
Irrigation sum	0 / 0	0 / 0	0 / 0
Yield	2344 / 819	1870 / 487	2235 / 443

Averages and standard deviations are calculated on basis of 9 years of weather data (10 years for rain-fed barley which is sown after winter time). Seasons with premature crop failure (due to prolonged drought) are considered in the calculations for wheat and not for barley. For this reason, standard deviations for wheat on loamy soils have high values as the rain-fed crop failed in 2 out of 9 seasons and the irrigated crop in 1 out of 9. Barley (c.v. Joh!) failed in 2 out of 9 seasons due to excessive cold and calculations are based on the remaining 7 years. Excessive cold means colder then TLOW, which was set at -30 ºC for barley and -35 ºC for wheat.

As can be seen, average irrigated yield potentials vary between about 5000-6000 kg/ha. Average rain-fed yield potentials for wheat vary between about 1000-2500 kg/ha and for barley between about 2000-2500. The lower value for rain-fed wheat corresponds with loamy soils. Variation of relative yields of irrigated crops between soil texture classes agree with those of rain-fed crop, but the trends are different for wheat and barley. All simulated yield values appear realistic.
Simulated irrigated wheat potentials at PS-2 for the season of 1994/95, which was exceptionally wet, are close to 7700 kg/ha on all 3 soil types considered. In the mission report of Sharifi et.al.(1996) it is mentioned that during this season in Razan township, the actual yield of irrigated wheat was between 3200-5000 kg/ha. These latter figures refer to farmer yields which are not achieved with near-perfect irrigation regime and with lesser quantities of fertiliser applied.
Simulated rain-fed wheat yield was 3000-6000 kg/ha; actual yields were 1800-3800 in the Razan area. Irrigated barley yield potentials are simulated 3550-5300 kg/ha; yields in Razan area amounted to 3000-4000 kg/ha. Simulated rain-fed barley yields were 2350-2750 kg/ha. Apparently, simulation- and experiment results differ considerably from farmer results (during this rainy year). This observation suggests that, even though multi-year averages and agreement with experiment data seem satisfactory, simulation under specific circumstances (weather, management, soil) can easily divert from average values. It must however be clear that simulation concerns production potentials which, by definition, differ from actual productivity.

The cumulative net irrigation gifts for barley exceed those of wheat what is not conform expectations. Generally, barley is more drought resistant- and has lower irrigation requirements than wheat. In § 2.2.3.2.2 is explained how irrigation decision taking has been standardised. Present description of decision taking is probably is more favourable for grain production than is actually practised in Hamadan province.

Estimation of maximum fertiliser requirements (PS23) is done by subtracting nutrient base uptake (calculated on basis of defined minimum concentrations) from nutrient uptake at target yield and subsequently dividing by fertiliser nutrient content and fertiliser recovery fraction.

4.2.4.4.3.2 Generalisation

Validation as defined by Sharifi and cited in § 2.2 concerns control of model performance with a range of parameter settings including the range expected in the simulated land-use system. For practical reasons, only a limited number of parameters is considered. If not specified, simulated yield potentials refer to wheat yields.

Soil of calibration experiment

PS-2 yield potential in:

Year	1992	1993	1994
on:			
Loam	5523	6714	5495
Clay	4857	4577	6808

The model was calibrated for a wheat crop on a loam soil with irrigation timing as described. Simulated and measured experimental yields were near equal. On clayey soil, which occupies the greatest area of Hamadan province, simulated yields are generally within acceptable ranges but differences between soils seem to be very year-specific. Compared to yield on loamy soil, yield on clayey soil differs by -2200 to + 1300 kg/ha. The soil parameter settings are 'best estimates' but may still differ considerably from real soil properties in Hamadan province.

Elevation

Biophysical yield potentials (PS-1) in:

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994
at:									
1730 m.	10065	10297	9009	10528	8929	8373	8895	9207	8246
17 m.	12119	13404	12594	12801	12620	11735	12185	11778	8436

max.LAI at:

17 m.	9.3	7.5	6.5	9.2	6.4	7.2	8.7	9.2	5.7

Clearly, the simulated biophysical production potential of wheat (PS-1) is very high at sea level. The same holds for the maximum LAI value in about half of the years. Be aware however that although elevation has been reduced, weather circumstances did not change. This is not realistic. Most probably, the number of sunshine hours per day are less at lower elevation height and so is the intercepted radiation, leading to a reduction of daily assimilation. Simulated yields (PS-2) of irrigated wheat at an elevation of 17 m. were between +1000 to -300 kg/ha from those generated for an elevation of 1730 m.

Depth of the phreatic level; fixed or variable.

PS-2 yield potential in:

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994
at a:									
Fixed depth	3856	5190	5566	5089	5621	6891	6184	6207	7829
Variable depth	3866	0	4872	5120	5623	6924	6205	6211	7848

The (simulated) grain yield of wheat (c.v. Navid) on a clay soil and irrigated according to standardised timing with an initial depth of the phreatic level of 5.55 m., is hardly affected by the depth of the phreatic level, fixed or variable. However, in 1 out of 9 scenarios, the phreatic level rises to within the rooted soil and kills the crop (at JDN 83).

Sowing date

PS-2 yield potentials in 1992:

JDN	280	**285**	290	295	300	305	310	315	320	325
	5208	**6184**	6234	6234	6234	6258	6258	6213	6183	6183

The date of sowing of wheat on a clayey soil in the season of 1992/93 proved of very little importance for the simulated yield. Note however that these results apply only to this particular season and that germination was conditioned by the soil moisture content. In drier years, the effect on yield can certainly be very significant. Numbers in bold refer to the first sowing date on the crop calendar (simulated germination took place at JDN 330, probably after several re-sowings).

Presence or absence of residual water

PS-2 yield potentials in:

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994
with fallow	792	2655	2012	1026	1542	4829	1716	2794	5971
without fallow	146	1363	768	282	673	3015	799	1730	4026

The simulated effect of only 50 mm. of residual soil water at a depth between 60-120 cm. appears very significant. As average yearly rain fall amounts to 250 mm., 50 mm. of extra water is indeed considerable, especially if the moment at which this water is tapped by the wheat rooting system is favourable. This happens during the period just before early heading. Residual water has also a significant effect on barley grain yield even though the water is tapped earlier in the season. The root distribution of barley is such that less water is tapped when the deepest roots meet the concerned soil layer and more when the front roots have rooted the entire layer. This differentiation between the two crops with respect to root distribution is entirely based on general pictures of rooting patterns and needs to be verified.

4.2.4.4.3.3 Validation results at PS-3

The empirical relationship between fertiliser application and grain yield as calculated in § 2.2.2 has not been subject to validation because the relationship has not yet been calibrated. Other available experiment data than the data used for establishing the equation, concern only rain-fed crops. These generally yielded lower than the constant in the equation which has been assumed to be the minimum yield for well watered and not fertilised wheat and barley, which implies that the production of these rain-fed crops was not limited by nutrient shortage. Whether this assumption is correct, which implies that rain-fed crops don't response to fertilisation, is subject for follow-up research.

Grain dry mass at PS-3 = 3666 - 0.0436 $*N^2$ + 14.563 * (N+P)

4.2.4.5 Conclusions on model calibration and -validation

After validation and parameter fine-tuning for c.v. Navid, scenarios with original calibration settings led to (simulation) results which correspond even better with experiment data than the original (calibrated) simulation results. Simulation with soil moisture dependent germination and crop phenology dependent irrigation timing resulted in earlier germination, higher (simulated) grain yield potentials and lower total net irrigation.

Adaptation of the algorithm and definition of the crop physiology parameter values produced simulated (grain) dry mass production and crop development, which appear to agree very well with available experiment data and confirm what might be expected from historical yield figures from Razan pilot area. Simulated irrigated wheat grain yield differed only a few percentages from experiment data and associated nitrogen fertilisation requirements were underestimated with maximally 30%. Simulated phosphorus requirements differed ± 25% from observations. Model adaptation and crop parameter definition are both verified.

Agreement with validation experiment data from the season of 1994/95, which was an exceptionally rainy season, remains relatively poor. This may be caused by the fact that Ekbatan weather data substituted Tajarak weather data.

Simulated yields of selected crops and varieties are strongly dependent on the amount and timing of irrigation. Some scenarios failed due to excessive cold or prolonged drought, the latter only on loamy soils. As yearly rainfall is only about 250 mm. residual fallow water is highly effective for rain-fed crops, despite the low assumed quantity of 50 mm.

The role of reserve or 'pool' assimilates has not been investigated in the simulations;
reserve accumulation may play a role where great differences exist between day- and night-time temperatures. This applies to Ekbatan only for a few days in the year.

One should be aware that simulation results for single land-use systems (with defined weather, soil and management) can divert clearly from average values, expected values or measured values. Model performance is such that reliable yield estimation for the Razan pilot area is feasible.

4.2.5. Design of a conceptual data model for crop forecasting system *

Crop forecasting system, when modelled by one process, consists of many external entities, which some of them are represented in the context diagram given in Figure 4.19.

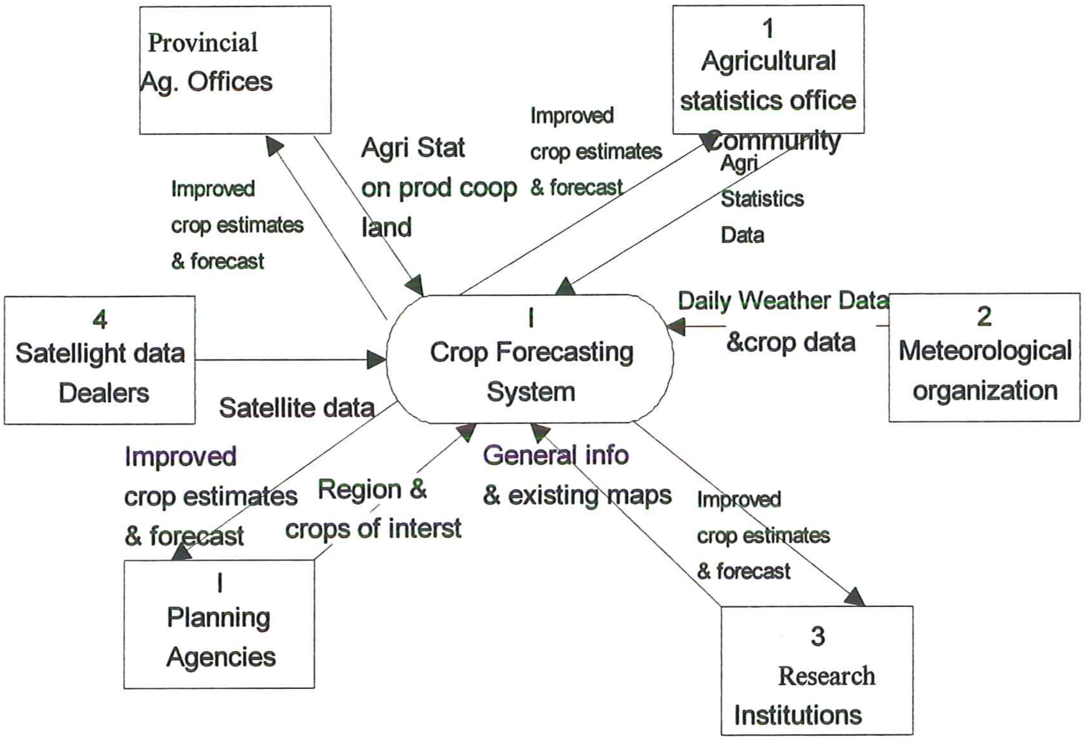


Fig 4.19.: Context Diagram

4.2.5.1 Main Subsystems of Crop Forecasting System

As has been explained earlier crop forecasting system consists of three subsystems namely crop inventory subsystem and yield forecasting subsystem. These are graphically represented in the top level diagram of the system (Figure 4.20.). The first two processes are depicting the two main subsystems and the third representing a process which integrates the two subsystems. Following the diagram the main processes which all together with their input/output data make up the crop forecasting system are explained briefly.

* This chapter is adapted from research being carried out by M. Marua.

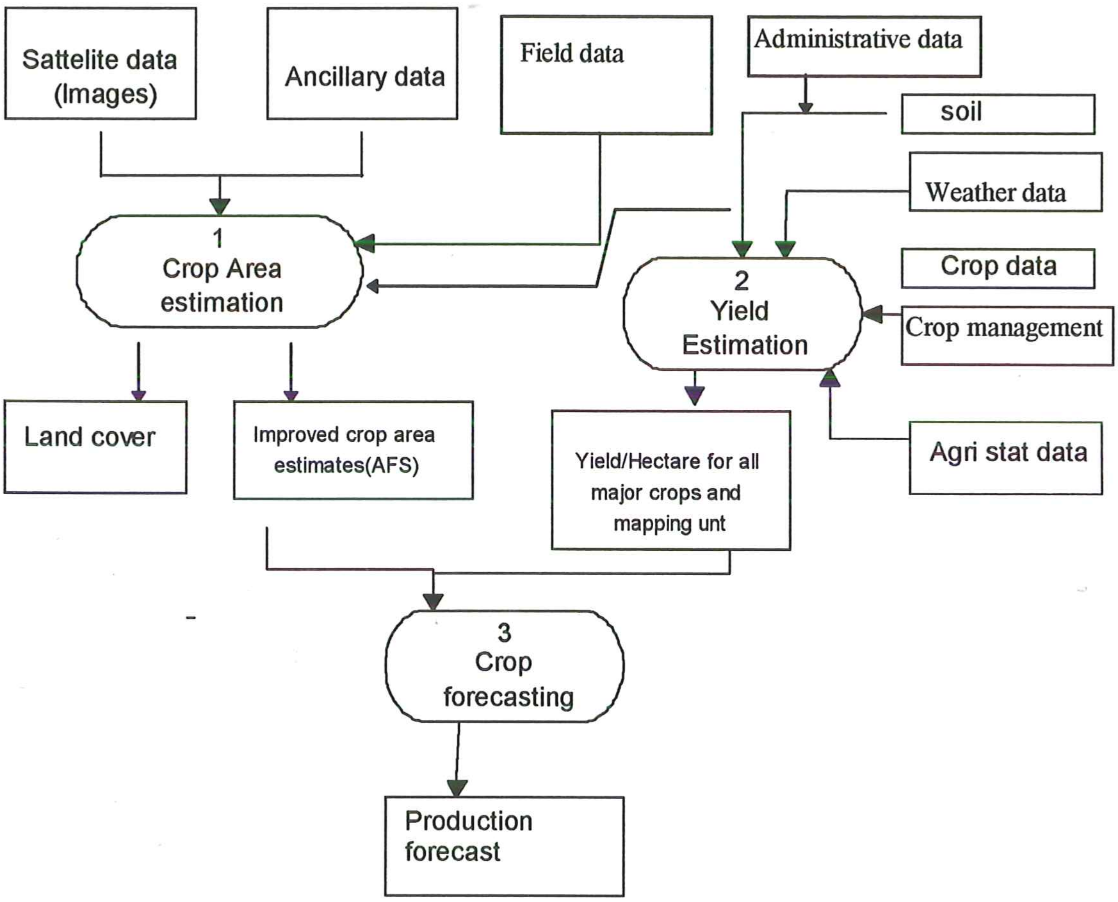


Fig. 4.20 Top Level Diagram

The first process labelled by crop area estimation As has been explained earlier, generating crop area estimates and a land cover map with its associated thematic data particularly for large area involves a number of activities like stratification, developing appropriate sampling techniques, ground survey, image classification etc. and stores for images and different types of thematic and spatial data which can be the original input, intermediate results of subprocesses and final outputs.

The second process labelled by yield forecasting retrieves administration data (administration map and village locations agricultural stat), weather data (both static weather station attributes and daily weather data), soil data (both spatial and thematic data) and agricultural statistics at village and district level (area). Based on these inputs it produces estimated yield per mapping unit for all selected major crops. The representation in the diagram does not explain anything except generalised input and output data types. This process involves models like crop growth simulation model, regression model etc. with their input datasets and output datasets.

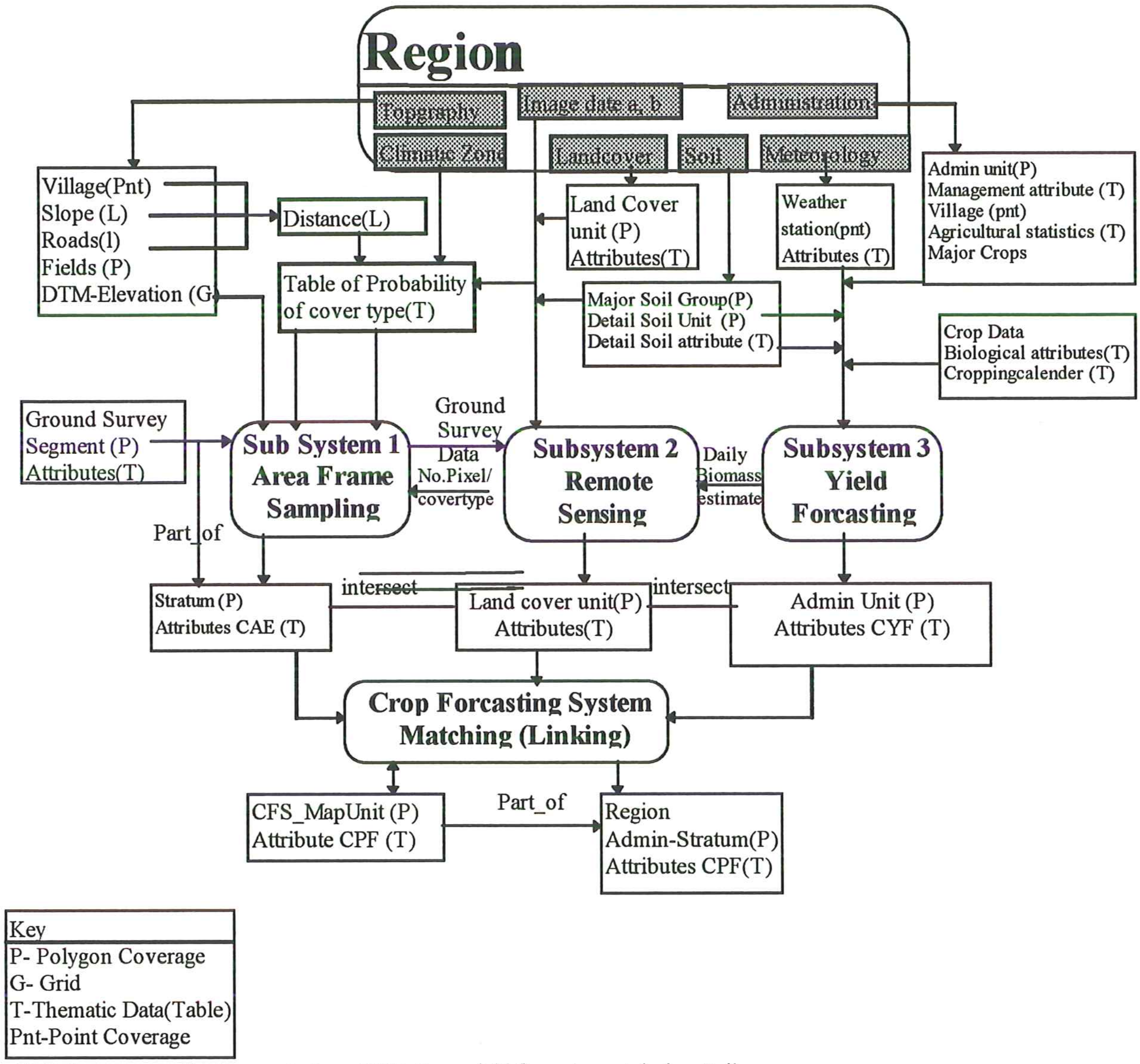
The last process is crop forecasting: It integrates the results of subsystem 1- improved crop area estimates per stratum for every crop and improved landcover map and subsystem 2- yield prediction made for every selected crop in every administration unit to produce the total production forecasted in the region covered by different types of crop type. As seem there are not much complicated processes or stores but some which are required to integrate, generalise and display the results in both spatial and thematic formats.

The above diagram shows the outline of CFS, but clearly indicates the main processes (subsystems) and stores (for input/output datasets). The advantage of the adopted methodology is that it enables to model the data at the top level and list the input/output requirements. In fact the system requirements or user requirements in general have been already started explaining together with the diagrams. The following subsection describes the data model at the top level.

4.2.5.2 Conceptual Data Model- Global Representation

The conceptual model for GIS application is always related to the requirements of some mapping discipline like soil mapping discipline or some discipline involved in spatial management or analysis like crop production forecasting. The first step is to decide which data is relevant, which entities are important, how they should be described and how their relationships should be represented. In a GIS application like CFS, this means the decision which terrain feature should be represented, which thematic description they should have and how they should be represented geometrically and in what format raster or vector. Earlier the relevant entities to CFS, thier description and their relationship have been modelled in each discipline as a precondition to describe their relationshipship in CFS at top level conceptual model.

A conceptual model describes the essential semantics of system data. As in a top level DFD, a conceptual model consists a number of symbols joined up according to certain conventions, a conceptual modelling technique known as ERD. (Hawryszkiewycz, 1994). However, for a complex system like CFS that involves diverse data, several entities and relationships and several processing units in which several entities are embedded like homogenous mapping units can not be easily portrayed by a concise ERD. The top level conceptual model represented by a top level ERD which is less concise. It is considered as a global data model since the diagram shows the data(input/output) requirements of the system or each subsystems that can be implemented at any level (regional, national, or global). In one diagram, it is difficult to represent all elements of conceptual model, though the relevant data, entities, format, are shown. The detail description of each entity and the relationship between entities from different domains will be explained while detailing each subsystems of CFS. Figure 4.21. shows the global data model of the crop forecasting system.



CAE: Crop area estimate per stratum; CYF: Crop yield forcast per Admin _Soil
CFS_Mapunit: Intersection Soil, staratum, Landcover, Soil Units; CPF: Crop production

Fig. 4.21. GLOBAL DATA MODEL- CROP FORECASTING SYSTEM

4.2.5.3 Crop Area Estimation Subsystem

Crop inventory subsystem of CFS in general includes identification of crops, estimation of their area and mapping their area. But in this section as indicated in the topic, only processes and stores necessary to crop area estimation and to producing improved crop area estimates are considered. Infact most of the processes required for crop identifications and hence mapping are all applications of remote sensing which is already indicated as a process in the model.

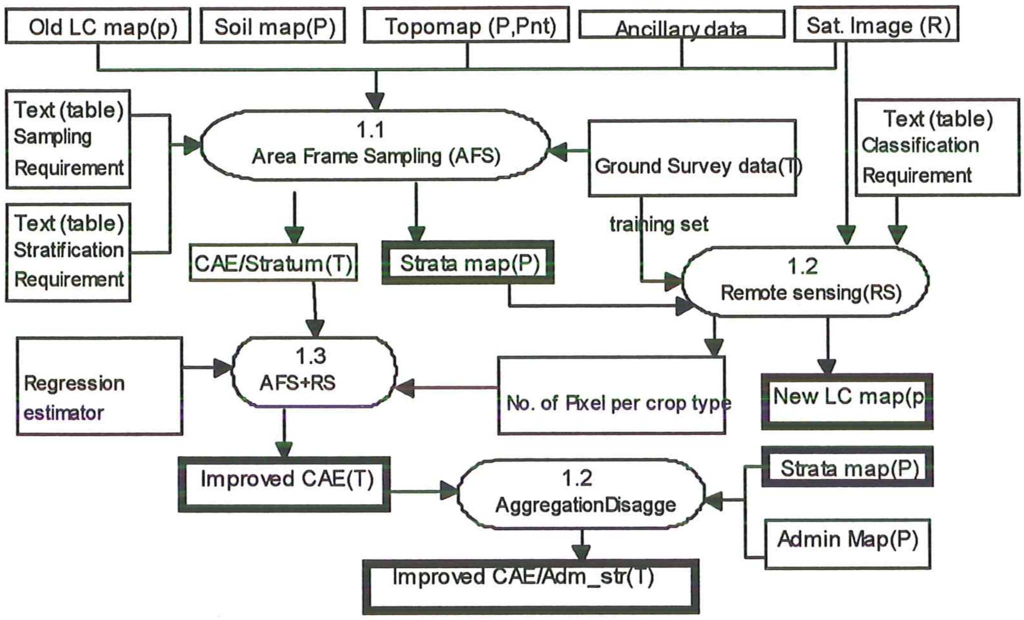


Fig. 4.22. Lower Level DFD of Crop Area estimation and Improved Land Cover Mapping

At this level four sub processes can be mentioned: area frame sampling, remote sensing, the combination of the two subprocesses and aggregation/ disaggregation.

Area frame sampling uses landcover/use, soil map, topography map and sattelite image and other ancillary like DTM, cropping calendar together with requirements for sampling, stratification and image classification to produce non spatial *crop area estimate per stratum.* Area frame sampling in general has several stages/activities involved in it. Of all stratification based on knowledge of the area, ground survey based on selected segments on topography map and derivation of crop area estimates based on the results of the above stages are most important ones.

A process or an application of Remote sensing is used to derive the outputs: *number of pixels per cover* type that can be used to improve the crop area estimates made by the above process and updated *land cover map* that can be an intermediate input to the next process of the subsystem. To do so, this process uses selected training set obtained from ground survey data and images of a specific date or dates with the appropriate classification method.

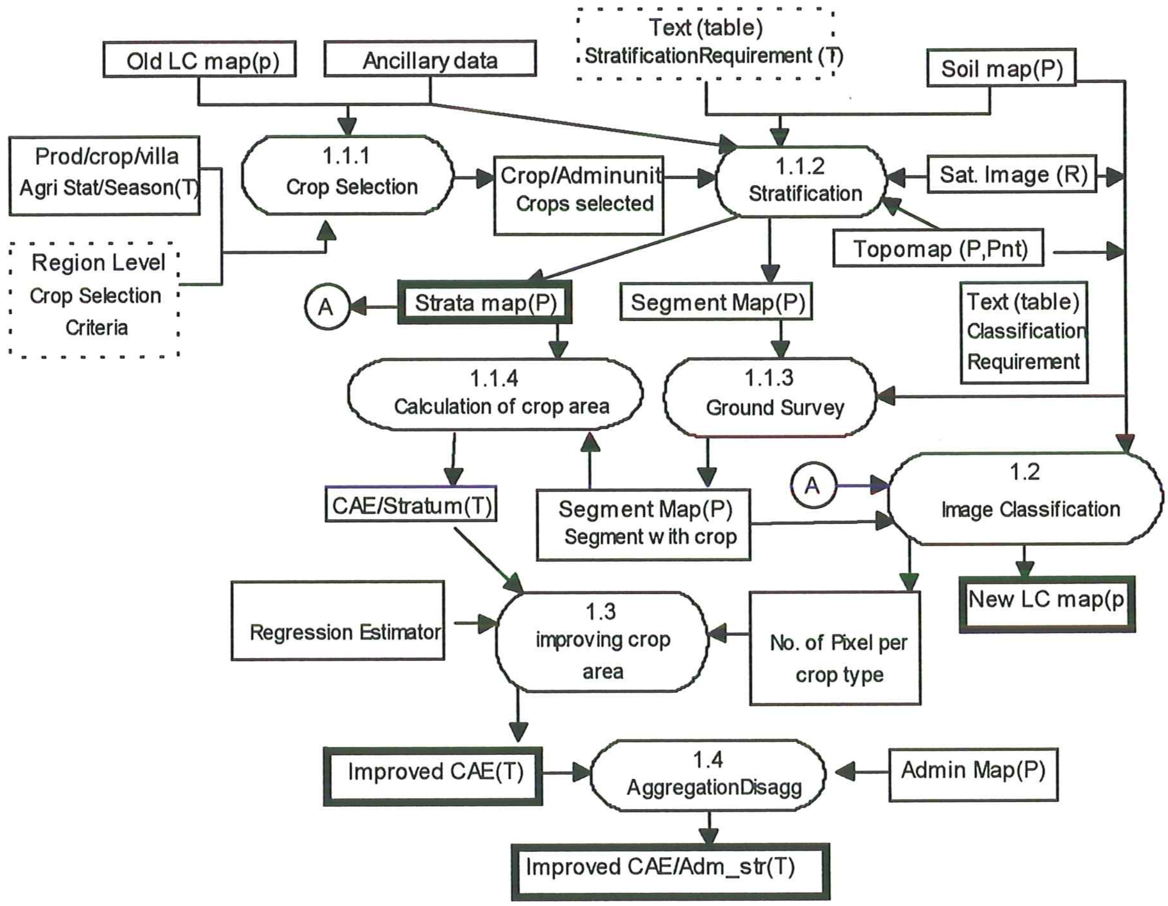
The process labeled by **AFS+RS** uses the results obtained from the two subprocesses to linearly compare the two results and then to produce *improved crop area estimates.*

The last process: **Aggregation/Desaggregation** first aggregate (calculate sum of) crop area of crop identified in a stratum and then disaggregate this total crop area to every administration unit if it is intersected by that stratum. Superimposition of administration boundary and strata map of the region provides the properpotion (area) of a stratum in every administration unit and hence to derive the crop area for each unique combination of these units and the crop itself.

This subsystem will be further detailed to explicitly identify processes and data stores that can be input the physical model which maps these components in a certain computer system.

4.2.5.3.1 Detailed Processes of Crop Area Estimation and Landcover Mapping

At detailed level, sub system one has six processes which creates the data stores required to put subsystem 1 in operational manner. Here it should be noted some processes given in the diagram below may still have subprocesses but for the sake of emphasis and legibility. All stores for input/output data sets (except intermidiate data sets) of these processes are given. For instance image classification, as explained earlier, has several subprocesses but non of them are mentioned here since the diagram should be as simple as possible for legibility one hand and it is not the purpose of this report to include all activities in CFS.



CAE= Crop Area Estimate; LC= Land Cover; Adm_str= intersection of admin unit and stratum P= Polygon; T = Table

Fig 4.23. Detailed Process Model of Subsystem 1

Short description of the newly added processes will be given below and the corresponding table that describe the input/out put data of each process will be given in table 3.1 Appendix 3. Note that CRUD matrix provides an information that tells which process Retrieve, Create, Updates, and Delete records or attributes of entities. (Adopted from CGMS- ver 3.1).

Processing Unit 1.1.1- Crop selection: A responsible body in the region may identify major crops (that can be both staple, cash or fodder crop) with the corresponding attributes like crop calendar (that may vary with in the region), therefore by this process new variety can be added and/or unwanted crop can be deleted. The selection of crop may be based on historical data, old land cover map or a some other criteria. These data can be availed for this group from CFS data base. Since the selected crops have spatially varying properties like crop calendar a table that consist subregion, crop, crop calendar, etc. will be created. Note that attributes of biological properties will be dealt with in subsystem 2.

Processing Unit 1.1.2- Stratification: A certain region will be stratified based on some criteria (that might be stored in a table format or a sort of document) and the inputs data image (that is stored in Image data base) and some other ancillary data like landcover map(old), soil map, cropping calendar(from crop/admin. file) and topography map that consists village and field structures. The results of this processes are selected segments and strata map that might be obtained by visual interpretation of images or super imposition of factors of crop growth like soil and landcover maps.

Processing Unit 1.1.3- Ground Survey: Note that as you can see it is included no only processes that can be automated but also processes which may not be momentary automated (like ground survey that can sometimes be automated by the use of GPS and computer technology) are included. The identified segments which can be drawn on topo map or hardcopy of image is used as input to the process to create a data store of correctly identified segments with field crops.

4.2.5.3.2 Conceptual Data Model of Subsystem 1- Detailed Level Data Model

An important aspect of systems analysis is the analysis of data. As with a DFD, an abstract or implementation independent model of the data is developed first. This is then converted to a physical implementation (Hawryszkiewycz, 1994). According to him and others, data analysis is a more difficult subject than DFD since data abstraction is not as obvious as a DFD abstraction. A data model, however, is often more abstract and difficult to relate to actual system components. Often it contains more than one function or it must show associations that are not visible as physical things in the system. This implies data model has to be made up of more than one level, and different ideas are used at each level.

Due to this justifications, we have already shown the conceptual model of crop forecasting system. This model represents only the major data objects from each domain and the relationships between them. The model together with definitions of the each and every objects given above captures the natural semantics of the system, although the relationships between the objects from the different domains are not yet explicitly represented. Now at this level it is necessary to organise the conceptual model in a shape since we have already divided the system into its main subsystems and shown the break down of each subsystem, as it has been elaborated for subsystem 1 and as it will be done the same to the other subsystems in the respective sections, using different levels of DFD.

Detailed data model of subsystem 1, as given below, shows the objects from different domains (as identified above) required to the system, objectified relationships, cardinality (that shows how many times an object in an entity set is associated with other objects in another sets) and relation type (may or must).

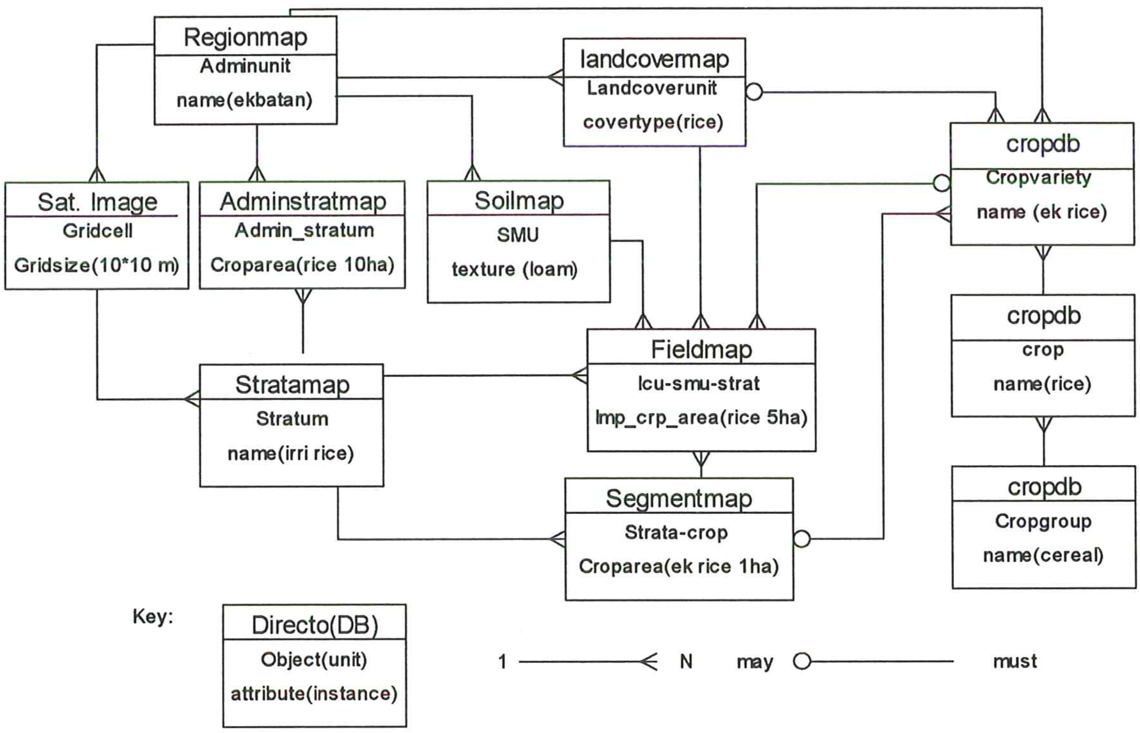


Fig 4.24. Detailed Data Model of Subsystem 1

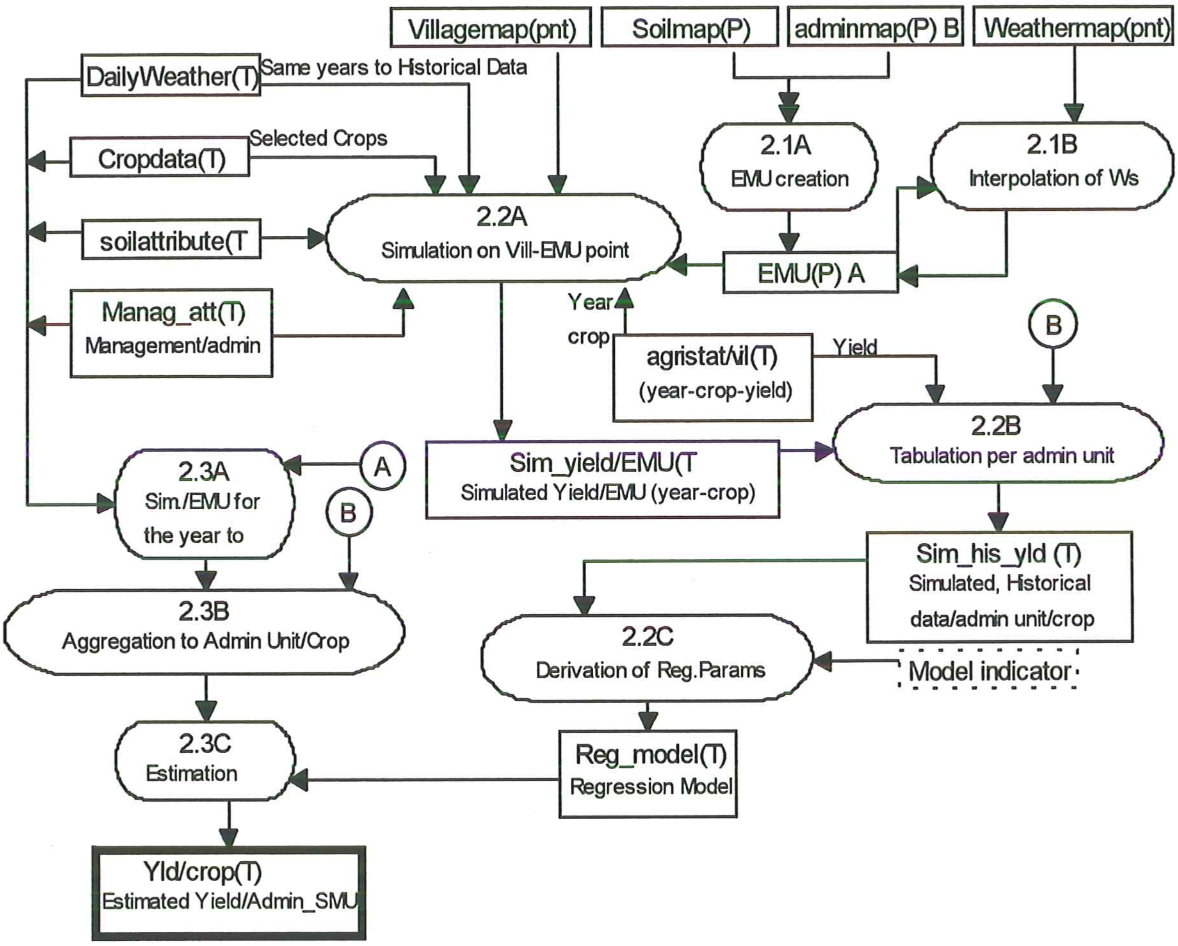
The above diagram describes the conceptual data model of subsystem 1 as the database can be a table if the instances (values) of the object (entity) identified are records or a spatial database (coverage or gridbase including raster data) if the instances of the object (entity) are described interms of polygon, line, point or raster cell. that has position and topological relationship with other instances. The instantiation is given only for one of the attributes that clearly describe the object or that can be an identifier. In Appendix 4, data dictionary of these objects is given. The data dictionary define the objects interms of their source (processing unit or database), atomic object (polygon, line, point, raster cell, or non spatial) and instances for major attributes.

4.2.5.4 Yield Forecasting Subsystem

This subsystem, as explained in chapter three, consists of several activities/stages which has to be performed before arriving to a simulation model which can be used to quantify group growth or to estimate a crop yield or biomass during the growing period. Some of them can be mentioned as follow:

- quantitative description of the natural resource base in terms of relevant for agricultural production like weather, soils, water resources.
- identification and collection of possible crops/varieties with their relevant physiological/ phenological/ physical characteristics
- development of crop growth simulation models appropriate for the major crops in the study area
- calibration and verification of the models
- derivation of yield per crop and per mapping unit
- crop forecasting system.

When considered the whole activities of development of a model which enables deriving yield/crop/mapping unit, there are a lot of processes and datasets involved. But the assumption in this thesis is that most of the activities (except data preparation on weather/soil/climate/administration etc. and for driving yield/crop/mapping unit and system development for execution of the models) will be elaborated by others. Following bellow the processes required to simulate a crop growth which is dependent on the site where it grows and then to estimate yield which should be related to historical data are presented in the lower level data flow diagram.



P= Polygon; T = Table; Pnt= Point

Fig 4.25. Yield Forecasting Subsystem- Lower Level DFD

Calculation of Simulation Unit (EMU Creation) : The basic of any simulation model is the dependency of a yield on crop (variety), soil and weather. Before a yield simulation is performed on a certain land unit, that land unit must be uniform in terms of soil, administration boundary, hydrological unit, climatic zone and other homogeneity of crop growth factors. This process uses only soil mapping unit and administration unit to create a homogenous land unit called elementary mapping unit (EMU).

Interpolation of WS (calculation of weather data on EMU): As explained above simulation is dependent on weather and other factors so that it is necessary to interpolate the weather data in to each mapping unit (EMU). EMU- weather is calculated from the meteorological data on weather stations which are located within or nearby the study area. Before we proceed to the next processing unit it is necessary to briefly describe in the context of CFS.

Elementary Mapping Unit (EMU)- from CFS Domain- Area Object

As explained above in the "Object Definition" section above, this mapping unit does not belongs to any of aforementioned domains but it does in CFS since it is the smallest unit on which crop yield can be simulated, estimated and forecasted. Crop growth simulations are done for suitable units which can geometrically be a point or a polygon. Although in most simulation models simulations are performed on a site specific crop requirements and suitability criteria, simulations can be performed also on a polygon base information so long as the basic inputs are homogeneous all over the polygon.(Hooijer, van der Val, 1994).

The main inputs of crop growth simulation models varies from one to another. It may not be possible to identify inputs to all models since each one is designed for different purposes and hence to use different inputs (in most cases they might be similar) and different outputs. It may not necessary here to explain which model uses which input data and deliver which type of output- but one should think that there may not be a standard model as to which all of its input/output can be defined. As it is explained in chapter 4.7, in this research, PS123 (production Situation 1, 2, 3) is used as an input model to the CFS and the whole description of the model will be given there. . But generally it uses site specific soil, climatic, crop properties and requirements and other related data.
Here the assumption is that these data can be generalised to a higher mapping unit which can be represented by an area feature. So far it has been discussed on how a soil unit, weather unit, admin. unit, crop unit can be stored in the data base. The simulation unit (EMU) which depends on these units, therefore, can be created by superimposition of the factors (like soil on admin.), interpolation of weather station to every EMU and by assuming only one crop will be simulated on one simulation unit.
The following diagram is given to show its relation with the other units.

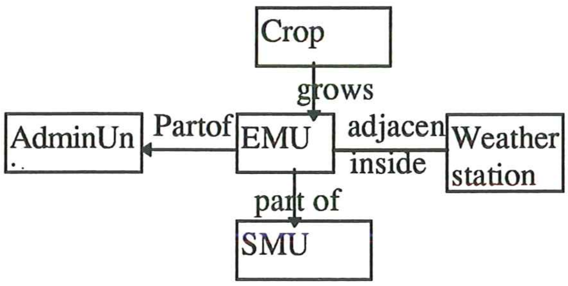


Fig 4.26. Data Model of Elementary

Mapping Unit in the context of CFS
Simulation on Village-EMU point: This process consists the core functions to simulate crop growth based on the data on units indicated above. However, this process is required to simulate for every EMU for all past years in which historical (agricultural statistics) data is available. To perform the simulation, first all the village point and the EMU should be linked by means of point in polygon operation of village map on EMU map of the region. Then the simulation will be performed for each past year in which agricultural statistics (historical data) is available and on all EMUs where the villages are spatially located. The crop data and weather data for a particular year are retrieved based on the crop and the year obtained from agricultural statistics and the soil data is retrieved based on the EMU-Village code. This process will terminate when the execution is performed for all past years in

which historical data is available. If weather data is not available for the year in which historical data is available, long-term average might be used. This will be explained latter in this chapter.

Tabulation per Admin. Unit: Here tabulation means putting the yearly or seasonal simulated yield and historical yield together in a table that contain records for one administration unit only. The final aim of CFS is to forecast production for selected major crops at the smallest administration unit. Because of that both the yearly simulated yield which is at every village-EMU intersection point and agricultural statistics which is already at village level should be tabulated together for every administration unit.

Derivation of regression Parameters: A linear regression equation or other regression model can be used for regional yield forecasting. Prior to the forecasting the regression parameters must be calculated. Regression parameters depend on administration unit and the period when yields are forecasted. The regression equation includes the average official yield and the technological time trend over the past years, with or without a model indicator to account for the year specific weather effects. (Hooijer, Van der Wal, 1994). This section will be further discussed in chapter 5. Now the developed regression model; in this process uses historical and simulated yield which account for site specific soil, weather, crop, and administration factor and a selected model indicator.

Simulation/EMU for the year to predict: After having the regression model for each administration unit, this process can be used every season to simulate for the selected crop in every mapping unit based on the weather data of the first few weeks or months of the growing season and the relatively static soil and crop attributes data. The simulated yield will be aggregated to every administration unit and the yield estimation to every administration by the subsequent processes to finally get estimated yield per administration unit and crop. But the final result is non spatial since the simulated yield on EMUs is already aggregated to every admin. unit in which adjacent EMUs does not exist.

4.2.5.4.1 Detailed Process Model of Yield Forecasting

At detailed level, sub system two has eleven processes which creates the data stores required to put subsystem 2 in an operational manner. In fact from the basic principle of data modelling, the model should not contain such a number of processes, however all the processes mentioned below are essential to clearly understand what is being performed in this subsystem. As it can be seen from the diagram, all subprocesses can be categorised into three main groups vis. data pre-processing like creation of EMU, yield simulation for the past years and estimation (forecasting) for the current year before harvest.

Processing unit 2.1.3- Generalisation: Since crop simulation here is based on mapping units which are represented by area feature, generalisation of horizon or site specific soil information is mandatory. However, this is not to mean that all parameters like rooting depth which may not be generalised simply has to be aggregated together rather all the necessary (assumptions or) data for the model to be adopted have to be handled atleast in one to many relationship.

Processing Unit 2.1.4- Calc Long Term Average (LTA): Daily weather data might be missing either on some of the climatic parameters or on some days with in the crop growing period of the year. To perform the simulation this missing values, therefore, have to be replaced by the LTA which is calculated by this process.

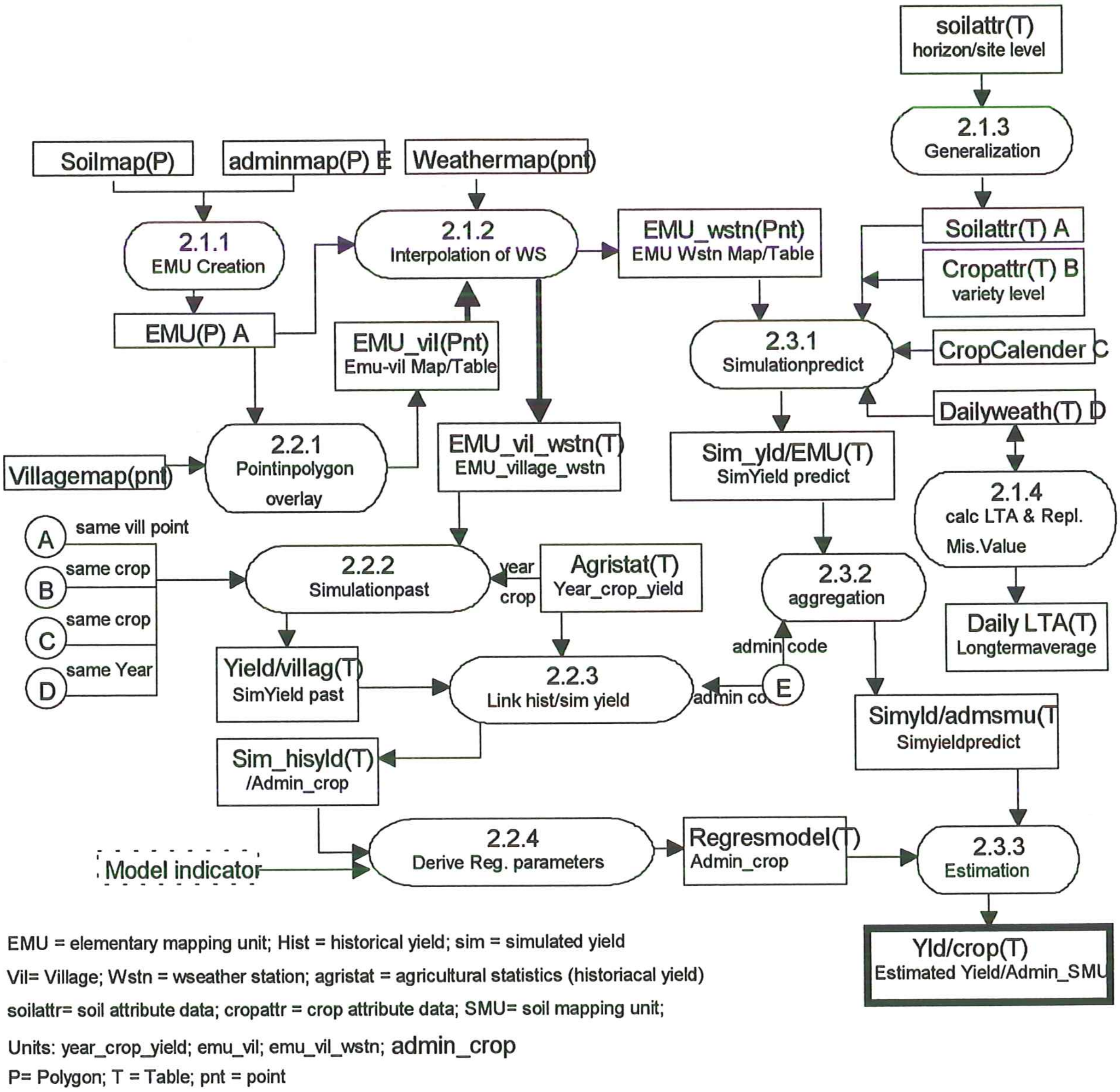


Fig 4.27. Detailed Process Model of Subsystem 2

Processing Unit 2.2.1- Point in Polygon operation: To link the villages which are spatially represented by point feature and EMUs which are represented by this area feature, this process has to be performed. So that it can be possible to link the historical data consisting year, crops and the corresponding yield with soil, crop and weather attributes of EMU in which yield will be simulated to the corresponding historical yield.

Processing Unit 2.2.3- Link Sim-Hist yield: After simulating for all villages, crops, and past years, both yields has to be tabulated for each administration unit.

Processing Unit 2.3.2- aggregation: Since the regression model is based on a unique combination of admin. unit and crop unit, the simulated yield on same EMUs but not necessarly adjacent has to be aggregated by this process to every unique combination of admin., soil and crop combination.

4.2.5.4.2 Conceptual Data Model of Subsystem 2:

Note that data modelling methods adopted to subsystem 1 also used to this subsystem and subsystem 3. The detail explanation of the method given there, therefore, can be referred to these models below.

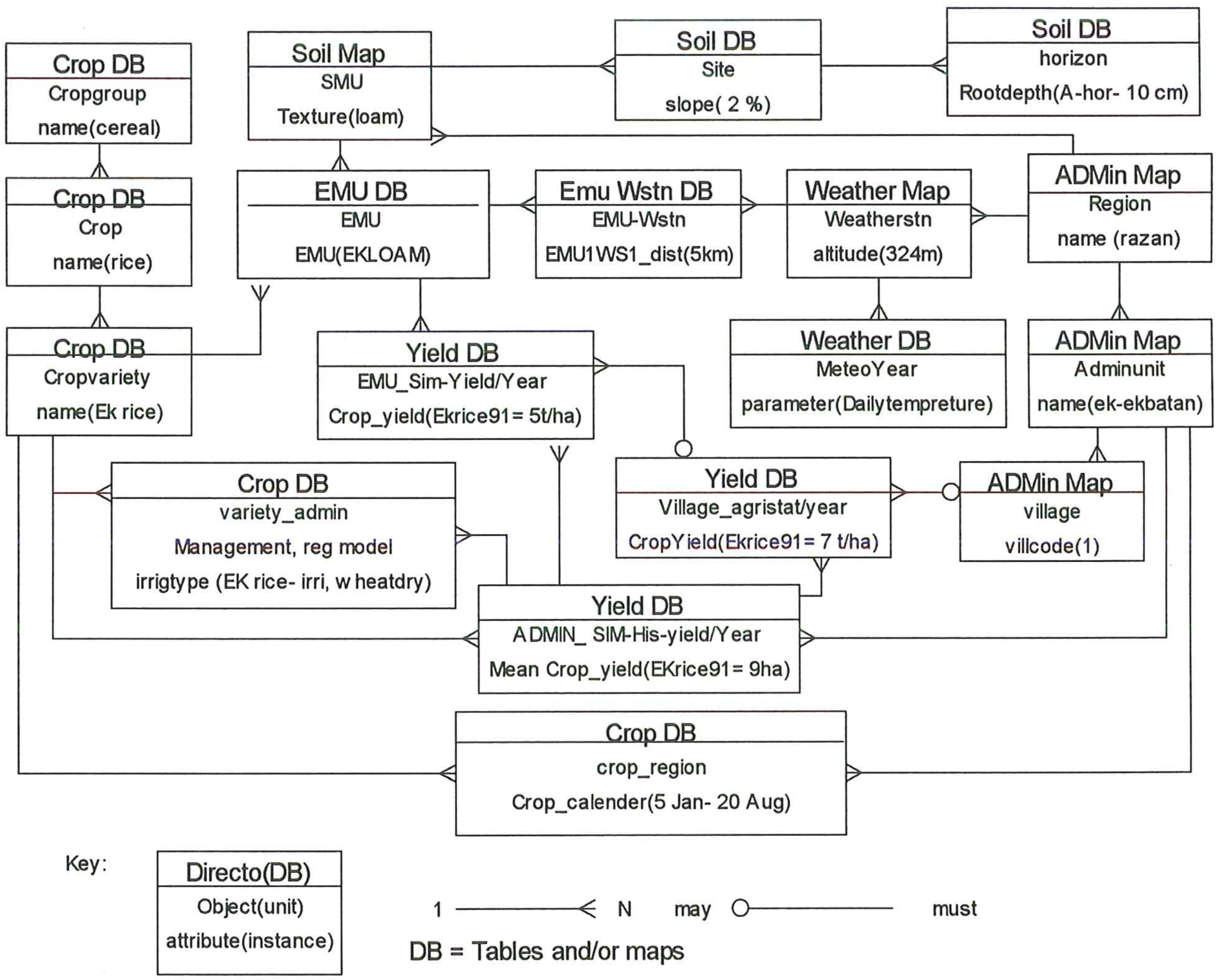


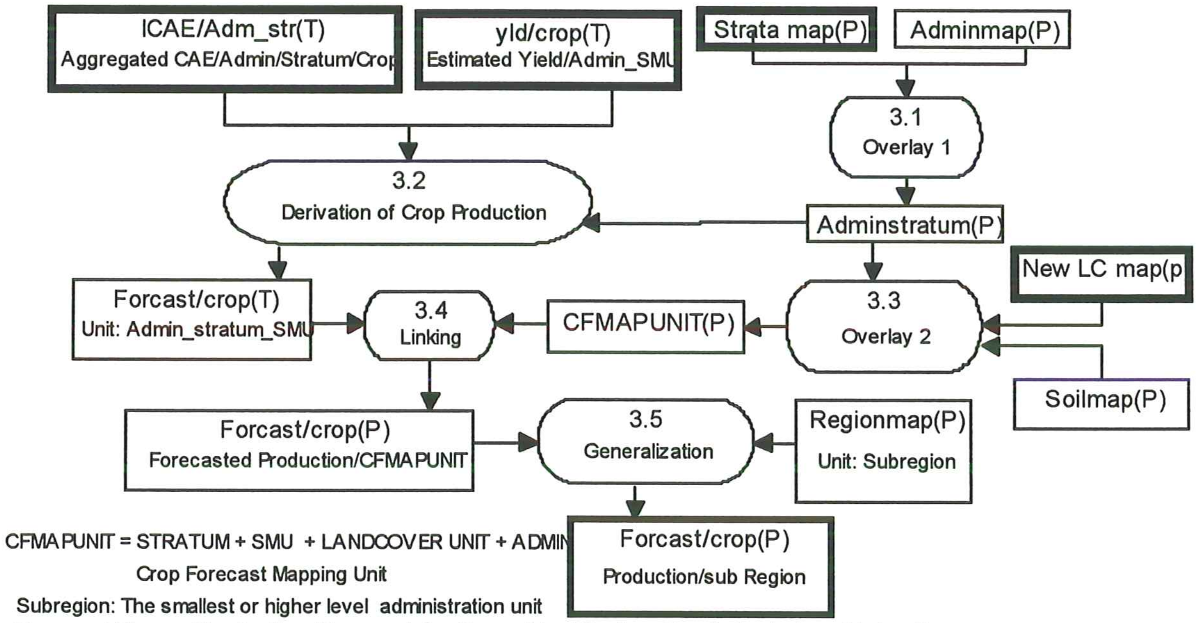
Fig 4.28. Conceptual Data Model of Subsystem 2.

The above diagram describes the conceptual data model of subsystem 2 as the database can be a table if the instances (values) of the object (entity) identified are records or a spatial database (coverage or gridbase including raster data) if the instances of the object (entity) are described interms of polygon, line, point or raster cell. that has position and topological relationship with other instances. The instantiation is given only for one of the attributes that clearly describe the object or that can be an identifier.

4.2.5.5 Crop Production/Forecasting Subsystem -

4.2.5.5.1 Detailed level Process Modelling

As mentioned previously crop production is the product of the two essentially independent factors of crop area and yield estimates. In this subsystem there are no many processes involved since the main inputs crop area estimation per strata and crop yield estimation per admin. unit are already elaborated in subsystem 1 and subsystem 2 of crop forecasting system. The main processes here are used to establish linkage between different results of the above subsystem and generalising the production by means of extrapolation or other generalisation method.



Forecast/Crop= Production Forecast for Crops identified and/or Selected as Major Crop

ICAE= Improved Crop Area Estimate

Fig 4.29. Detailed Process Model of Subsystem 3

The description of each processing unit given in the diagram will be given below and the data dictionary in Appendix 4.

Processing Unit 3.1- Overlay 1: This process performs superimposition (overlay) of the two spatial components: administration boundary and strata boundary to create a mapping unit of strata and admin. unit and a table consisting a key attribute.

Processing Unit 3.2- Derivation of Crop Production: This process links the results obtained from subsystem 1 (improved crop area estimates/admin_stratum) and subsystem 2 (yield estimates/admin_SMU) via a key file created in process 1 above and derives the product of the two results to create a table consisting records of crop code, crop area, stratum, admin. unit, SMU and production.

Processing Unit 3.3- Overlay 2: To create a spatially distributed crop forecast, overlay operations can be used to link landcover map which is a result of subsystem 1 above, soil map the map created in the first process here.

Processing Unit 3.4- Linking: This process links the mapping unit obtained from processing unit 3.3 and the table created by process 3.2 to create a spatially distributed crop forecast.

Processing Unit 3.5- Generalisation: After having crop forecast on every unique combination of administration unit and stratum, soil mapping unit and landcover map, generalising the crop forecast to higher level administration boundary within the region will be performed based on 1) thematically aggregating the forecast for a particular crop growing on same mapping unit (crop forecasting) which are part of the higher adminstration boundary and 2) generalizing the mapping units(crop forecasting) which are not representable at that administration level. The process also enables to desplay the result based on the mapping unit already mentiond or on each mapping unit (SMU, STRATUM, ADMIN Units) for comparison and contrasting the individual effects.

Further data processing model is no more important. Following below the data model of sub system 3 will be given.

4.2.5.5.2 Conceptual data Model of Subsystem 3

Note that data modelling methods adopted to subsystem 1 also used to this subsystem as well. The detail explanation of the method given there, therefore, can be referred to this model too.

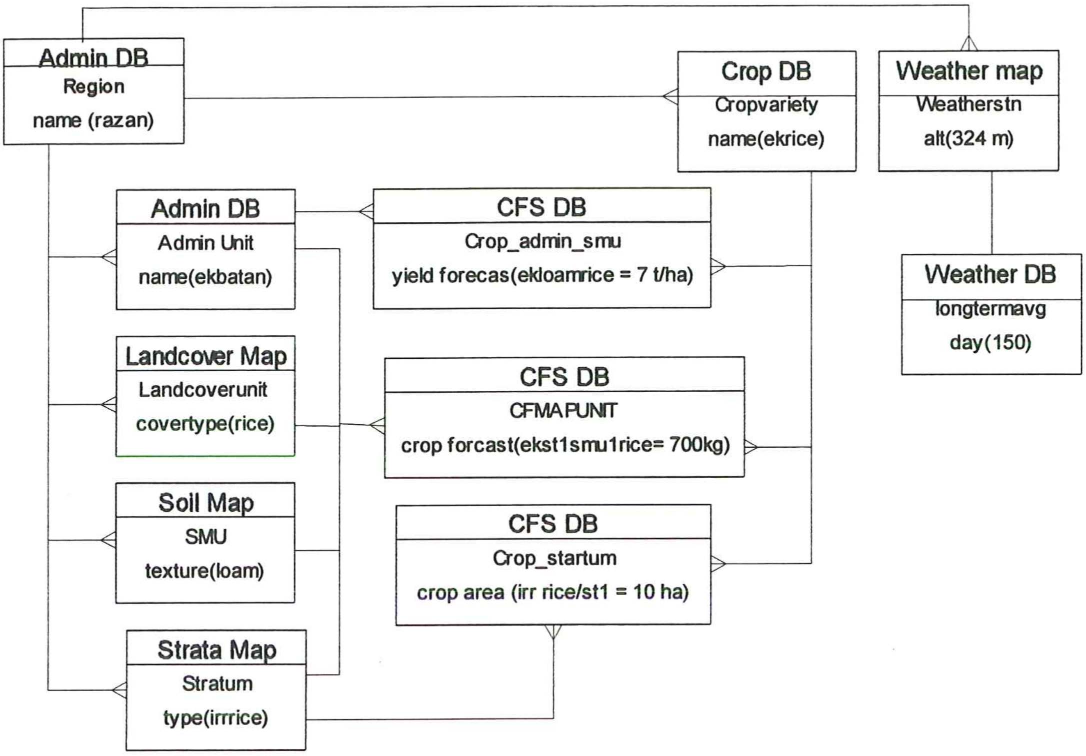


Fig 4.30. Detailed Data Model of Subsystem 3

The above diagram describes the conceptual data model of subsystem 3 as the database can be a table if the instances (values) of the object (entity) identified are records or a spatial database (coverage or gridbase including raster data) if the instances of the object (entity) are described interms of polygon, line, point or raster cell. that has position and topological relationship with other instances. The instantiation is given only for one of the attributes that clearly describe the object or that can be an identifier.

4.2.5.6 Summary

Both the static (Data) and dynamic (processes and data flows) components of each sunsystem of the system (CFS) have been explained in a top down approach using diagrams to show conceptual models of, tables to briefly explain the structures and text to clearly describe the components and their relationships in the system. The data or the input/intermidiate/output datasets of the system have been defined interms static properties like objects/entities, attributes and their relationships. The sources of each datasets or domains of objects and their relationships in the context of CFS and GIS have been explained as well. The subsystems and their processing units have been discussed interms of the basic database operations like retrieve/use, create, store, update etc. and so the data flows form one process to another are clearly indicated. In general the conceptual solutions provided so far are considered to be satisfactory to create an effective information system to support CFS at regional level in a GIS environment.

5. Implementation of the crop forecasting method at the province level (May - August 1997)

5.1 Implementation of crop inventory

"Processing of AFS data collected in the fieldwork area and what does this mean for future implementation."

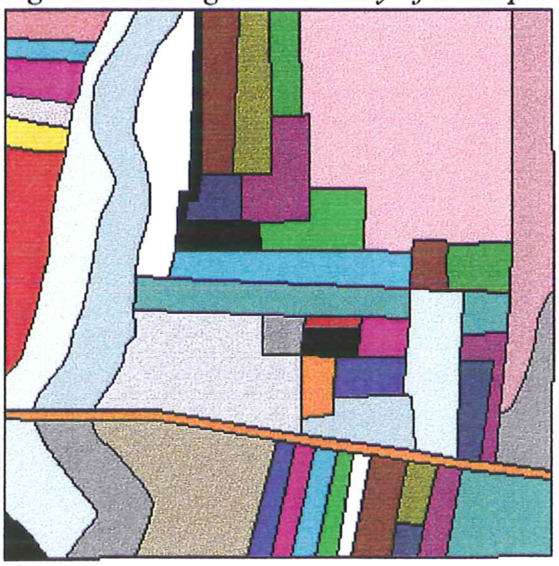
5.1.1 Data collection during the field trip.

At the beginning of the fieldwork three crews were available, consisting of a remote sensing expert, an experienced enumerator and augmented by personnel of the local branch in Hamadan. For each crews (more than) adequate transport was available (4*4 vehicles) as well as three GPS systems, compasses and smaller equipment.

During the first three days the required methods of surveying were explained to the crews. For training purposes all crews went to the same segments. The next two days the crews visited separate segments. During the remaining period of 6 days the sampling was done in earnest, during which 16 of the 24 segments in the Razan area were finished. In total, including the training, 20 segments were sampled by the fieldwork crews. After returning to Teheran the local branch finished 4 more segments, resulting in 21 sampled segments within the Razan township.

After the fieldwork the overlays were digitised and the 'survey tables' made in digital format. As an example one of the digitised overlays (segment 189, for representation see figure 4.1.10 and 4.1.11) is given in figure 5.1.

Figure 5.1. A digitised overlay of a sample segment (189).



For more details on the findings during the fieldwork see the fieldwork report.

5.1.2 Calculation of estimated crop areas (AFS).

5.1.2.1 Methodology

Data handling.
Before any calculation could be executed, the data had to be organised. Because the amount of data will increase tremendously when the AFS method is used to sample the complete province, as practice, the data was put into a database. This also proved to be useful for the currently available data. The analysis of data, not only for the calculation of areas, became much easier. The data base was often combined with a spreadsheet because many calculations are easier to execute in that environment (figure 5.1.1). When an overall database program is selected by ASID, an information expert can integrate all the calculations in that particular program.,

The database program used in this case was Paradox 5.0, combined with the spreadsheet Excel. The database consists of four major tables:

* ***crops*** (a hand made table including segment numbers, tract numbers and the crop codes
* ***combtot2*** (a combination of the Arc-info PAT tables of all segments; the combination of these made the querying easier)
* ***selsegx*** (a table made in a Gis with the segment (identification) numbers, the strata codes and the co-ordinates)
* ***cropcode*** (a table with the crop codes, their description and whether they are irrigated or not)

With these tables almost all analysis could be done by querying, creating forms and spreadsheet calculations.

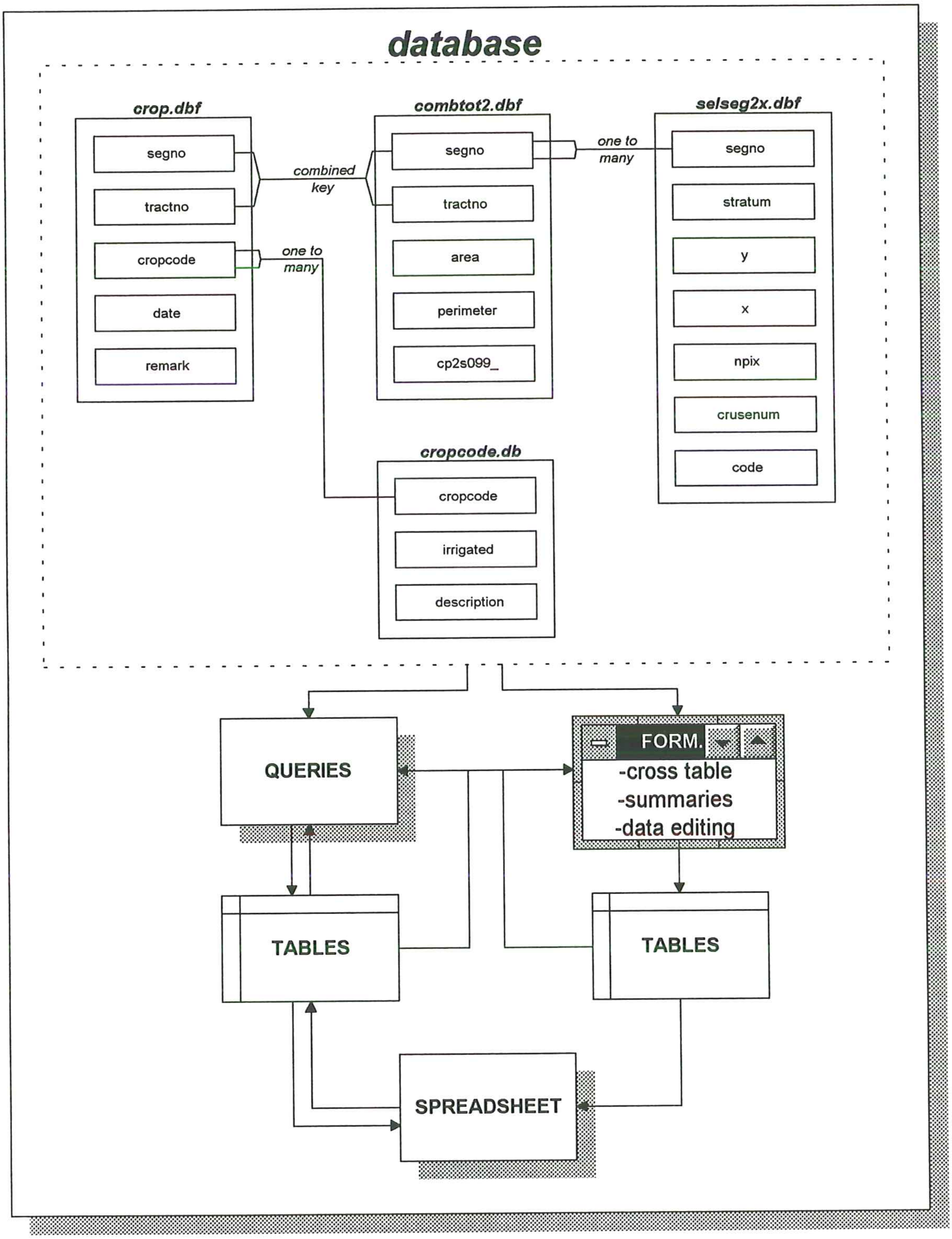


Figure 5.2. Representation of the method used for data handling.

The calculation.

The formulas used to calculate the estimated areas and the coefficient of variance are given below (Gallego, 1995). If Z_{hc} is the area of cover type 'c' in the stratum 'h' of the total area D_h, and $y_{hc} = Z_{hc}/D_h$, we get the estimators:

$$\bar{y}_{hc} = \frac{1}{n_h}\sum_{i=1}^{n_h} y_i$$

$$Z_{hc} = D_h \bar{y}_{hc}$$

$$Var(\bar{y}_{hc}) = \left(1 - \frac{n_h}{N_h}\right)\frac{1}{n_h(n_h - 1)}\sum_{i=1}^{n_h}(y_{ic} - \bar{y}_{hc})^2$$

$$Var(Z_{hc}) = D_h^2 Var(\bar{y}_{hc})$$

For the whole region:
(This will only hold for equal size segments).

$$Z_c = \sum_{h=1}^{H} Z_{hc}$$

$$\bar{y}_c = \frac{1}{N}\sum_{h=1}^{H} N_h \bar{y}_{hc}$$

$$Var(Z_c) = \sum_{h=1}^{H} Var(Z_{hc})$$

$$Var(\bar{y}_c) = \frac{1}{N^2}\sum_{h=1}^{H} N_h^2 Var(\bar{y}_{hc})$$

$$CV(Z_c) = \frac{\sqrt{Var(Z_c)}}{Z_c}$$

N = total number of segments in the region
n = number of samples (segments)
D_h = area of stratum h (real area)

i = segment i (1 till n)
y_i= proportion of sample segment 'i' covered by cover type 'c' in stratum 'h'
Z = estimated area
Z_{hc} = estimated area of cover type 'c' in stratum 'h'
$\bar{y}_{hc} = Z_{hc}/D_h$ = estimated proportion of stratum 'h' covered by cover type 'c'
Var = variance
$\bar{y}_c$ = estimated proportion of total area (sum of all strata) covered by crop c
CV = coefficient of variance

5.1.2.2 the results

The results of the calculations are given in table 5.1. It is clear that the major crops in the area (Razan) are wheat, barley and alfalfa, this is conform the expectations (progress report 1). Interesting is the amount of fallow land; this is a large portion of the area which hardly ever shows up in the agricultural statistics. It would be very interesting to be able to recognise the fallow fields by satellite classification because these fields have a high probability of becoming cultivated the next year.

Table 5.1. Summary of the estimated areas and coefficient of variances in Razan and each stratum

			<------Rasan------>		<-irrigated agriculture (20)->		<-rainfed agriculture (30)->		<-fragmented rainfed agriculture (60)->	
CROP-CODE	Irrigated	Description	estimated area Z [hetares]	CV (Z) [%]	estimated area Zh [hectares]	CV (Zh) [%]	estimated area Zh [hectares]	CV (Zh) [%]	estimated area Zh [hectares]	CV (Zh) [%]
102	y	wheat	19751	29.6	6934	20.8	6067	59.7	6750	64.7
103	n	wheat	44826	17.8	2316	81.2	33030	12.2	9479	69.7
104	y	barley	2335	24.5	1237	28.9	79	59.8	1018	43.6
105	n	barley	11027	27.3	0	0.0	2026	60.5	9001	30.6
112	y	beans	70	81.2	70	81.2	0	0.0	0	0.0
114	y	chickpea	2692	47.8	797	77.7	1125	80.4	770	87.9
115	n	chickpea	2040	35.6	0	0.0	570	49.0	1470	45.7
116	y	lentil	135	54.4	35	45.8	100	71.5	0	0.0
117	n	lentil	663	34.3	0	0.0	20	94.4	643	35.2
156	y	watermelon	3822	44.1	2198	58.9	818	94.4	805	93.2
160	y	cucumber	109	66.6	85	81.2	24	94.4	0	0.0
166	u	other vegetables	187	73.5	47	81.2	140	94.4	0	0.0
170	y	potato	56	81.2	56	81.2	0	0.0	0	0.0
174	y	tomato	42	57.9	7	81.2	15	94.4	21	93.2
202	y	alfalfa	10436	41.8	2231	38.4	5558	67.7	2647	76.8
203	n	alfalfa	5100	70.2	0	0.0	939	61.1	4161	84.9
204	u	clover	113	74.5	0	0.0	113	74.5	0	0.0
458	u	watermelon (seed)	54	94.4	0	0.0	54	94.4	0	0.0
474	u	sainfov	143	81.2	143	81.2	0	0.0	0	0.0
478	u	clover (seed)	153	93.2	0	0.0	0	0.0	153	93.2
504	u	kidneybean	41	94.4	0	0.0	41	94.4	0	0.0
700	u	unknown	49	94.4	0	0.0	49	94.4	0	0.0
701	u	orchard	7142	43.2	1088	81.4	4618	59.0	1436	79.4
702	x	building	777	67.4	0	0.0	777	67.4	0	0.0
703	x	bareland	6067	52.2	546	50.0	2441	72.8	3080	84.7
705	x	road	1508	27.9	366	41.1	798	42.8	344	56.6
706	x	waterbody	1041	72.8	0	0.0	56	94.4	985	76.8
707	x	rangeland	25658	18.9	364	85.1	10933	27.6	14361	26.4
708	x	fallow	20532	20.4	472	21.8	8982	30.0	11079	29.0
709	x	fallow (plowed)	35384	17.0	6304	27.1	25476	22.2	3604	31.3
710	u	unknown	52	68.9	17	81.2	35	94.4	0	0.0
711	u	river	830	67.4	0	0.0	335	94.4	495	93.2
712	u	river shulder	1425	80.2	0	0.0	215	87.3	1210	93.2
713	u	khanat	193	84.9	0	0.0	0	0.0	193	84.9

5.1.2.3 the variation found in the samples and those expected in the future

The coefficients of variation (CV) found in the field work area (table 5.1.1) are high, but that was to be expected because the sampling scheme was designed for the whole province. In fact only 21 of the 200 samples were taken due to time constraints. Though about one percent of the Razan area was sampled, the influence of the number of segments on the CV is quite high (see table 5.1.3). Thus no reliable area estimated can be calculated. This was a known factor but, though the alternative - selecting samples in only one stratum- would have given better area estimates, the result would have been that no information was collected about the other strata. This would have given problems for planning the next fieldwork.

The behaviour of the CV's is as it should be; meaning that cover types covering extensive areas have a lower CV as those covering only small areas. This results from the adopted statistical method. To have a low CV for non major crops the amount of samples must be much higher.

Gallego (1995, page 38), by combining the data of several AFS exercises, has found that the CV can be predicted with an r^2 of 0.776 by the formula:

$$cv \cong \frac{371.5 * y^{-0.462}}{\sqrt{n}}$$ *(n= number of segments, y= proportion of cover type in the area)*

This formula works reasonably well in Razan with crops covering a substantial part of the area (table 5.1.2).

Table 5.2. actual coefficients of variance compared to predicted ones.

Crop	area (y) [%]	n	cv (actual)	cv (predicted)
wheat (df)	21.9	21	17.8	19.5
range land	12.5	21	18.9	25.2
fallow	10.0	21	20.4	28.0
sainsov (seed)	0.1	21	81.2	235
clover (seed)	0.1	21	93.2	235

n= number of sample segments, cv(actual) = the cv as calculated from the the data collected in the field, cv(predicted)= cv as calculated via the above mentioned formula.

With this formula an idea of the expected CV's for sampling of the whole province can be predicted under different sample schemes (different number of samples), see table 5.1.3.

Table 5.3. Predicted CV's under different sample densities.

Crop cover (%)	n=200	n=100	n=50	n=21
20	6.6	9.3	13.2	20.3
10	9.1	12.8	18.1	28.0
5	12.5	17.7	25.0	38.5

n= number of sample segments

5.1.2.4 comparison of calculated areas (AFS) with agricultural statistics

The areas as calculated via the AFS method (table 5.1.1) were compared with the most recent agricultural statistics which were available (tables 5.1.4, 5.1.5 and 5.1.6). These statistics consisted of three separate sets. The first includes unofficial statistics collected at township level from the period 1994-1995. The second consists of official data from the bureau of agricultural statistics (ASID) in Teheran of the same date. The third set only covers the grain crops, but the data is from the same period as the fieldwork and was released by ASID as well.

Table 5.4. Comparison of calculated areas (1996) with unofficial (township) agricultural statistics (1994-1995) of the Razan area.

Crops		area form AFS (ha)	CV from AFS (%)	area from agric. Statistics (ha)	difference (%)
cereals	ir. Wheat	19751	29.6	20000	1.3
	r.f. wheat	44826	17.8	30000	-33.1
	total wheat	64577	-	50000	-22.6
	ir. Barley	2335	24.5	8700	272.7
	r.f. barley	11027	27.3	0	x
	total barley	13362	-	8700	-34.9
	maize	0	0	100	x
	total	77939	-	58800	-24.6
forage	ir. Alfalfa	10436	41.8	-	-
	r.f. alfalfa	5100	70.2	-	-
	total alfalfa	15536	-	6400	-58.8
vegetables	potato	56	81.2	400	608

x= when one of the statistics gives an area of zero while the other does have a value, the difference is not calculated; - = non existing; ir.= irrigated, r.f.= rainfed; agric.= agricultural

Table 5.5. Comparison of calculated areas (1996) with official (ASID) agricultural statistics (1994-1995) of the Razan area.

crops		area form AFS (ha)	CV from AFS (%)	area from agric. Statistics (ha)	difference (%)
cereals	ir. Wheat	19751	29.6	18500	-6.3
	r.f. wheat	44826	17.8	38000	-15.2
	total wheat	64577	-	56500	-12.5
	ir. Barley	2335	24.5	7000	199.8
	r.f. barley	11027	27.3	350	-96.8
	total barley	13362	-	7350	-45.0
	maize	0	-	120	x
	total	77939	-	63970	-17.9
forage	ir. Alfalfa	10436	41.8	2986	-71.4
	r.f. alfalfa	5100	70.2	120	-97.6
	total alfalfa	15536	-	3106	-80.0
vegetables	potato	56	81.2	170	203.6
	beans	70	81.2	40	-75.0
	onion	0	-	40	x
	tomato	42	57.9	60	42.8
	sugar beet	0	-	70	x
other	clover(total)	266	-	70	-73.7
	summer crops	0	-	720	x
	sunflower	0	-	270	x
	fennel	0	-	1000	x
total cultivated area	**(sum from table 5.1.1)**	103795	-	74310	-28.4

x= when one of the statistics gives an area of zero while the other does have a value, the difference is not calculated; - = non existing; ir.= irrigated, r.f.= rainfed; agric.= agricultural

Table 5.6. Comparison of calculated areas (1996) with official (ASID) agricultural statistics (1995-1996) of the Razan area.

crops		area form AFS (ha)	CV from AFS (%)	area * from agric. Statistics (ha)	difference (%)
cereals	ir. Wheat	19751	29.6	22059	11.7
	r.f. wheat	44826	17.8	51315	14.5
	total wheat	64577	-	73374	13.6
	ir. Barley	2335	24.5	5556	138.0
	r.f. barley	11027	27.3	980	-91.1
	total barley	13362	-	6536	-51.1
	total	77939	-	79910	2.5

ir.= irrigated, r.f.= rainfed; agric.= agricultural; * cultivated area

From the above three tables can be concluded that:

in general:

- The differences seem to be high especially for the minor crops. This is misleading because the AFS method was designed for the complete province (200 sample segments) and not the Razan area (only 21 sample segments). Therefore the inaccuracies can be quite high, as can be derived from the CV's and table 5.1.3.
- No error margin is given for the agricultural statistics, only for the results from the AFS method.
- The areas of barley derived from AFS are quite different from those gathered by the agricultural statistics bureau's. The reason of the difference might be that the surveyors (AFS) thought that fields were not irrigated but in fact they were (still, the surveyors were quite capable) or there is some mistake in the agricultural statistics. To be able to asses this the method of obtaining the agricultural statistics will have to be examined. A third reason of the differences might be that different definitions are used, especially considering: when is a field called irrigated?.
- The agricultural statistics only give data on crop areas while other cover types, like fallow, are interesting as well for instance regarding crop rotations.
- In general the crops covering relatively small areas show higher differences as the crops covering larger areas. Part of this can be explained by the fact that the AFS method is not optimised for the smaller crops, this can be clearly seen from the CV's of those crops.

Table 5.4.:

- The difference is in several cases higher than error margin (CV) of the calculated areas. The difference in areas of irrigated wheat is lower than the CV and the total of alfalfa will come very close. For the remaining cover types the situation is more complicated. For one, no accuracy assessment of the agricultural statistics is available so the comparison is not complete. Still some of the differences are so high that the variance of agricultural statistics can be assumed to be considerably lower. This is the case for: maize, potato and barley. Barley is explained in the general heading. The reason for the large differences for maize and potato is unclear but it must be noted that potato is a fast changing crop. Not much is known about maize in Razan, but it might be possible that it is only grown in a small part of the township and thus is missed by the sampling grid.

Table 5.5.:

- It is not clear why the data from table 5.1.4 and 5.1.5 differ; but the official statistics are further off the AFS results as the unofficial statistics, especially considering alfalfa. It is completely unknown why.
- The areas of wheat from the official statistics is very close to those derived from the AFS method. Barley is much less accurate again. But the total area of cereals is well within the CV's. It must be noted that the areas will never completely fit because they differ one year in recording.
- The total cultivated area is rather different but this might the result of both the difference in recording date and the relatively high CV's of the AFS method. Still this is something that will have to be checked with the satellite imagery.

Table 5.6.:

- The areas of wheat are well within the error margin while barley still causes problems.
- The difference between the total area of cereals is extremely low. This is interesting because it gives the hint that the total agricultural area as derived from AFS might be accurate (see remarks on table 5.5).

5.1.3 Number of fields in the segments.

During the field work it was found that there were to many tracts within the segments. This meant that many segments could not be finished within one day or only by working exceptionally long hours. It is advisable to finish a segment in one normal working day to reduce sampling errors. According to Gallego (1995) the number of tracts within one segment should be between 20 and 30. This was definitely not the case as can be seen from table 5.7.

Table 5.7. Number of tracts per segment and stratum

Stratum 20		**Stratum 30**		**Stratum 60**	
segment number	number of tracts	segment number	number of tracts	segment number	number of tracts
261	56	183	74	99	14
350	137	260	69	177	72
433	98	266	58	181	58
		267	15	187	9
		271	45	188	25
		343	66	189	51
		345	54	259	70
		349	13	265	45
		351	22		
		355	31		
AVG. =	**97**	**AVG. =**	**44.7**	**AVG. =**	**43**
AVERAGE OVER ALL STRATA = 51					

There are two options to realise a reduction in the number of tracts per segment:

a. Keeping the segment size equal for the whole area. This reduces the time needed for preparation and analysis. Unfortunately this means that the segment size will become:
(1000*1000)/(30/97)= 577*577 meters (table 5.1.7). This will increase the number of segments to be sampled by a factor of 3.2. Thus about **600** segments would have to be sampled for the whole province. This method is thus unacceptable.

b. Introducing variable segment sizes. This means that the segment size will become different for each stratum. The resulting segment sizes will become (see above paragraph for calculation of factors):
Stratum 20: (1000*1000)/(30/97)= 577*577 meters [factor 3.2]
Stratum 30: (1000*1000)/(30/44.7)= 820*820 meters [factor 1.5]
Stratum 60: (1000*1000)/(30/43)= 836 *836 meters [factor 1.4]
For the whole province about 200 segments would have to be sampled with a segment size of 1000*1000 meters. Taking into consideration the relative areas of the different strata, the number of segments to be sampled would become about:

20[(200* 13.3%*1.66)*3.2]+30[(200* 35.6%*1.13)*1.5]+60[(200*25%*1.16)1.4]+misc. = **362**
*stratum[(number of segments with 1000 meters * relative area stratum in province * sampling rate)*

This number is still high but much more acceptable. According to the recent results from European experiments (MERA, 1996), the size of the segment can be reduced as long as the number of fields in the segment are large. This knowledge will be used in the modification of our sampling design for the entire province.

5.1.4 Distribution of crops

Table 5.8. The occurrence of different crop types within the sampled segments.

cropcode	20.00(avg)	20.00(tot)	30.00(avg)	30.00(tot)	60.00(avg)	60.00(tot)	Rasan (Tot)
102	13048	822038	26191	576194	31242	749817	2148048
103	16168	274848	31361	3136064	28458	1052934	4463847
104	5248	146941	3737	7474	11307	113065	267481
105			12839	192589	19224	999633	1192222
112	2096	8385					8385
114	4721	94410	26697	106787	14240	85439	286636
115			10836	54182	13595	163145	217327
116	2058	4117	4721	9442			13559
117			1860	1860	7118	71179	73039
156	11340	260815	25911	77732	22319	89277	427823
160	10120	10120	2278	2278			12397
166	1852	5557	13342	13342			18899
170	3357	6715					6715
174	784	784	1440	1440	2305	2305	4529
202	6457	264731	25132	527767	19595	293926	1086424
203			11151	89209	13995	461840	551050
204			3549	10647			10647
458			5097	5097			5097
474	16976	16976					16976
478					8515	17030	17030
504			3925	3925			3925
700			4654	4654			4654
701	9931	129102	23082	438549	17715	159438	727090
702			14767	73833			73833
703	12971	64855	21071	231785	85522	342088	638728
705	14454	43363	10844	75906	7617	38086	157354
706			5252	5252	27367	109468	114720
707	21579	43159	18539	1038172	16112	1595073	2676404
708	5598	55984	14453	852729	18940	1231082	2139795
709	14662	747786	26879	2419125	8523	400563	3567474
710	1989	1989	3318	3318			5307
711			15903	31806	55009	55009	86815
712			5105	20419	134430	134430	154849
713					10668	21335	21335

20= stratum 'irrigated agriculture'; 30= stratum 'rainfed agriculture'; 60= stratum 'fragmented rainfed agriculture'.

The average field size (table 5.1.8) of crops is interesting for two reasons.

1. The mistakes and inaccuracies that can be made during sampling in the field are higher when there are more borders to draw. Ideally this should not be a problem because when the amount of tracts in a segments is limited (between 20 and 30) smaller fields will mean more segments and more segments means (statistically) a lower variance. In our case the number of segments is limiting thus the accuracy of cover types with small tracts is lower than those with larger tracts.
2. To build a training set for supervised image classification the sample segments are used. From the sampled tracts a border is subtracted to limit possible inaccuracies during overlaying. The border will most likely be one pixel of the satellite image, which means 20 meters. Thus fields of

$(20+20)^2$= 1600 square meters will not appear in the training set; but because most fields are irregular, it is save to assume that field sizes up to 4000 m^2 are likely to disappear. These fields constitute 3.0 % of the total sampled area. This is not much but does present a problem for certain cover types like: beans (112), irrigated lentil (116), tomato (174), clover (204), kidney bean (504). It has to be noted that the cover types mentioned only cover small parts of the area (table 6), they are not part of the 'major crops'.

5.1.5 Analysis of stratification

The crop coding system used during the field work makes a distinction between irrigated and non-irrigated crops of the same type. This information can be used to say something about the quality of the stratification (which is based on landuse classes).

Table 5.9. The percentages of irrigated and non-irrigated fields found in the segments belonging to the three different strata.

	STRATUM		
IRRIGATED	***irrigated agriculture***	***rainfed agriculture***	***fragmented rainfed agriculture***
yes	53.9%	13.1%	16.8%
no	9.2%	34.7%	33.7%
x (not applicable)	31.8%	49.9%	44.6%
unknown	5.1%	5.3%	4.9%

Three conclusions can be made from table 5.1.9:

1. In general, within the strata the percentages of irrigated fields behave as was expected. Within the stratum 'irrigated agriculture' the highest percentage of irrigated fields can be found while the percentage of non-irrigated fields is very low. The stratum 'rainfed agriculture' behaves just the opposite, with a high percentage of rainfed agriculture and less irrigated agriculture.
2. There is quite a bit of irrigation within the rainfed stratum (13.1 %)
3. The strata 'rainfed agriculture' and 'fragmented rainfed agriculture' behave rather similar.

A second check of the effectiveness of the stratification is the ratio between the variance with and without stratification. This can be calculated by the following formula (Gallego, 1995):

$$Eff_{stratification} = \frac{Var_{nostr}}{Var_{str}}, \qquad Var_{nostr}(\bar{Y}) = \frac{N-n}{n(N-1)}\left\{ Var(\hat{y}_{st}) + \left[\sum_h \frac{N_h}{n_h} \sum_{hi=1}^{n_h} y_{hi}^2 \right] - \hat{y}_{st}^2 \right\}$$

Note: Var_{nostr} is not the same as a variance calculated as if it were straightforward random sampling

For the Razan Dehestan the effectiveness of stratification is: 1.002 (same for all crops). This means that if no stratification was used 1.002 as many segments would have to be sampled to reach the same variation. This seems not very effective but because the sample scheme was developed for the whole province and some inaccuracies (that can be rectified) were clear after visiting the field, thus the result is promising.

From table 5.9, the effectiveness of stratification and information gathered during the fieldwork (see fieldwork report) it can be concluded that using the landuse map for stratification is possible after some refinements of this map. These should include: firstly, finding out what the makers of the landuse map mean by the class 'fragmented rainfed agriculture'. This seems to be very difficult thus the only solution is to compare this stratum with the satellite imagery available. Secondly, (and related to the first) is to sub-divide the stratum 'fragmented rainfed agriculture'. It is clear from the field and the imagery that some parts of irrigated agriculture can be recognised within this class. This will have to be based on the available satellite imagery. This imagery consists mainly of a Landsat TM from 1990.

Thus the conclusion is that the landuse map can only be used for stratification after some refinements which will be made by visual classification of imagery.

5.1.6 Analysis of quality of data collected in the field.

The analysis can only be done in a roundabout way because the actual situation is never known. But for some parts of the method an indication can be given.

Error of notation in the field.
Several mistakes were made during the notation of tracts and their codes in the field. Some could easily be rectified by asking the surveyor (name on the segment tables). Others were more difficult. After a check of 14 segments, 2.9 % of the sampled area was not defined properly in the survey tables. This included non-existing crop code numbers etc., quite a few of these could be traced and rectified.

These were the traceable mistakes, after overlaying the sampled segments with the SPOT-XS image of 15-7-96 more tracts became doubtful (see figure 5.1.3a). The possible mistakes in notation of cover type is difficult to asses because the clear difference in reflectance characteristics may be the result of different management practices. Still these tracts should have been sub-divided according to the fieldwork guide.

One important conclusion of analysing possible mistakes is that the fieldwork guide must be followed much more scrupulously during the next fieldwork. Even small details like underlining the 6 and 9 already proved to be a reason of uncertainty. Though due to the low number of segments sampled a lot of mistakes could be traced but this will become more difficult during the next fieldwork.

Digitising error.

The total areas of the digitised segments were added and compared to the ideal situation, which is the number of segments times 1000*1000 meters. The difference between them was 0.53%. This is well within working limits.

5.1.7 Alternative sampling methods

A fact is that the sample scheme as originally envisioned will require too much input, both in labour and money. Thus alternative methods or adaptations of the existing method will have to be researched.

grid sampling:
During the fieldwork grid sampling has been done on those segments which had too many tracts or when the representation was not useful. It was found that the grid sampling method also saved a lot of time. This has also been recognised by Gallego (1995). One of the possible options is to change the method to one that only uses grid sampling and no recognition of tracts. A disadvantage is that the grid sampling method is less accurate than the sampling of tracts. This has been evaluated by overlaying a grid on five segments sampled during the fieldwork. Two grids have been used, one is the grid as proposed during the fieldwork. This entails sampling of the lower left quarter (500*500 meters) of the segments with samples every 50 meters. The other entails the sampling of the complete segment (1000*1000 meters) but with a sample every 100 meters. The results are displayed in table 5.8.

Table 5.10. The difference in sampling with a grid method compared to sampling tracts.

Segment number:	181.00			260.00			261.00			266.00			433.00		
Crop code	grid50	grid100	tract	grid50	grid100	tract	grid50	grid100	tract	grid50	grid100	tract	grid50	grid100	tract
102				0.00	0.00	0.73	4.13	34.71	32.89				1.65	11.57	15.92
103				57.02	53.72	55.27				12.40	38.84	38.15	54.55	29.75	27.48
104													0.00	8.26	7.07
105	16.53	24.79	25.08												
112							0.00	0.83	0.84						
114							0.00	0.83	1.02				0.00	0.00	0.36
116							0.00	0.00	0.29				0.00	0.00	0.12
117	0.00	3.31	1.64							0.00	0.00	0.19			
156													0.00	6.00	5.25
160													0.00	0.00	1.01
170							2.48	0.83	0.67						
202							35.54	12.40	11.69				0.00	4.13	2.05
203				8.26	5.79	5.32									
474							0.00	0.83	1.70						
478															
701	0.00	1.65	1.00				14.05	7.44	11.33	26.45	11.57	13.02	0.00	0.00	0.29
702										8.26	3.31	2.10	0.00		
703							1.65	2.48	1.95	1.65	0.00	0.82	0.00	3.31	4.14
705													1.65	1.65	2.91
706										0.00	0.83	0.53			
707	59.50	47.93	51.23	6.61	9.09	8.90	4.96	6.61	4.17	21.49	17.36	18.15			
708	10.74	5.79	9.47	23.14	20.66	19.52	4.96	3.31	2.46	9.09	12.40	12.06	0.00	0.83	1.08
709	13.22	14.05	11.65	4.96	6.61	8.54	32.23	29.75	30.89	20.66	14.88	14.99	42.15	31.40	32.54
712				0.00	0.83	1.90									

From table 5.10 can be deducted that the method of sampling a 1000*1000 meters grid with samples at every 100 meters gives a better result than the method proposed during the fieldwork. This is partly a result of the fact that the method proposed during the fieldwork covers only one quarter of the area compared to sampling 1000*1000 meters. However it does illustrate that the variation within a segment can not be captured in one quarter of its area. Therefore if the method proposed during the fieldwork will be used, more samples are needed than the number selected until now (=200). How many more cannot be assessed with the date available, but it will differ per stratum. The optimum size and density of sampling in a grid might be determined by analysis like 'semi-variograms'. This will have to be studied if this method is chosen.

A practical problem might be that sampling a 1000*1000 meters will be to difficult and thus take to much time. The distances are quite large and in many cases it will not be possible to recognise the edges of the sample area. This means that more recognition points will be needed (like coloured poles) etc (see fieldwork guide). The point is that if the amount of time needed for sampling is to be reduced, large segments will have to be used and they have to be finished in one day. Therefore the use of 500*500 meter segments is not feasible as table 2 shows, maybe segments in the region of 750*750 meters can be sampled in one day and give a good representation of the situation.

5.1.8 Classification of satellite imagery

5.1.8.1 Supervised classification

Method
With the AFS sampling a lot of ground truth has been collected to create a sample set for supervised classification.

The first step was to fit the sample segments on the SPOT-XS image. This was done because the representations of the segments were based on SPOT-PAN images. These SPOT-PAN images were geocorrected with 1:250000 topographic maps and the results are not as good as the geocorrection of the SPOT-XS. Therefore the SPOT-XS was selected as the base-map. The positioning of the segments on the SPOT-XS was done by control points selected on SPOT-PAN and SPOT-XS. These control points were then applied to a map of the combined segments. The results of this method were acceptable (figure 5.3), especially when the borders of the fields are not used in creating the sample set.

The second step is building the sample set. This is done in steps of increasing complexity until reaching a acceptable result. At first the entire set of sampled fields will be used to create the sample set. Then the borders of fields will be excluded to reduce the geographic error. The excluded border will be either one or two pixels (e.g. 25 or 45 meters). After these steps the area is subdivided into smaller parts to create more than one training set. It is assumed that the reflectance properties of the cover types will have a lower variation within a sub-area as between sub-areas. The first step in subdividing the area will be based on the strata, later either polygons or a soil map may be used. Simultaneously with subdividing the area, the cover types will be subdivided as well into different clusters. There are several ways to do this. One is to take the sample set outside of the GIS system and execute a specialised clustering program. The data transfer from and to the GIS system is a difficult operation and will take some time to implement. An other method is to do the clustering 'by hand'; this entails creating the sample set by hand and when the reflectance values of a field differ to much from a given cluster a new cluster will have to be generated. This method is not very satisfying because it takes quite some time and the results will differ from person to person but when it is executed by an expert the results will be acceptable.

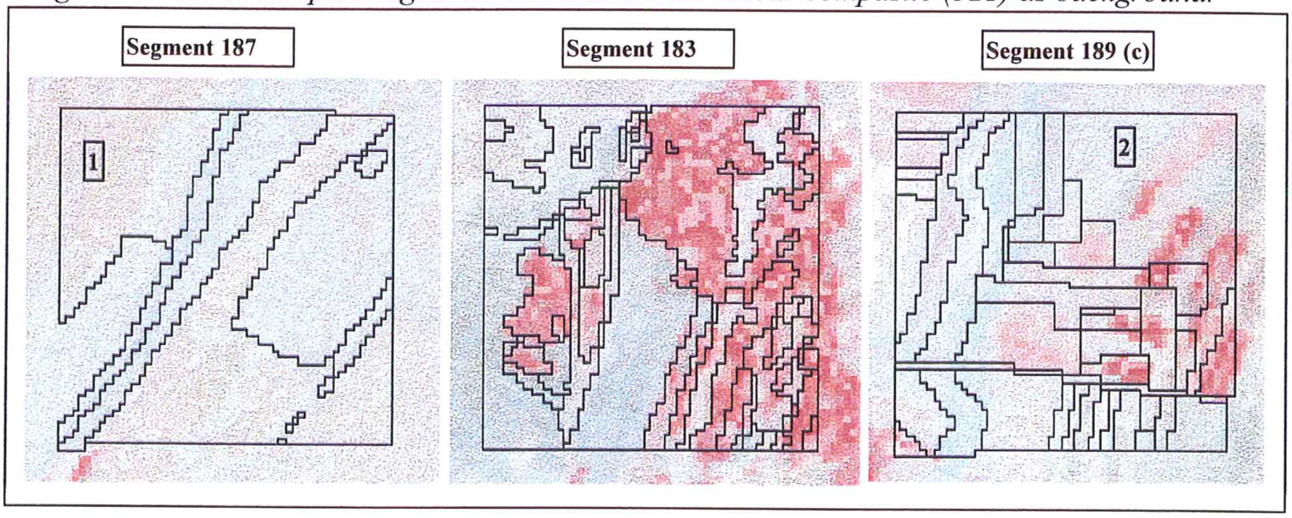
Results

The actual classification proved to be no easy task. The use of all segments, without a boundary of 25 meters, gave a classification accuracy of only 37 % average accuracy and 16 % overall accuracy using the maximum likelihood classifier. The use of the K-nearest neighbour algorithm on the same sample set gave better results (38 % average and 52% overall accuracy). This has to do with the shape of the clusters in the sample set.

(Note: average accuracy is the average of the accuracy's reached per cover type while overall accuracy is calculated as an weighted average (relative amount of pixels) of the cover types)

The results as described above are not as disappointing as they may seem because even in a relatively small area like Razan it is not to be expected that large classes like grains, fallow and pasture can be represented by one cluster (figure 5.3 a, tract 1). The next step is thus logical: clusters of the major cover types will have to be subdivided while subdividing the area as well (strata). An other problem to address is that of the sampling error made in the field. As can be seen from figure 5.1.3 c, tract 2, some errors have been made. This kind of variation within one cover cannot exist and if it were possible these fields should have been subdivided into different tracts on the basis of management, as is stated in the fieldwork guide.

Figure 5.3. Three sampled segments with a SPOT-XS colour compasite (321) as background.



Due to the high variation in reflectance with cover types an other method of supervised classification has been tried. The method is developed by B.G.H Gorte (1995) and entails the use of an modified K-nearest neighbour algorithm, a subdivision of the area in small areas (based on the polygons of the landuse map and the 1:250000 soil map) and the use of prior probabilities. The advantage of the method is that the prior probabilities are not fixed but improved in a stepwise iterative process. The results were promising; the modified k-nearest neighbour algorithm (search radius = 17, number of neighbours = 12) gave an average accuracy of 67% and an overall accuracy of 42%. The subdivision of the area in combination with prior probabilities gave even better results (figure 5.1.4) but this has only been tested on part of the Razan township and will have to be fine tuned.

Figure 5.4. confusion matrix of an sub-area in Razan township.

	1	2	3	4	5	6	7	8	9	10	11	uncl	ACC
1	959	22	27	2	117	47	47	19	11	15	17	0	0.75
2	21	2083	132	45	39	13	2	28	290	69	453	0	0.66
3	2	16	141	2	6	0	0	0	0	12	11	0	0.74
4	2	60	12	25	1	3	0	2	0	1	44	0	0.17
5	12	38	16	6	122	53	12	0	0	0	11	0	0.45
6	152	4	5	3	26	541	30	6	0	4	8	0	0.69
7	1	16	0	1	4	0	131	0	10	43	19	0	0.58
8	124	12	4	2	0	6	0	86	0	1	1	0	0.36
9	21	222	184	16	29	0	0	7	359	58	191	0	0.33
10	18	49	99	26	29	13	0	8	15	268	196	0	0.37
11	42	361	84	44	36	11	13	21	129	102	1793	0	0.68
REL	0.71	0.72	0.20	0.15	0.30	0.79	0.56	0.49	0.44	0.47	0.65		

```
average accuracy    =  52.61 %
average reliability =  49.71 %

overall accuracy    =  60.53 %
overall reliability =  60.53 %
```

5.1.8.2 Knowledge based classification.

This method of image classification has the capability to be highly successful but to implement it at suggested in progress report I is not feasible. High resolution satellite imagery is to expensive to be made available and with the currently acquired SPOT-XS no accurate area estimates can be made. Still, the concepts of knowledge based classification are used in other methods, like improvement of area estimates via a regression estimator (paragraph 5.1.8.3) and a method of deriving area estimates from imagery directly as described below..

Satellite image classification can be done in two ways, the first is the most logical and entails linking reflectance to cover types. The second method is to select reflectance classes and assess the percent of cover types within the reflectance classes. This second method has been tested on the data available.

The first step was to classify the SPOT-XS image in reflectance classes. This can be done in two ways (see also the next paragraph). One consists of unsupervised clustering with algorithms available in any image processing software. The second is to manually define classes as was proposed for knowledge based classification in progress report I. For this test unsupervised classification was used due to time constraints. The image was clustered into 15 reflectance classes.

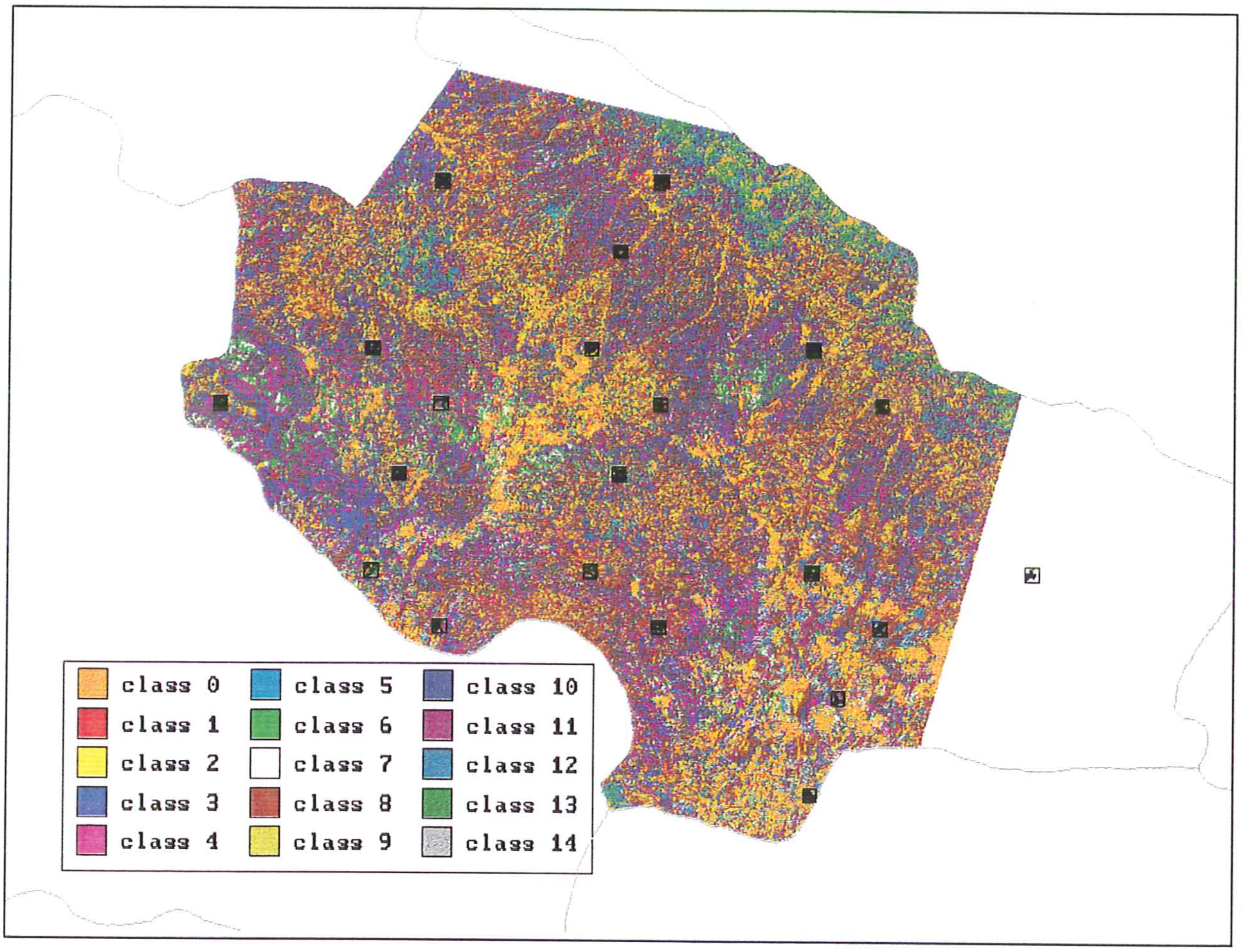
Step two is to relate the reflectance classes to cover types. To do this a confusion matrix (figure 5.7) was made by crossing the classified image with the complete sample set.

The third step is to calculate the actual areas of the cover types. To do this firstly the total area of the reflectance classes within Razan had to be calculated. Because the image available does not cover the total area (19 % is missing) a correction factor had to be used to modify the results of the GIS operation. The factor was very simple and entailed the allocation of the missing area to the reflectance classes based on the relative areas found in the image. With a spreadsheet the areas of the cover types could be easily calculated. In table 5.11 the results of this calculation are given and compared to the areas as calculated with the AFS method. In figure 5.5 the map of the reflectance classes with the sample segments is displayed.

Table 5.11. Area calculation with a satellite image classified into reflectance classes compared to the areas as derived from the AFS method.

CROPCODE	Irrigated	Description	Estimated area (Z) [ha.] from the AFS method	CV (Z) [%]	area estimate from reflectance	Difference reflect-afs
102	y	wheat	19751	29.6	23599	16.3
103	n	wheat	44826	17.8	50798	11.8
104	y	barley	2335	24.5	2661	12.3
105	n	barley	11027	27.3	14708	25.0
112	y	beans	70	81.2	76	7.6
114	y	chickpea	2692	47.8	3294	18.3
115	n	chickpea	2040	35.6	2100	2.9
116	y	lentil	135	54.4	121	-11.0
117	n	lentil	663	34.3	722	8.2
156	y	watermelon	3822	44.1	4229	9.6
160	y	cucumber	109	66.6	159	31.4
166	u	other vegetables	187	73.5	194	3.3
170	y	potato	56	81.2	49	-14.4
174	y	tomato	42	57.9	38	-11.3
202	y	alfalfa	10436	41.8	10247	-1.8
203	n	alfalfa	5100	70.2	7071	27.9
204	u	clover	113	74.5	104	-8.2
458	u	watermelon (seed)	54	94.4	51	-6.1
474	u	sainfov	143	81.2	141	-1.4
478	u	clover (seed)	153	93.2	149	-2.5
504	u	kidneybean	41	94.4	28	-46.7
700	u	unknown	49	94.4	130	61.9
701	u	orchard	7142	43.2	6548	-9.1
702	x	building	777	67.4	840	7.4
703	x	bareland	6067	52.2	7556	19.7
705	x	road	1508	27.9	1604	6.0
706	x	waterbody	1041	72.8	1161	10.3
707	x	rangeland	25658	18.9	32077	20.0
708	x	fallow	20532	20.4	33037	37.9
709	x	fallow (plowed)	35384	17.0	46526	23.9
710	u	unknown	52	68.9	55	6.4
711	u	river	830	67.4	891	6.9
712	u	river shoulder	1425	80.2	1981	28.1
713	u	khanat	193	84.9	219	12.2

Figure 5.5. The map of the reflectance classes overlayed with the sampled segments and the administrative boundaries.



The results from the method of combining reflectance classes with a confusion matrix to calculate areas is promising as can be seen in table 5.1.11. Most of the areas as found via reflectance classes are within the CV as calculated for the AFS derived estimates. One disadvantage of the method is that no clear map can be produced; classes in the map refer to probabilities of occurrence of cover types and not cover types directly.

Some improvements to the method are needed. One is that the missing area has to be allotted in a more realistic way. The allocation would have to be based on percentages of reflectance classes in the different strata and not simple extrapolation. An other is selecting reflectance classes manually, as described in the next paragraph, to make them easier to analyse and standardise the results. A third method of improvement is to check the sample set in more detail (see paragraphs above). It is also possible to exclude some areas from being assigned agricultural use with the land use map because some cover types have not been sampled (like the mountainous areas). More refinements may be possible but depend on time available related to possible improvements to the area estimates.

5.1.9 Improvement of AFS with the classification result

There are two methods to execute this procedure.

The first one is described by Gallego (1995) and Chapter 4 of this report. The method entails:

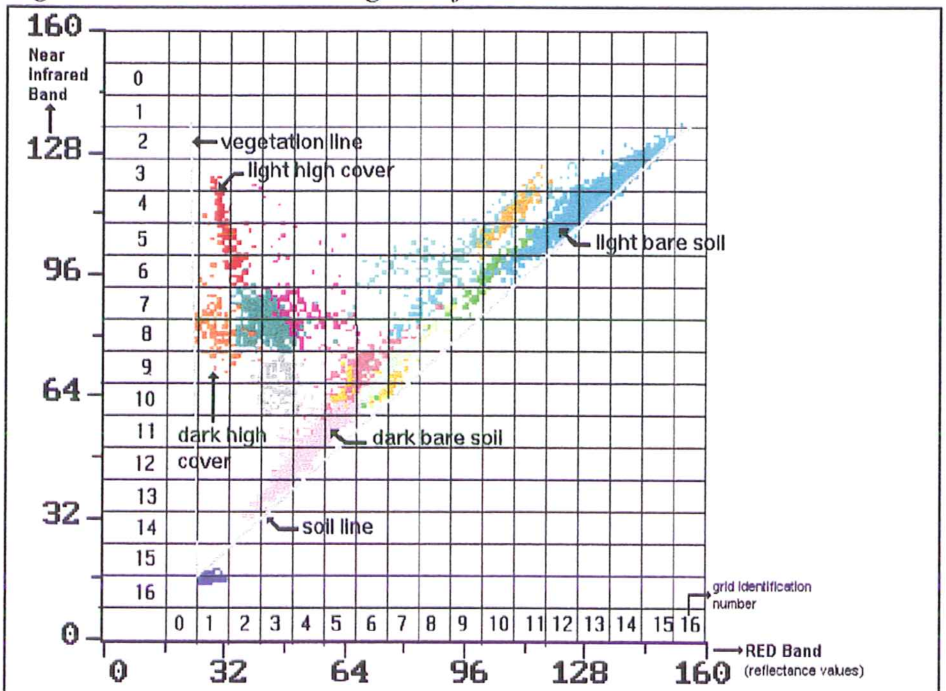
- classifying the imagery by supervised classification into real cover classes.
- calculating the percentage of each crop in the classified image within each segment.
- creating a linear regression between the percentages of cover types found in the segments of the classified image with the actual (ground truth) percentages as recorded in the field.
- With this relation the estimated areas from AFS are improved (with the knowledge of the area between the segments which is ingrained in the satellite image)

The second method is similar to the one described above but instead of using a image classified into real cover types an image classified into spectral classes is used. Spectral classes are classes that have a certain fixed range of reflectance values in each of the used spectral bands. The image classified into spectral classes is crossed with ***all*** the sampled segments (ground truth) to create an confusion matrix. This matrix gives information of the percentage of all cover types in each of the reflectance classes.

For building the regression estimator instead of the cover types found in the classified image, the percentages of the confusion matrix are used. Thus, for each segment the relative area of reflectance classes is calculated and combined with the information of the confusion matrix the areas of cover types can be estimated within that segment. The big advantage of this method is that the image does not have to be perfectly classified into cover types which, as described above might be time consuming or even not possible, but into reflectance classes.

The reflectance classes can be based on strait-forward unsupervised classification (never exactly the same results) or on predefined classes (always the same result). Which one of these is used has little influence on the result but the interpretation of predefined classes is somewhat easier. This is because the possible occurrence of cover types in predefined reflectance classes is known. This can be clearly understood from figure 5.1.6 in which an example is given of subdivision into 16*16 reflectance classes. A subdivision into so many classes is not useful for analysis of the Razan area because per reflectance class not enough pixels of known cover type will be available.

Figure 5.6. Standard scattergram of SPOT bands 2 and 3



light high cover=vegetation with a high cover percentage and a high ratio of horizontal leaves
dark high cover=vegetation with a high cover percentage and a high ratio of vertical leaves

In figure 5.7 the results are given of a cross between the sample set and a reflectance classes map. The reflectance classes map was generated within ilwis by unsupervised classification with 14 classes. More classes would not be advisable at this point because enough sample pixels must fall within each cell of the matrix to get an reliable result.

Figure 5.7. Confusion matrix with the percentage of each cover type within a reflectance class.

cropcodes	0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	14.0
	<---reflectance classes--->														
102	16.3	7.0	2.8	7.1	4.4	14.9	6.7	0.0	19.5	10.3	3.2	1.4	0.2	0.0	6.2
103	21.6	0.6	0.2	15.3	12.7	2.1	5.5	1.2	24.1	11.5	0.7	1.4	0.0	0.0	3.2
104	26.5	6.9	3.1	9.5	6.6	11.2	0.1	0.0	18.3	12.1	1.3	0.6	0.0	0.0	3.7
105	4.8	1.1	0.4	19.7	18.8	4.5	4.7	0.2	25.8	15.5	0.8	2.3	0.1	0.0	1.2
112	22.7	31.8	13.6	0.0	0.0	9.1	0.0	0.0	0.0	9.1	13.6	0.0	0.0	0.0	0.0
114	27.2	7.3	2.0	16.3	15.1	4.4	4.2	0.4	12.3	6.5	1.0	0.3	0.0	0.0	3.0
115	38.7	1.9	0.4	12.8	4.3	3.3	0.0	0.0	20.4	12.6	0.4	0.9	0.0	0.0	4.4
116	25.0	17.9	28.6	0.0	0.0	0.0	0.0	0.0	0.0	14.3	3.6	10.7	0.0	0.0	0.0
117	24.1	6.9	2.3	15.5	4.0	6.3	1.1	0.0	13.8	23.0	1.1	1.7	0.0	0.0	0.0
156	27.2	7.1	3.4	5.4	5.1	11.0	0.0	0.0	18.6	14.5	4.4	1.3	0.1	0.0	1.8
160	0.0	0.0	0.0	6.5	0.0	0.0	0.0	0.0	6.5	74.2	0.0	12.9	0.0	0.0	0.0
166	10.6	2.1	0.0	14.9	0.0	4.3	0.0	0.0	59.6	8.5	0.0	0.0	0.0	0.0	0.0
170	21.4	28.6	14.3	0.0	0.0	21.4	0.0	0.0	14.3	0.0	0.0	0.0	0.0	0.0	0.0
174	20.0	0.0	10.0	0.0	0.0	30.0	0.0	0.0	20.0	10.0	0.0	0.0	0.0	0.0	10.0
202	41.0	7.6	5.1	6.8	2.8	8.5	1.5	0.0	11.8	7.8	2.5	0.9	0.0	0.0	3.6
203	0.2	0.4	0.0	26.3	20.0	2.6	4.1	1.0	29.3	13.4	0.1	2.6	0.1	0.0	0.0
204	24.0	0.0	0.0	24.0	4.0	0.0	0.0	0.0	48.0	0.0	0.0	0.0	0.0	0.0	0.0
458	8.3	8.3	0.0	25.0	0.0	25.0	0.0	0.0	33.3	0.0	0.0	0.0	0.0	0.0	0.0
474	62.8	9.3	9.3	0.0	0.0	0.0	0.0	0.0	0.0	2.3	14.0	2.3	0.0	0.0	0.0
478	31.7	7.3	12.2	0.0	0.0	4.9	0.0	0.0	0.0	43.9	0.0	0.0	0.0	0.0	0.0
504	100.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
700	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	0.0	84.6	0.0	0.0	0.0
701	65.9	5.7	9.0	1.6	0.3	3.4	0.3	0.0	3.4	3.2	4.3	2.0	0.4	0.0	0.5
702	24.7	4.2	4.7	13.2	14.7	8.4	6.3	1.6	5.8	0.5	1.1	0.0	0.0	0.0	14.7
703	6.0	0.6	0.9	12.6	14.5	5.0	10.3	0.1	42.2	3.9	0.2	0.9	0.0	0.0	2.7
705	19.4	6.5	4.1	13.2	4.1	10.6	0.3	0.0	21.0	15.0	1.3	1.8	0.0	0.0	2.6
706	49.5	4.5	3.5	6.6	11.4	0.0	9.3	0.7	4.8	5.9	2.8	1.0	0.0	0.0	0.0
707	10.5	1.9	0.9	14.9	7.2	2.9	3.6	0.8	25.0	25.4	1.0	5.0	0.2	0.0	0.7
708	7.4	1.9	1.1	17.8	13.8	4.3	3.7	0.2	24.1	14.2	1.0	7.0	1.1	0.1	2.3
709	7.2	2.7	1.3	14.3	10.0	2.6	4.1	0.6	25.5	24.0	1.6	4.5	0.4	0.1	1.1
710	0.0	30.8	7.7	30.8	0.0	0.0	0.0	0.0	23.1	7.7	0.0	0.0	0.0	0.0	0.0
711	1.9	0.5	0.0	3.3	0.0	0.5	0.0	0.0	69.8	20.0	3.3	0.9	0.0	0.0	0.0
712	0.0	0.8	0.0	10.6	29.6	2.3	4.9	0.0	39.9	7.2	0.0	3.6	0.0	0.0	1.0
713	0.0	0.0	0.0	0.0	0.0	2.0	0.0	4.0	92.0	0.0	0.0	0.0	0.0	0.0	2.0

5.2.2. Derivation of yield estimates of wheat and barley on various soil materials in the Razan township under defined management, using 10 years of weather data.

5.2.2.1 Methods

Most of this exercise was described in 4.2. Production potentials for selected varieties of wheat and barley were calculated for several soil types of Razan township under defined management practices using weather data (of Ekbatan) of the past 10 years. Ekbatan weather data had to be used as no complete weather data sets were available for Razan township. It will be discussed for follow-up purposes whether it is better to maintain full (consistent) synoptic data sets or to substitute only rainfall data by available location-specific rainfall data. The soil materials of the Razan township were identified from the soil map stored in Arc-Info. The soil map covers only parts of the area and the cultivated area. Soil characterization, or better land unit characterization, considers some 30 variables. For the time being, only the "soil texture class" is used as a discriminating criterion, assuming that the genesis of the soils of the cultivated parts of the long, slightly sloping piedmont plains (Bakhsh) has been uniform (lithosols excluded). Most certainly, the depth of the phreatic level varies over the sloping plains as convexity and concavity seems to occur; this shall be taken into consideration in follow-up research.

At the time of writing of this report, yield estimates could be derived, but their reliability is still unknown. Historical data on crop yields are village-specific. Villages are part of administrative units which recommend / apply specific management activities and which have different soil types and weather etc. Crop performance can be simulated by polygon but is at this moment not yet practical. It is planned to be attempted before January 1997.

Follow-up research will most probably be directed towards integration Crop Growth Modeling and Crop Monitoring by means of GIS. MANA (PS123) should be able to read and process information derived from PATs (polygon attribute tables) and to write information towards PATs.

Statistical relationships between simulated production potentials and actual (historical) yields will be identified for each land unit with the aim to derive yield estimates with known accuracy. Relationships will first be established for the smallest possible number of strata, as dictated by the number of historical samples / data (and corresponding simulation results).

So far, yield estimates for Razan township are based on tentative correlation(s) between historical yield data and yield potentials simulated for the same years. No differentiation in soil type etc. is made yet. Some historical data are annexed.

Table 5.12. Actual & simulated PS-2 production

Historical data on actual yields in Razan township (average & std.deviation) :

	Wheat		Barley	
Year	Irrigated	Rain-fed	Irrigated	Rain-fed
1990/91	2558 (539)	546 (308)	3068 (475)	150 (75)
1991/92	2495 (898)	556 (163)	2898 (691)	0 (0)
1992/93	2927 (1174)	968 (232)	3644 (1016)	0 (0)
1993/94	2964 (479)	1114 (150)	3344 (557)	4700 (2300)

Simulations:

Wheat	Irrigated (c.v. Navid)				Rain-fed (c.v. Sardari)			
	Loam	Claylo.	Clay	**aggregate**	Loam	Claylo.	Clay	**aggregate**
PS-2 yield potential in:								
1990/91	7530	5400	5620	5936	680	1440	1540	1338
1991/92	7100	7220	6890	7030	1530	4720	4830	4137
1992/93	5700	6080	6180	6045	0	1940	1720	1820
1993/94	7260	6150	6210	6400	1220	3050	2790	2554

Barley	Irrigated (c.v. Joh!)				Rain-fed (c.v. Zarjo)			
	Loam	Claylo.	Clay	**aggregate**	Loam	Claylo.	Clay	**aggregate**
PS-2 yield potential in:								
1990/91	0	0	0	0	2890	2390	2700	2645
1991/92	6620	5420	5910	5905	1810	1560	1720	1690
1992/93	6560	6470	6800	6653	2520	1820	2200	2150
1993/94	7580	7320	7390	7407	2600	2680	2680	2664

5.2.2 Results

5.2.2.1 Results at PS-2

Simulation per year at PS-2 was stratified according to soil texture class (loamy, clay loamy and clayey soils) and then aggregated with the purely hypothetical ratio of frequency of soil texture occurrence in Razan township of 20:30:50% (in the absence of actual data). This ratio needs to be re-established when proper geographical data become available. The relations between simulated production at PS2 and actual productions as measured by ASID are illustrated in table 5.12. The bold lines indicate the averages of the measured yields per year. These average figures make clear that the actual yields of the irrigated crops are limited to about 2500-3500 kg/ha by a factor which has not been modeled. This factor might be nutrient availability. The average figures of the rain-fed crops, the figures of barley not to be taken too seriously because only two observation points were considered, show a rather clear agreement of actual yields with potential PS-2 yields until actual yields reach a maximum and then decline. This illustrates that water availability was the production limiting factor until that maximum was reached. The limiting factor after maximum can probably not be explained by nutrient shortage because the associated actual productivity is still far below the unfertilized productivity of the irrigated crop (unless irrigation water provides fertilizing nutrients).

The corresponding regression model is as follows (X = simulated PS-2 yield potential):

Irrigated wheat:	Actual yield = $-58131 + 19\,X - 0.0015\,X^2$	($R^2 = 0.828$)
Rain fed wheat:	Actual yield = $-1093 + 1.65\,X - 0.0003\,X^2$	($R^2 = 0.980$)
Irrigated barley:	Actual yield = $-39484 + 12.66\,X - 0.00093\,X^2$	($R^2 = 1.000$)
Rain fed barley:	Actual yield = $-450131 + 101.5\,X + 0.026\,X^2$	($R^2 = 1.000$)

When the origin is included in the regression model, and soil material is considered exclusively as clay loam (nearly 100% of the soils of the soil map are indicated as having a clay loamy texture) the following equations are valid:

Irrigated wheat:	Actual yield = $-6.679 + 0.9765\,X - 0.000085\,X^2$ 95% confidence range = 1088.4	($R^2 = 0.990$)
Rain-fed wheat:	Actual yield = $-56.0573 + 0.7365\,X - 0.000127\,X^2$ 95% confidence range = 381.5	($R^2 = 0.960$)
Irrigated barley:	Actual yield = $-4.31875 + 0.7253\,X - 0.000034\,X^2$ 95% confidence range = 1642.4	($R^2 = 0.898$)
Rain-fed barley:	Actual yield = $-242.013 + 1.0998\,X$ 95% confidence range = 3022.9	($R^2 = 0.6055$)

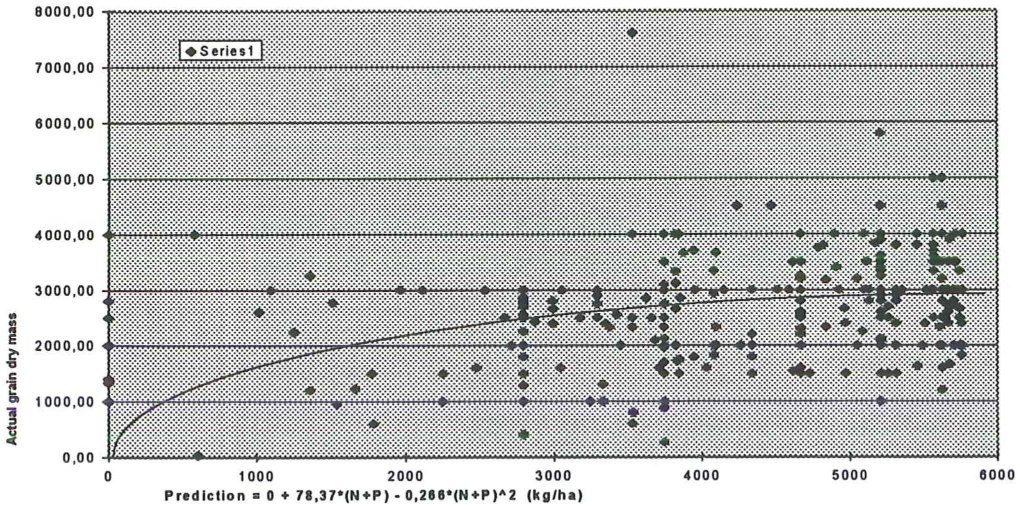
5.2.2 Results at PS-3

The above suggests the probability that actual productivity of irrigated crops is limited by other factors than water shortage like nutrient shortage. As ASID provides historical yield data in combination with fertilizer management data, it is expected that the simulation of yield potentials at PS-3 might result in a more reliable relation between potential- and actual yields. Preliminary results are presented in the next figures. The relations between predicted- and actual yields in Razan township are based on prediction as a function of (N+P) as was established in § 2.2.2 for irrigated wheat. As the actual yields often are less than the experimental unfertilized yield (the constant in the equation), the established equation through the origin was identified as most appropriate:

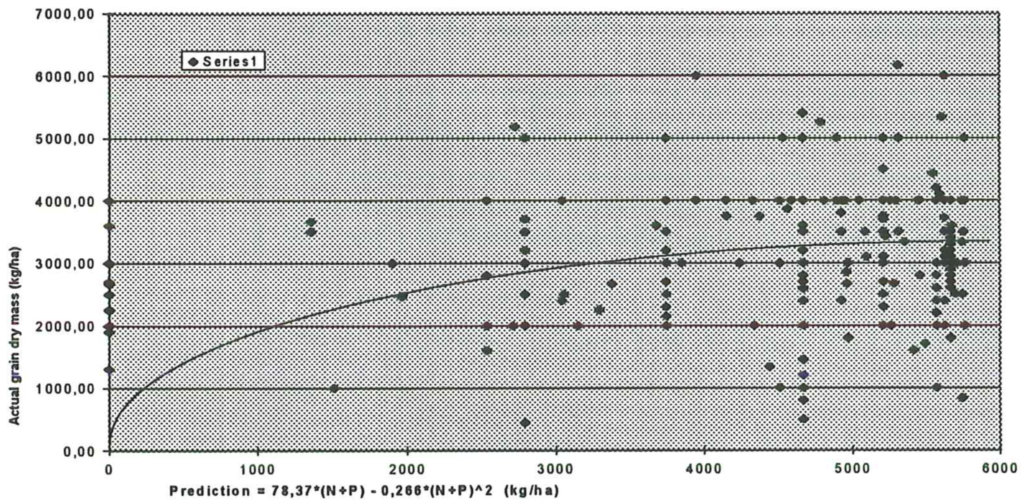
prediction of grain dry mass (kg/ha) at PS-3 = $78.369 * (N+P) - 0.2665 * (N+P)^2$

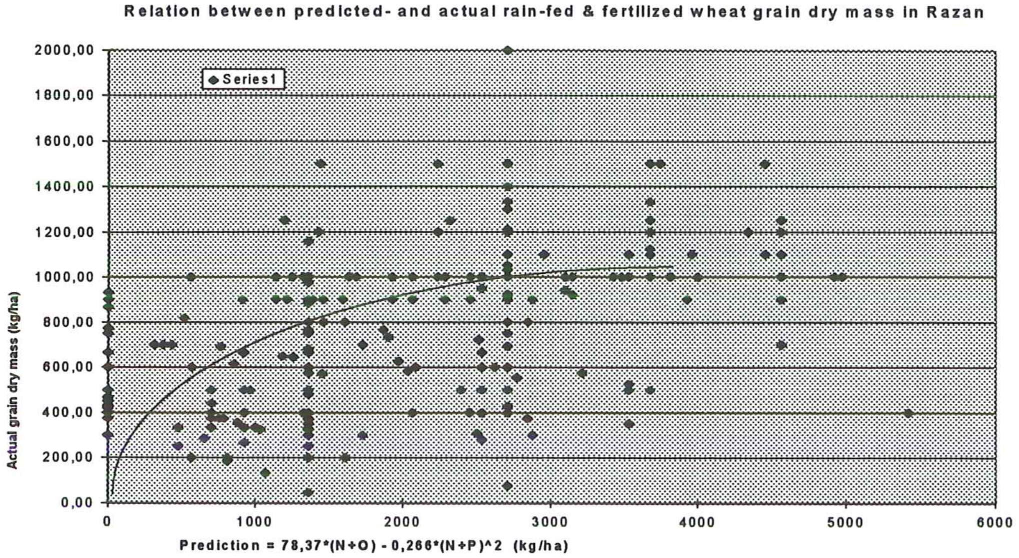
The following figures 5.8 and 5.9 are entirely based on this empirical relationship and are not yet coupled with yield potentials at PS-2.

Relation between predicted- and actual irrigated & fertilized wheat grain dry mass in Razan



Relation between predicted- and actual irrigated & fertilized barley grain dry mass in Razan





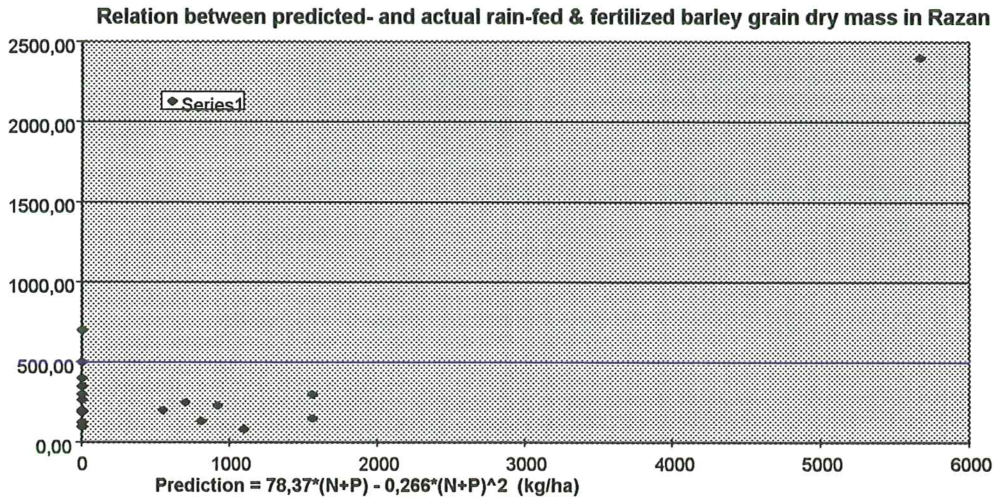


Figure 5.9. a, b, c & d. Visual illustration of degree of agreement between predicted- and actual grain dry mass yields in Razan township.

5.2.2.4 Conclusions

Derived yield estimates for Razan township appear very reliable and accurate but one should be aware of the fact that the statistical value is only limited because the number of the dependent variable statistically treated (actual yield observations) was small and the number of the independent variable (simulated yield at PS2) was very small. The number of strata considered was only one (1). All eventually yield differentiating land- and land use parameters were aggregated together. It might be expected that the use of more data will in first instance improve the range of applicability of the regression model. At present, the applicability of the model is limited to the minimum and maximum values of the PS-2 yield potentials as indicated in the associated graphs. Use of more data allows to improve the knowledge of the accuracy of the regression models because in the present model, deviation has not been taken into account. When a 100% soil coverage of Razan is available and linked to the location of the villages associated with the historical yield figures, a more final regression model will be established which will know a higher level of stratification. It might be expected that the fit between simulated- and actual yields will improve when fertilizer dose will be a discriminating criteria.

5.2. 3 Implementation and evaluation of the yield estimate method

As no weather data of 1996 were available, the crop forecasting data model could not be applied. Instead, two substituting simplified procedures were followed. First, 4-year averages of potential yields were used for estimation of the actual yield in 1996. Only the 4-year averages on clay loam were considered (as this soil material dominates the texture of the soils of the region). The actual yields are estimated within 95% confidence ranges.

Actual yield of irrigated wheat: 2240 - **2780** - 3330 (kg/ha)
Actual yield of rain-fed wheat: 820 - **1010** - 1200 (kg/ha)
Actual yield if irrigated barley: 2430 - **3250** - 4070 (kg/ha)
Actual yield of rain-fed barley: 570 - **2080** - 3590 (kg/ha)

Secondly, a forecast procedure is followed, using the 9 year-average of the simulated total above ground dry mass (DM) of irrigated wheat at JDN 150. This average was 8230 kg/ha with a standard error of 1620 kg/ha (see annex 5). Using the forecast equation established in § 4.3.3.3;

Forecast of simulated irrigated wheat grain yield at PS-2:
$= 2955 + (0.322 * 8230) = 5685 (\pm 800)$ kg/ha
Please, note that the ± 800 is a mean value of deviation of predictions for all values of DM and that the error at the 9-year average of DM is most probably of lower value.

Using the actual yield estimate equation established in § 4.2.3.2.1;

Estimated actual irrigated wheat grain yield:
$= -6.679 + (0.975 * 5685) - (0.000085 * (5685)^2) = 2790$ (kg/ha)

The great difference between predicted potential- and predicted actual yield is remarkable but is simply explained by the fact that the potential yield is simulated at PS-2 and not at PS-3 and by the fact that simulated timing of irrigation was assumed to have been near-optimal, what most probably is not the case at farmers level in Razan township.

The following table shows that, when the ± 800 kg/ha standard error of simulated yield is taken into consideration, the estimated actual yield does only change very little. This is due to the character of the 2nd order polynomal relation between actual- and potential yield (assumed to cross the origin). This relation is still subject for further amelioration by further stratification and further agronomic analysis of the circumstances in Razan township. The predicted value is similar to the predicted value with the (over-) simplified methodology because the same multi-year data were used.

Irrigated wheat on clay loam

Actual yield as a function of Potential yield

	- std.err.	average P	+ std.err.
average A	2728	2780	2742
+95%	3272	3333	3286
-95%	2184	2245	2198

5.2.4. Overall conclusions

Calibration results at PS-2 (water limited production) and PS-23 (fertilizer requirements) appear to be near-perfect. Validation results are within ranges of expectation. In the specific season of 1994/95, which was an exceptionally wet year, validation results diverted from validation experiment data, what possibly might be partly explained by the fact that actual weather data were substituted with weather data from Ekbatan station.

Validation of model performance for the (ranges of) circumstances to be expected in Hamadan province was satisfactory. Simulation of daily growth of wheat and barley varieties, with management was differentiated in 'irrigated', 'rain-fed' and 'fertilized', and with identified soil types and 9 years of weather data, resulted in yield potentials within the ranges expected for the Razan pilot area data.

Collaboration in system development is in progress. Most emphasis was given to model calibration and validation which are a precondition for identification of a working regression model of the relationship between simulated potential productions and historical actual productions. Relationships were stratified according to crop type and irrigation regime and the resulting accuracies were characterized with R^2s of 0.99 for irrigated wheat, 0.96 for rain-fed wheat, 0.90 for irrigated barley and 0.61 for rain-fed barley.

Due to technical difficulties encountered by team members, the reliability of the multi-year yield estimates of Razan township still can be improved. Effective data exchange within the team is recommended to give priority in follow-up research which will allow proper further stratification of the historical data with respect to soil material and other relevant parameters (to be incorporated into the model). Next to further stratification, the reliability is expected to be improved by better knowledge of the actual applied irrigation regimes. Improvement as well is expected from simulation at PS-3 (water- and nutrient limited production) as the relationships between potential- and actual yields are satisfactory described by a 2nd order polynomal. This indicates an increase of actual yields with increasing potential yields (at PS-2) until a maximum is reached, followed by a decrease in actual yields with further increasing potential yields. Some promising results in analyzing the relation between nutrient availability and crop production at research stations in the region have already been achieved, even though the operationalization of these achievements requires incorporation into the algorithm of the dynamics significant at PS-3. Precaution in doing so is justified because the calculation of the rates of nutrient release by soil organic matter mineralization resulted in unexpected high values.

Further it is suggested to make crop forecasting a function of satellite image based crop cover estimation and (WDVI based) LAI estimation, leading to re-parameterization- and initialization of the crop growth simulation model, which subsequently allows forecasting on the basis of extrapolated generic weather conditions and/or extrapolated generic crop growth patterns. However, mid-season LAI estimation by means of simulation is most probably more accurate and reliable than on the basis of satellite image interpretation. Further analysis (on irrigated wheat) showed that simulated above ground dry mass is a more significant yield forecasting variable than LAI. On basis of this variable, the multi-year potential grain yield at maturity of irrigated wheat was 'forecast' from the 1st of June onwards and the associated multi-year actual grain yield was estimated.

Last but not least it must be remarked that the above is the result of a preliminary exercise conform the means which were available (2 months).

ACRONYMS

ASID	Agricultural Statistics and Information Department, Ministry of Agriculture, Tehran, Islamic Republic of Iran
CGMS	Crop Growth Monitoring System
CPBKF	Crop Production in Burkina Faso
GIS	Geographic Information System
MANA	Adapted present version of PS123 (Mana stands for standardization of MANAgement decisions)
IMO	Iranian Meteorological Organization, Tehran
ITC	International Institute for Aerospace Survey and Earth Sciences, Enschede, the Netherlands
PS123	A simple dynamic crop growth simulation model at two levels of abstraction with corresponding fertilizer requirements (Production Situation 1,2 & 3)
SSO	Storage Organs

6. TRAINING AND DOCUMENTATION

6.1 Training activities:

One of the objective of the project is technology transfer and training the respective personnel in ministry of Agriculture to successfully operate and conduct the crop forecasting system. This was planned to be achieved through training and well documentation of the developed method. Therefore substantive amount of effort is devoted this activity. The activity related to this are: carried out as follows:

- **On the job training:**

On the job training is a countinous process in which all the Iranian counterparts whom are involved in the project are getting familiar with the concpts and the related techniques which are used in the project. In addition to this some special training on the job training programme has also been foreseen and conducted as follows:

- On the job training on the area frame sampling
- Upgrading the ASID data processing capabilities

These activities were carried out during the first field work and the detailed programme and its evaluation is reflected in the Field work Report (Sharifi, et.,al, 1996)

- **Professional training**

Training through shorts courses at ITC: A training programme for three of ASID staff members is planned to be carried out in early 1997 in the following topics:

- Digital image processing
- Modelling of agricultural production system
- Information system development

Long term training program: To gurantee the implementation of the project a long term training program (17 months) is planned for one of the ASID staff. This is being carried out as of September 1996 and includes various aspects of GIS, information system development and remote sensing application for crop inventory.

6.2 Documentation:

The results of the activities which have been carried out in the framework of this research are documented in the following:

- First Progress report, submitted on December 1995
- Project initiation mission report, submitted on April 1996

- Data collection and field work report submitted on Augest 1996
- Explanatory report on Hamadan data sets July 1996
- The current mid-term report January 1997

7. PROJECT TIME TABLE AND WORKING PLAN

The development of methods/procedures and implementation of activities in all phases is planned as follows:

1. Project initiation phase March 1995 (March 1996)

1.1 Review and analysis of existing methods (March- December 1995)
- Crop inventory
- Yield forecasting

1.2 Selection of an appropriate method
- Crop inventory
- Yield forecasting

1.3 Project initiation trip (January - March 1996)
- Study of the current situation
- Preliminary study of existing data and data sources
- Assessment of the selected approach
- Selection of a pilot area
- Creation of the required local project set_up
- Finalization of the working plan

1.4 Preliminary data collection in Iran (ASID, March - May 1996)
- Statistical discipline
  - Study and summarize relevant activities of organizations that currently produce estimates of the productions of main agricultural commodities in Iran.
- Remote sensing activities
  - Identification of existing satellite data and preparation of data indexes
  - Ordering and acquisition of the required satellite data
  - Geometric and radiometric correction of all available satellite imagery
  - Identification of (indexes of) air photo coverage of the pilot area
  - Identification of (locations of) all sample fields on air photos or Spot data (this will be carried out in collaboration with ITC)
  - Collection of information on crop patterns, rotations, and crop calendars of major agricultural commodities in the pilot area. This information should be collected at the lowest possible level, at Dehestan level if possible
  - Preparation of a photomap of the pilot area using 3 existing Spot Pan. images

- Preparation of a 1/100,000 topomap of the province on the basis of the existing 1/50,000 topomap

- Modelling of the main agricultural commodities
  - Identification of the existing meterological stations in the province and its neighbourhood and their availability of daily weather data
  - Identification of the existing crop phenological data as collected by different organization and their format and availability
  - Identification of the existing soil data, format and their sources

- Information management and GIS
  - Study to design and develop an adequate information system for crop forecasting to
  - Organize the basic existing geographic data
  - Organize the basic existing thematic data (original questionnaires of) different sources such as the Agricultural Statistics Project, Production Cooperatives (costs!) and Services Centres.
  - Support all the processes used in the crop forecasting system

2. Design of a prototype crop forecasting method for the pilot area (March - May 1996)

2.1 Design of the crop inventory method at ITC (March - May 1996)
- Stratification of the province based on the land use and satellite data
- Design of the required area frame sampling
- Preparation of instructions for field work

2.2 Deign of the yield estimate method at ITC (March - May 1996)
- Design of crop inventory and yield forecasting method
- Preliminary calibration of the crop growth simulation model

2.3 Field data collection from the pilot area (May - June 1996)
- Preparation and training of field crews (at least 3)
- Data collection and on the job training for AFS
- Data collection for calibration and validation of simulation models

2.4 Data collection in Iran (ASID, July - December 1996)
- Statistical discipline
  - Study and summarize relevant method/procedures of organizations that currently are producing estimates on the production of main agricultural commodities in Iran.
- Remote sensing activities
  - Ordering and acquisition of the required satellite data
  - Geometric and radiometric correction of all available satellite imagery

        - Classification of satellite data using field data

- Modelling of the main agricultural commodities
    - Collection of daily weather data for all stations in the province and its neighbourhood
    - Collection of crop phenological data
    - Collection of associated soil data
    - Collection of historical production data

- Information management and GIS
    - Digitalization of all the segments and required maps
    - Study to design and develop an adequate information system for crop forecasting to:
        - Organize the basic existing geographic data
        - Organize the basic existing thematic data (original questionnaires of) different sources such as the Agricultural Statistics Project, Production Cooperatives (costs!) and Services Centres.
        - Support various processes used in the Crop forecasting system

2.5 Implementation and evaluation of the crop inventory method for the Pilot area (Razan) at ITC, July - December 1996
- Implementation of the AFS
- Improvement of AFS based on classification of satellite data
- Evaluation of the crop inventory method

2.6 Implementation and evaluation of yield forecasting method for the pilot area (Razan)at ITC, July - December 1996
- Calibration and validation of the simulation models for major agricultural commodities
- Running the simulation models for the pilot area using collected data
    - Development of a proper forecasting model for the pilot area
    - Evaluation of the yield estimate method

2.7 Development of conceptual model for crop forecasting system at ITC, July - December 1996
- Development of a conceptual model for yield estimate
- Development of a conceptual model for Crop inventory
- Development of a conceptual model for crop forecasting system

3. Training of the Iranian counterparts

3.1 On the job training (Iran)

3.2 Short term training (2 months at ITC, early 1997)
- Remote Sensing and GIS, one person for two month starting Feb.1.1997.
- System Development ,one person for two month starting Feb.1.1997.
- Modelling of crop production ,one person for two months starting February, 1997.

3.3 Professional training (18 months at ITC, from September 1996)

4. Design of the crop forecasting method for the entire province at ITC (January - April 1997)

4.1 Preparation of the mid-term report
- Documentation of the results
- Development of the detailed plan for field work

4.2 - Crop inventory design
- Design of the crop inventory for the entire province
- Preparation for field work

4.3 - Yield estimate design
- Design of the yield estimate for the entire province
- Preparation for field work

4.4 Continuation of data collection in Iran (ASID, January - April 1997)

- Remote sensing activities
  - Ordering and acquisition of the required satellite data. Minimum one coverage of Landsat TM or IRS-1c, or Spot, and Resource-01 collected in the growing period June - July 1997
  - Preparation for field work. Finding a proper aerial photography or high resoulution satellite data to locate field segments is very important information, without which the AFS can not be implemented.

- Modelling of the main agricultural commodities
  - Collection of daily weather data for all stations in the province and its neighbourhood
  - Collection of crop phenological data for the major agricultural commodities in the province (if possible at Shahrestan level)
  - Collection of crop calendar for the major crops in the provience (at Shahrestan level)
  - Collection of soil data as specified before
  - Collection of historical production data including:

- collection of information from all production cooperatives. For this purpose the same questionair which is used for current statistical project will suffice
- Collection of the same type of information from Service centre

- Information management and GIS
    - Study to design and develop an adequate information system for crop forecasting to:
    - Organize and provide access to the basic existing and collected data including:
        - All digitalized segments
        - Land use map
        - Topographic maps
        - Satellite data
        - Geographic points (villages)
        - Administration units (Province, Shahrestan, Bakhsh, Dehestan and Villages)
        - Soil map and related data
        - Weather stations and their related data sets
        - Crop phenology
        - Crop calendar
    - Organize and provide access to the existing basic thematic data (original questionnaires of) different sources (raw data not processed data) such as the Agricultural Statistics Project (Tarhe Jarie Amar), Costs of production (Hazinehe Tolid), Production Cooperatives; and Services Centres.
    - Support various processes used in the Crop forecasting system

- Statistical discipline
    - Collaborate with the other group to collect data and develop the require information system
    - Preparation for the field work 1997

5. Implementation of the crop forecasting method at the province level. The approach is similar to what developed for the pilot area "part 2 and 3" and modified in part "4" (May - August 1997)

5.1 Implementation of crop inventory (Iran, Iranian counterparts)
- Implementation of the AFS
- Improvement of AFS based on classification of satellite data

5.2 Implementation of yield forecasting (Iran, Iranian counterparts)
- Running the simulation models for the pilot area using collected data
- Development of a proper yield forecasting model for the pilot area

5.3 Derivation of the production estimates (Iran, Iranian counterparts)

5.4 Preparation of final document for crop inventory (ITC)
5.5 Preparation of final document for yield estimate (ITC)
5.6 Preparation of final document on the conceptual data model for the entire crop forecasting system (ITC)

6. Evaluation of the results (ITC, Iran) (September 1997)

6.1 Evaluation of the crop inventory method
6.2 Evaluation of the yield forecasting method
6.3 Overall quality of the production estimates
6.4 Development of the final documents

- Field data collection for area frame sampling at provincial level
- Processing of the field data and derive area estimate
- Geometric and radiometric correction of the above satellte data
    - Identification of the location of the AFS segments in Satellite data
    - Classification of satellite data
    - Estimation of crop acerages

ANNEX I, Steps in Area Frame Sampling method, based on progress report I, modified with knowledge acquired later in the project.

Stratification:

Goal: dividing the study area in units (strata) on the basis of homogeneity of the research objects (this project: major crops/cover types)

possible methods:
a. visual classification of (high spatial resolution) satellite images
b. combining information layers in GIS
c. classification of satellite images
d. combination of a to c

method chosen: firstly a, later d.
 * why: **a** = easiest with limited data resources, d = with more knowledge better results (landuse map now available)

details (steps) chosen method a:
- gain knowledge of area on the research object(s)

- create a satellite image with best possible recognition of research object(s).
 * normally: - colour composite (with image enhancement, depending on software and image),
 * chosen: - the combination 453 (RGB)
 * why: -highest variation between bands in relation to vegetation cover recognition

- chose number of strata
 normally: - not to many strata, usually between 3 and 8
 chosen: - 8
 why: - these units were recognisable on the Tm image. Exact importance for research object (the major crops) not yet fully known, may be redraw or combined later.

- delineate areas with homogeneous distribution of the research object(s)
 * normally: - a polygon (sub unit of a strata) should not be smaller as 10 sampling units

details (steps) chosen method d:

 chosen: the classes from an existing landuse map.
 why: exact importance for research object (the major crops) not yet fully known, may be redraw or combined later

sampling design

Goal: creating a statistically correct method of taking samples in the field, depending on type of information needed and possible inputs.

possible methods:
a. point sampling
b. area sampling
 b1 absolute random sampling
 b2 systematic (square grid) sampling
  b2a aligned sampling
  b2b modified aligned sampling
  b2c unaligned sampling
 b3 unsystematic (non square grid) sampling

method chosen: b2b
 why: - method b2b gives best (statistical) results, while reducing the inputs needed, in relation to cover recognition (progress report and Cochran 1963)

details (steps) chosen method:

- chose sampling rate (number of segments)
 normally: - different sampling rates per strata
- sample rate of total area between 0.5 and 1.2%
 chosen: - 1.0% of total area
 - per strata: range between 0.0% and 2.7%)
 why: - 1.0% means about 200 samples for the whole study area, this number means that the expected variance (CV) of the results will be between 27 and 4% (0.8 % will give between 33 and 6 %) (Gallego 1995, p41).
 - some strata will include a very low percentage of the major crops (study object) and the recourses for sampling can be more effectively used for sampling other strata

- chose size of sampling unit (segment)
 normally: - between 500*500 to 1000*1000 meters in Europe, depending on field size
 - 20-30 fields within a segments is advisable
 chosen: - before rapid appraisal trip: 1000*1000 meters
 - after: depending on results trips
 why: - after analysing the TM image this segments size comes closest to including 20-30 fields within a segment for the large parts of the study area. It may be that after fieldwork and analysing SPOT PAN images this statement will not hold as true

- chose size of cells in square grid

normally: - between 100 and 400 sampling units (segments)

chosen: - 256

why: - nice two bit number

- create square grid

normally: - start grid in corner of map (when the research objects are not correlated with the position of map units

chosen: - upper right corner of map

why: - UTM co-ordinates used in most maps of the region, unfortunately the extreme Western part of the province is located in another zone. To make spatial analysis easier, the co-ordinates of the Western part are fake (so only one zone remains) thus starting the grid in the upper right corner is more accurate for most of the province

- locate sample units (segments) spatially

normally: -between 2 and 8 sample units (segments) in one grid cell (with modified aligned sampling), depending on the strata in which the cells/segments are located, this figure refers to the stratum with the highest sampling rate

chosen: - between 0 and 4 (maximum sampling rate)

why: -educated guess (in relation to existing literature)

data collection and preparation

Goal: data collection (cover types of the selected sample units (segments))

Possible methods:

a locate selected segments on aerial photographs (use overlay to draw cover in field)
b locate selected segments on high resolution satellite images (use overlay to draw cover in field)
c. locate selected segments on high resolution satellite images (use grid sampling to record the cover types in the field)

method chosen: for rapid appraisal trip: b and c

why: - no recent aerial photographs available of the area thus recent SPOT PAN was used

- some of the segments too complicated to draw the field boundaries on an overlay (spot-pan not perfect) thus only points within a regular grid (within the segment) are sampled.

details (steps) chosen method:

- locate selected segments on images

- print images
  normally: - enhance image to be able to recognise field boundaries as good as possible
  chosen: - execute same enhancement on all segments to reduce work load
  - no filters used (distorts the edges of fields)
  - only stretching

- train the surveyors
  normally: - make a >guide to eliminate ambiguity among participants
  - evaluate the sampling with the surveyors (e.g. problems encountered)
  chosen: - all above

- go to field
  normally: - one or two segments can be sampled per day, if it takes more than one day than only part of segment is sampled and or grid sampling is used (if which part of a segment to be sampled is chosen before going into the field it is statistically right)
  - draw the field boundaries on a overlay on the hard-copies

- prepare collected data for analysis
  normally: - digitise the fields boundaries from the overlays made in the field
  chosen: - the digitising will be done by the counterpart
  - transfer digital data to ITC for (parallel) processing
  - convert data to format needed

crop area estimation

Goal: calculating the area estimates for the study area.

possible methods:

use formulas related to the chosen method of sampling

details (steps) chosen method:

- analyse cover percentages within each segment
  normally: -by GIS operations on vector based system
  chosen: - probably arc-info pc.

- execute formulas
- review results

ANNEX II, The fieldwork guide (the basics)

Acknowledgements

The information in this document is partly based on the (draft) JRC reports (J.C.Porchier & Gallego) and modified by field experience specific for this project.

Introduction.

This guide will give practical information to surveyors on how to go about sampling a segment in he field. Though the rules described in this guide are to be strictly followed by the surveyors, vigilance is expected of those surveying segments because not all eventualities can be foreseen. A good co-ordination is needed between the central offices and the people in the field to constantly improve and update this guide.

The main purpose of the surveyor during fieldwork is delineating areas of uniform cover (tracts/fields) within a pre-defined area (a segment) and describe the cover type of each of those tracts/fields. The delineation will be done on the basis of a representation (satellite image or aerial photograph) of he segment. This representation will give information on field boundaries and will thus greatly reduce the time needed to map the cover types of a segment. Without this information the sampling of a segment will take to much time and other methods must be used. This might be the case in areas with very small fields or in areas where the boundaries of fields have been changed. When the surveyor experiences this situation in the field, for a certain segment, he/she must change his sampling method from delineating boundaries to grid sampling. The grid sampling method can also be used when parts of the segment prove to be to difficult to delineate field boundaries.

In the next paragraphs of this guide a summary is given of what the surveyor needs to do his job and what is expected of him. Later chapters will describe these matters in more detail.

Materials needed.

To survey a segment, the surveyor will require:

- Adequate means of transport (depending on the area)
- A table describing the co-ordinates of the segments.
- A small scale (1:250000) topographic map
- A topographic map (1:50,000 - 1:25,000 map or a SPOT-PAN image with co-ordinate grid) on which the segment is shown.
- A large scale representation of the segment for drawing the boundaries of the fields/tracts. This can be:
    a. an aerial photograph with a scale of 1:10000
    b. a satellite image with a scale of 1:10000 **and** an image with a scale of 1:5000 (SPOT-PAN, IRS-1C or any other very high resolution satellite).
- A survey table to record tract numbers, crop codes, crop description and remarks.

- A questionnaire for the surveyor to record general information about sampling a segment.
- a transparent film to overlay on the representation of the segment, on which the surveyor will trace the segment boundaries, the field/tract boundaries and tract codes, and the segment number.
- A clipboard
- A compass
- A ruler and a 'ruler' depicting degrees.
- A thirty-meter tape
- Minimally two clear makers (flags or coloured poles)
- A black pencil and an eraser
- fine inedible markers (black and red) for drawing on transparent film.
- A copy of the crop-code nomenclature
- These guidelines

Steps for sampling a segment

evening, previous to going in the field

1. Note down the co-ordinates of the segment (from a table)
2. Locate the segment, using the co-ordinates, on a small scale topographic map (1:250000).
3. Transfer the location of the segment to a larger scale topographic map or satellite image (1:50000). When the maps can not be taken into the field, make a copy of them.
4. Put the representation (enlargement of satellite image or aerial photograph) of the segment on a clipboard and fasten the transparency securely in place (when needed with tape).
5. Copy the number of the segment on the transparency and the survey table.
6. Draw the corners of the segment on the transparency.

the day of going into the field

7. Check before leaving if all equipment is ready to use.
8. Locate the segment
   8.1. drive to the vicinity of the segment with help of the topographic maps.
   8.2. find the segment in the field with help of compass and or GPS.
9. Find a starting point which is both clear on the representation and in the field.
10. Check whether field patterns in the representation can be seen in the field. If the pattern is recognisable follow version_A.
    When the field patterns are unrecognisable check the co-ordinates of the segment and your position in the field carefully. If the position proves to be correct select the grid sampling method (version_B).

11A. Start drawing the boundaries of the fields on the overlay, making sure that you always know where you are within the image.
12A. Always draw the numbers of the tracts with the top to the north of the segment.

13A. Don't forget to fill in the remarks of the survey table.
14A. Check, before leaving the field, that all the tracts have a (unique) number and the survey table is filled in properly.

11B. Find one of the four corner points of he lower left 500*500 meters of the segment in the field.
12B. Put a clear marker 50 meters to the east of west, depending on the chosen corner point.
13B. Mark a direction north or south (depending on the chosen corner point) and take a point sample every 50 meters over the full 500 metres. Put the crop code, crop description and remarks in the table.
14B. After 500 meters, go 50 meters east or west and walk back in the direction of the marker previously put in the field. Before starting off don't forget to put a second marker 50 meters east or west to have a fixed direction for the third leg of the sampling.

after coming home

15. When there are corrections on the overlay, redraw it.
16. When the enumerating table has corrections in it, rewrite it.
17. Fill in the questionnaire.
18. Prepare for the next day.

Orientation

Locating a segment

A segment can be located via maps or by GPS. The latter works much faster but with a little experience the former method works as well in most cases. Experience in the field has shown that finding a segments is easier when an additional representation is given, covering a larger area than just the image.

Orientation within a segment

This has to be done by counting steps, compass and the representation of the segment. The use of GPS is somewhat limited in this case because taking accurate readings will take to much time.

Sampling via tracts

General information

The main purpose for the surveyor sampling a segment is to recognise areas with uniform landcover. To help him/her in this quest a representation of the segment is available. This representation is either a printout of a satellite image or a aerial photograph. It should be noted that this representation can never be up to date and thus will only give information about possible tract boundaries. Even these boundaries might be changed over time thus the representation should be regarded with extreme care. Still the representation gives useful information and will speed up the survey. Thus the general method for sampling will be to overlay the representation with a transparent and to draw the boundaries of tracts on this. Within each tract a (tract)number is written which refers to the survey table in which the crop description has to be written.

What is a tract

A tract is an area of uniform land cover, and therefore subject to the same management practices, whether or not the land is used for agriculture.

Thus A single field may be split into tracts, either by a difference in land use or by a clear difference in management practices. This might be an area of wheat which is partly irrigated, an area of wheat of which a part is weeded and another part not or an area of wheat with distinct differences (over larger areas) in height or quality of the crop.

A tract may also contain another tract (an "island"), such as a pond , a copse, or buildings.

Although the objective of the survey is to record agriculturally productive areas, it is necessary to describe other land cover accurately in order to make it possible to analyse the satellite images that will be used to monitor crop development.

Minimum size of a tract

Given the 20-30 meter ground resolution of the satellites used for classification, it is useless to plot linear elements such as very narrow fields, roads, paths, hedges, creeks, below 20 meters of width, as areas.
The same counts for elements with a size smaller the size of a pixel (e.g. ponds, houses, copses).

A group of such narrow or very small elements can sometimes be arranged so as to generate a feature more than 20 wide. The external borders of this element are traced and the enclosed area is given a suitable code.

This is beyond any doubt the most delicate point of the segment survey, for it is impossible to give rigid instructions and thus the surveyor must be able to show initiative and make up his mind, without losing time on marginal situations.

Criteria for grouping classes and complex units

The decision to categorise land cover is guided by the effective contents of the tract. In this paragraph some rules are given for defining the land cover of a tract:

- Two contiguous tracts containing the same crop, but which are clearly subject to different management practices, must be separated.
- Two tracts containing the same crop, but which are separated by a linear element such as a road, track or hedge, must be marked as being separated, even if the linear feature is less than 20 meters wide.
- Contiguous tracts of permanent pasture divided by fences must be drawn as separate tracts.
- A farm and its outbuildings, including the farmyard, or a house and its garden, are to be treated as a single tract if located in an agricultural area or forest and if it covers more than 400 square meters.
- Urban areas are considered to make up a single contiguous tract, and the individual buildings, roads, parking lots etc. are not differentiated. Urban areas are outlined as a single tract on the transparency.
- Linear features less than 20 meters wide are drawn as a single line. Thus a single line would be used to represent a narrow track (2-3 meters wide), a canal (3-5 meters wide), a secondary road (5-10 meters wide) and so on.
If the linear feature is more than 20 meters wide it must be drawn as having area, as would be the case for:
    - arterial roads and motorways (including black top, shoulders, banks and bordering trees)
    - several non-agricultural linear features juxtaposed (for example, collinear hedges, track, bank and drainage ditch)

Drawing tracts

Drawing lines
A tract is represented by a closed outline, which may include the line marking the edge off a segment.

The surveyors will have be able to make a good drawing, but must simplify the observed country in order to avoid complicating the drawing by irrelevant and useless details. The lines must be straight or broken lines, or simple curves. It is not necessary to plot all the irregularities and all the details.

Linear features like roads or rivers are important landmarks for interpretation. Thus when an area has a uniform land cover but is dissected by a road, the surveyor must draw two different tracts.

The surveyor must ensure that the tract boundaries meet without gaps at the corners. The line should also be firmly drawn so that there are no irregularities in thickness.

Numbering tracts

In a segment the tracts are numbered to the surveyors whim, usually in function of his route, and the number of tracts is only known at the end of the survey. As a result of this a surveyor easily forgets to draw a tract or give it a number. This kind of mistake is common, especially near corners and limits, or where the fields are very small, and difficult to check.

All numbers must be written with the same orientation, the top of the numbers to the north. The figures 6 and 9 must be underlined. Tract boundaries must be drawn using straight (preferably ruled) lines or smooth curves, without attempting to follow exactly all irregularities.

the survey table

The questionnaire should be completed in black pencil and, if necessary, corrected in ink.

The header information on the questionnaire is filled in before arriving at the segment.

The surveyor uses his copy of the crop-code nomenclature to fill in the questionnaire. It is essential that the criteria and definitions provided in the nomenclature document are followed scrupulously. For the fieldwork the nomenclature table of the Iranian statistical office (ASID) was used because the surveyors were used to work with it. The table was not perfected for this kind of survey and thus some classes had to be added during the fieldwork, after consultation of the survey co-ordinators. Part of the nomenclature table is given in table 4.1.3.

All questionnaires which contain crossing-out, or which are muddied, or which are otherwise scruffy, must be copied up the same evening as they were originally filled out, by the same surveyor who carried out the actual survey.

The questionnaire must be filled out using the nomenclature provided.

Crops must be identified following these rules:
- If more than one crop is present in a tract, the percentage of each must be recorded in the field questionnaire on the remarks.
- When using the code "other", the surveyor must always note the name of the crop.
- The surveyor should always strive to classify the crop as accurately as possible, using the most detailed level of the nomenclature that he can.

Grid sampling

general information

The grid sampling method is designed as a backup option when the representation of the segment does not give additional information. The grid sampling method must only be used in extreme cases because the information gathered this way is more difficult it interpret and of lesser quality (point instead of complete areas)

There are two ways to use the grid sampling method:
1. To completely replace sampling via tracts.
2. To complement sampling via tracts within a segment.

The first way is to be used when the representation of the segment gives no additional information. This can be the case when the field boundaries have changed to much or the field size is very small (smaller as anticipated during the sampling design).
The second way is to be used when within a segment areas with very small fields are present. This can occur for instance near villages where a kind of homestead gardens are present. the time it takes to draw the tracts of these small fields will be to much and it is more efficient to use grid sampling for these sub-areas.

the method

The basic method consists of walking in a strait line and every fifty meters a point measurement is taken. To be able to do this a known starting point is needed and a fixed direction of walking.

Solely grid sampling

When grid sampling is replacing sampling via tracts, only the lower left 500*500 meters of the segment is sampled. The first step is to locate one of the four corner point of this 500*500 meters square in the field. The best way is to start from a known point in the field (a point which is recognisable both in the representation and the field) and from that point locate a corner point.

The next step is to find the direction either north or south. The direction is dependent on the corner chosen as a starting point (lower left-> north, upper right-> south). When the direction is established a marker (a flag or coloured pole) should be put in the field 50 meters to the east or west (again depending on the chosen corner point) of the starting point. This marker is needed for orientation on the way back (the second leg of the sampling). This marker will make the sampling much easier because on the second leg no compass has to be used, one can simply walk in the direction of the marker.

After the marker has been placed the sampling can commence. The surveyor will walk in the chosen direction (either north or south) and take a point measurement every 50 meters. The rule for sampling a point is that the cover type is described which is present at the **toes** of the surveyor. The point is noted in the survey table and when needed remarks are made.

When the sampling point is at a border between cover types the surveyor should note the cover of the actual border in the survey table when **the border has a width of more than a** meter. When the border is lees than a meter wide the surveyor must note the cover type of the tract **to the back** of him. If the border is in the same direction as the surveyor is sampling, the cover type of the tract **to the left** of him should be noted.

After 11 ties of sampling the end of a leg is reached,

Examples of forms taken into the field by the surveyors.

Figure II.1. example of part of the questionnaire (survey table) taken into the field filled with some dummy data.

number of segment: *P2s189*

date: *13* **(day)** *13* **(month)** *1999* **(year)**

name (responsible) surveyor: *QQQ*

tract nr.	crop code	crop description	remarks (observations)
1	*102*	*wheat, irrigated*	*stubble of maize*
2	*103*	*wheat, rainfed*	*just flowering, crop before wheat: beans*
3	*112*	*beans, irrigated*	*bad shape (dry), wheat stubble*
4	*708*	*fallow*	*80% cover weeds crop before: wheat (some visible)*
5	*102*	*wheat, irrigated 80%, beans 20%*	*intercropping (rows)*
6	*104*	*barley, rainfed 60%,melon 40%*	*melon at edges tract*
7			
...			
41			

Figure II.2. Questionnaire for collecting general data on sampling and the segments as attached to the 'survey table'.

number of segment:..........

time of arrival at segment:...........

time of leaving the segment:............

- time needed for orientation of corner point of segment:.........

- time needed for delineation of tracts:...............

general description of segment:

- Morphology:
  - slope(steep, moderate, flat):..........
  - slope shape (rolling, dissected, ridges):...........

- General remarks: -..................................

-..................................

-..................................

remarks on survey itself:

- finding the segment(easy, difficult):.......
- reaching the segment (long walk, difficult terrain):........
- recognising cover types (easy, hard):..........
- recognising edges of tracts (easy, hard):........
- SPOT PAN useful: (very, hardly)
- general remarks of surveyor (what needs the central office to know ?):

-..

-..

-..

Table II.1. The crop codes and their description as used during the fieldwork; though only the crops found are given, not the complete table.

CROPCODE	Description	Irrigated
102	wheat	y
103	wheat	n
104	barley	y
105	barley	n
112	beans	y
114	chickpea	y
115	chickpea	n
116	lentil	y
117	lentil	n
156	watermelon	y
160	cucumber	y
166	other vegetables	u
170	potato	y
174	tomato	y
202	alfalfa	y
203	alfalfa	n
204	clover	u
458	watermelon (seed)	u
474	sainfov	u
478	clover (seed)	u
504	kidneybean	u
700	unknown	u
701	orchard	u
702	building	x
703	bareland	x
705	road	x
706	waterbody	x
707	rangeland	x
708	fallow	x
709	fallow (plowed)	x
710	unknown	u
711	river	u
712	river shoulder	u
713	khanat	u

Local Soil Series	: Va.Vajargah series
Report No.	: E.G
Representative Profile No.	:
Representative SDB Code	: VA 525

SOIL CLASSIFICATION

F.A.O Classification

F.A.O 88	: CMU	Humic Cambisol
Phase	:	

Soil Taxonomy

Great Group	: IOY	Dystrochrept
Sub Group	: UM02	Umbric
Texture	: 026	Fine Loamy
Mineralogy	:	
Reaction	:	
Soil Moisture	: UD	Udic:In summer.soil less than 45 continuously day is dry.
Temperature Regime	: TH	Thermic

Correlated Soil Unit	: I15	

SOIL PROPERTIES LIMITATIONS

SUBSOIL PERMWABILITY	: 3	Moderate. from 2 to 6 cm/h.
SUBSOIL STONINESS	: 0	<15% of coarse fragments
TOPSOIL TEXTURE	: H	Heavy(silty clay loam. sandy clay loam.clay loam)
TOPSOIL STONINESS	: 0	No coarse fragments
SOIL DEPTH	: 0	Very deep.soil deeper than 120 Cm.
TYPE_limiting LAYER	: 0	No limiting layer
INFILTERATION RATE	:	****

SOIL SALINITY & ALKALINITY LIMITATIONS

SOIL SALINITY	: S0	EC less than 4 mmhos/Cm.No or very slight limitat.
SOIL ALKALINITY	: A0	No alkalinity problem.ESP<10% PH<8.5.SAR<8

TOPOGRAPHY & EROSION LIMITATIONS

OVERALL SLOPE	: A	Level to very gently sloping: 0 to 2%
TRANSVERSAL SLOPE	: 0	Less than 1%
MICRO_RELIEF	: 1	Slight.30-15cm.Ave. Micro relief intensity.Earth moving 375-750 m3/ha
EROSION STATUS	: E0	No apparent erosion
DEPOSITION STATUS	: d0	No deposition of erosion products

DRAINAGE LIMITATIONS

GROUNDWATER TYPE	: F	Fresh water.Ec of ground water<1500 micro mohs.
GROUNDWATER DEPTH	: W0	No ground water table limitation
OTHER DRAINAGE LIMITATIONS	: 00	No drainage limitation
PONDING HAZARD	: P0	No ponding hazard.
FLOODING HAZARD	: F0	No flooding hazard.

IRRIGATION RATING

Irrigation Rating	: II	With slight limitations.
Limitation Sub Class	: T	Topography limitations:slope,relief,errosion...
	:	
	:	
	:	

Appendix 4: Data Dictionary

Data Dictionary for Objects in Subsystem 1 (Crop Area Esimation)

Object	Source (database)	Type	Major Attributes (Instance)	Description
Adminunit	Region Coverage	polygon	Adminunit_id (1), name (Ekbatan)	The smallest Administration unit in the region under study
Landcoverunit	Landcover map	polygon	Landcover_id (1), covertype (rice)	land cover unit identified on land cover map
Cropvariety	Crop database	nonspatial (record)	Variety_id (1), name (ekbatan rice)	the smallest unit from crop classification system
smu	Soil Map	Polygon	Smu_id (1), texture (loam)	A soil mapping unit identified by texture from soil map
Crop	Crop database	nonspatia (record))	Crop_id(1), name (rice)	the second largest unit from crop classification system one crop has one or more variety.
lcu-smu-strat	Objectified (subsystem1)	polygon	lcu_smu_strat_id,smu_id,landcover_id, strata_id, crop_id (1), Imp_crop_area (2 ha)	a unique combination of land cover unit, soil mapping unit and stratum.
Strata_crop	Objectified (subsystem 1	non spatial (record)	strata_id(1), crop_id(1), croparea(10 ha)	a unique combination of stratum and crop. Some of this unit (or combination) can be spatially represented on segment map.
stratum	strata map	polygon	strata_id, strata name (mountain)	a mapping unit from strata map
Admin_stratum	adminstratamap	polygon	admin_id, stratum_id, crop area proportion	a unique combination of stratum and adminstration boundary
Gridcell	sat. image	Gridcell	grid_value, covertype	raster data of the area from Landsat or others sattelite image.
Segnment	sementmap	polygon	segment_id, crop_id, actual crop area	a segment identifed on topo map or image from ground survey
cropgroup	crop database	nonspatial (record)	Cropgroup_id (1), name (cereal)	the largest unit from from crop classification system; one crop group has at least one crops

Data Dictionary of Objects in Subsystem 2.

Object	Source (database)	Type	Major Attributes (Instance)	Description
Horizon	SOIl DB	Record	Horizon(A), Rooting depth (10 cm)	The smallest unit of soil domain but un mappable because of its dimension
site	SOIl DB	point	Site No.(1), Slope (2%)	The second smallest unit of soil domain
SMU	Object(polygon)	polygon	SMU_ID(1), texture(loam)	The smallest unit from soil domain with area feature. Acceptable unit in the context of CFS
Variety, Crop, Crop Group as Described above				
Region	Admin DB	polygon	Nme (Razan)	A region under study
Admin. Unit	-do-	polygon	Name(ekbatan), Crop(ek rice), Irrigated (Y)	The smallest adminstration unit for CFS
village	-do-	point	Villcode(1), year(1991), agricultural survey (Y)	The smallest unit on which agricultural statistics is collected.
weatherstn	Weather Map	point	altitude(324m), latitude(26 o N)	Weather station location which can inside or nearby the region
EMU	EMU Map	Polygon	EMU_id(1), EMUlabel(Ekbbatan_Loam)	A relation unit of SMU and admin. unit
EMU-Wtsn	EMU_Wstn DB	Point	Distance(EMU1WS1 = 5 km)	A relation unit of EMU and weather station
Meteo year	Weather DB	Record	Day (5/6/91), Temperature, precipitation etc.	a year in which meateo data is available on a particular station
Agristat/year	Cropyield DB	Record	Year(1991), crop(ekrice), Yield(7 t/ha) etc.	A year in which agricultural statistics is available on a particular village
EMU_simyld/year	-do-	Record	EMU_id(1), Year(1991), crop(ekrice), yield(5 ha)	A relation table of EMU and year with its simulated yield
Admin_sim_his_yld /year	-do-	Record	year(1991), adminname(Ek), crop(Ekrice) average historical yield(9t/ha), simulated yield(7t/ha)	A relation table of a variety and admin. unit with aggregated historical and simulated yield.
Management	Crop DB	Record	Admincrop(ekrice), Year(1991), firtilizer(Y), Regression Model	A relation tabel of variety and admin. unit with an attribute of management data and regressio model
Crop_Region	-do-	Record	cropname(EKrice), adminname(ekbatan) , planting date (5 Jan)	A relation table of variety and region.

References.

Amitai, Y., (1992). **Multitemporal classification and interpretation of Spot images for monitoring of subsidised crops in Greece**. ITC, Enschede, pp.120.

Bronsveld, M.C., H. Kostwinder and S. Chutirattanapan, (1992). **Improving a land use map using geo-information systems and remote sensing. Int. symp. remote sensing and space '92**, Hat Yai, Thailand.

Buiten, H.J. & J.G.P.W. Clevers, (1990). **Remote sensing, theorie en toepassingen van land observatie**. Pudoc, Wageningen, pp.517.

Clevers J.G.P.W. and Verhoef W. 1993. **LAI estimation by means of WDVI: a sensitivity analysis with a combined PROSPECT-SAIL model.** Remote Sensing Reviews, 1993, vol.7, reprinted in: Molenaar M. (eds.) 1994. Remote Sensing and Geographical Information Processing; Concepts and applications for land use monitoring and agriculture. Wageningen Agricultural University.

Cochran, W.G., (1963), **Sampling Techniques**. Wiley & Sons, New York, pp.413.

Dewan M.L. and Famouri J. 1964. **The soils of Iran.** Soil Institute, Ministry of Agriculture, Iran. FAO, Rome, Italy.

Driessen P.M. 1996. **PS12S365, a simple model of the water limited production potential of annual crops, with attention for salt stress**. Dept. of soil science and geology, Agricultural University Wageningen, the Netherlands

Driessen P.M. and Konijn N.T. 1992. **Land use system analysis.** Wageningen Agricultural University, Dept. of Soil Science & Geology: Malang: INRES.

Famouri J. and Mortazavi M. 1970. **Drought frequency in Iran.** Publication No.243, Soil Institute of Iran, Ministry of Agriculture, Iran.

FAO 1972. **Iran, water management and soil reclamation.** Soil Institute and associated Pilot Development Project. FAO, Rome, Italy.

FAO 1995. **FAOCLIM.** (CD-ROM with meteorological data). FAO, Rome, Italy.

Fischer R.A. 1983. **Wheat.** In: Potential productivity of field crops under different environments. IRRI, Philippines

Gallego, F.J, (1995) **Agricultural estimates with area frame sampling**, JRC publications, Varese.

Gorte,B.G.H, (1995), **Improving spectral image classification by incorperating context data using likelihood vectors**, conference paper of 5th international conference on Image Processing and its applications

Goudriaan J. and Laar H.H. v. 1994. **Modeling potential crop growth processes:** textbook with exercises. Current issues in Production Ecology; 2. Kluwer, Dordrecht.

Groot J.J.R. 1987. **Simulation of nitrogen balance in a system of winter wheat and soil.** CABO-DLO simulation reports No.13. Wageningen, the Netherlands

Heinzmann, U. & Zollinger, G., (1995). **Validation of representativeness with relief parameters based on the comparison of two landuse classifications**. Catena 24, p69-87.

Houseman, E.E., (1973). **Area frame sampling in agriculture**. USDA, Statistical Reporting Service, Washington, D.C., pp.79.

ISRIC 1993. **FAOTOPS.** (Routine to convert FAOCLIMate data to PS123 format). Isric, Wageningen, the Netherlands.

Keulen v. H. and Seligman N.G. 1987. **Simulation of water use, nitrogen nutrition and growth of a spring wheat crop.** Simulation monographs, Pudoc, Wageningen, the Netherlands.

Keulen v. H. and Wolf J. 1986. **Modeling of agricultural production: weather, soils and crops.** Pudoc, Wageningen, the Netherlands.

Leenaars J.G.B., Dijksterhuis G. and Sori S. 1992. **L'investissement dans le gestion des eaux et des nutriments, basee sur la diversification pedologique a l'echelle villageois**. Annexe de communication a la WASCO, FAO, Bamako 1993. Bunasols, Burkina Faso. IB-DLO, the Netherlands.

Leenaars J.G.B. 1993. **Donnees d'essai de fertilization de sorgho en fonction de la toposequence de Saria, Burkina Faso**. Bunasols, Inera, IB-DLO.

Leenaars J.G.B. 1996. **Description of input data structures for dynamic crop growth simulation purposes in system development.** Development of a crop inventory and forecasting system for major agricultural commodities in Hamadan province, Islamic Republic of Iran. ASID, Tehran, Iran. ITC, Enschede, the Netherlands.

Lillesand, T.M. & R.W. Kiefer, (1987). **Remote sensing and image interpretation**. second edition. J.Wiley & sons, inc., New York, pp.721.

Mahler P.J. 1970. **Manual of land classification for irrigation**. Soil institute of Iran, Publ. No. 205.

Maselli, F.,C. Conese, L. Petkov and R. Resti, (1992). **Inclusion of prior probabilities derived from a non-parametric process into maximum likelihood classifier**. PE&RS 58, 2, pp.201-207.

Mather, P.M., (1987). **Computer processing of remotely-sensed images, an introduction**. J. Wiley & Sons, Inc. Cichester, pp.352.

Microsoft 1988. **QuickBASIC version 4.50 compiler.**

Porchier, J.C., **Organising and carrying out an area frame sampling survey**. in: Draft paper I on Monitoring Agriculture with Remote Sensing, JRC, Varense.

Ritchie J.T., Nix, Fischer R.A., Spiertz J.H.J. et al. 1988. **CERES wheat nitrogen model.** Print out of version 2.10.

Ruiter J.M.d., Stol W. and Keulen H. v. 1993. **Simulation of yield and quality of malting barley.** Proceedings Agronomy Society of N.Z. 23. 1993.

Russell G. 1990. **Barley knowledge base.** University of Edinburgh, Scotland. Pilot project for remote sensing applied to agricultural statistics. Joint Research Centre of the European Community.

Russell G. and Wilson G.W. 1994. **An agro-pedo-climatological knowledge-base of wheat in Europe.** University of Edinburgh, Scotland. Pilot project for remote sensing applied to agricultural statistics. Joint Research Centre of the European Community.

Sabins, F.F. jr., (1987). **Remote Sensing, principles and interpretation**. W.H. Freeman and company, New York, pp.439.

Sharifi M.A. 1992. **Development of an appropriate resource information system to support agricultural management at farm enterprise level (ARIS).** Ph.D. thesis, Wageningen Agricultural University, the Netherlands.

Sharifi M.A. and Driessen P.M. 1996. **Report on a project initiation mission to Iran. 1996.** Development of a crop inventory and forecasting system for major agricultural commodities in Hamadan province, Islamic Republic of Iran. ASID, Tehran, Iran. ITC, Enschede, the Netherlands.

Sharifi M.A., Keulen H. v., Bronsveld M.C. and Clavaux M. 1996. **Draft report on a field work trip to Iran, 1996.** Development of a crop inventory and forecasting system for major agricultural commodities in Hamadan province, Islamic Republic of Iran. ASID, Tehran, Iran. ITC, Enschede, the Netherlands

Srinivasan, A. & J.A. Richards, (1990). **Knowledge-based techniques for multi-source classification**. Int. J. Remote Sensing, vol.11 no.3, pp505-525.

Strahler, A.H., (1980). **The use of prior probabilities in maximum likelihood classification of remotely sensed data**. Rem. Sens. of Envirn. 10, pp 135-163.

Supit I., Hooijer A.A. and Diepen C.A. v. (eds.) 1994. **System description of the Wofost 6.0 crop simulation model implemented in CGMS.** Vol.1: Theory and Algorithms. The Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, the Netherlands. Pilot project for remote sensing applied to agricultural statistics. Joint Research Centre of the European Community.

Verberne E., Dijksterhuis G., Jongschaap R., Bazi H., Sanou A. and Bonzi M. 1996. **Simulation des cultures pluviales au Burkina Faso (CP-BKF3): sorgho, mil et mais**. IB-DLO nota 18. Bunasols, Inera, IB-DLO.

WRR 1992. **Ground for choices : four perspectives for rural areas in the European Community**. Netherlands Scientific Council for Government Policy (WRR). s'Gravenhage

Young C. 1996, draft. **Explanatory report on the Hamadan data sets**. Development of a crop inventory and forecasting system for major agricultural commodities in Hamadan province, Islamic Republic of Iran. ASID, Tehran, Iran. ITC, Enschede, the Netherlands.