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PROGRAMMING OF CROP YIELDS

(Systems approach as applied to soil reclamation)

SIC ICWC

Tashkent 2015

Scientific-Information Center of the Interstate Commission for Water Coordination
(SIC ICWC) in Central Asia

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List of Executors

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Acronyms And Abbreviations

ACS	Automated Control System
AFMAS	Project “Assessment of applicability of an equitable and sustainable financing model for agricultural water services in the agricultural sector of Uzbekistan”
AP	Agronomical Passport
CAR	Central Asian Republics
CINAU	Central Agrochemistry and Fertilizer Research Institute
DVY	Actual-Possible Crop Yield
ES	Agricultural Extension Services
FAO	Food and Agriculture Organization of the United Nations
ICWC	The Interstate Coordination Water Commission in Central Asia
IWRM	Integrated Water Resources Management
MVY	Highest Possible Crop Yield
NPK	Nitrogen, Phosphorus, Potassium
PAR	Photosynthetically Active Radiation
PY	Potential Crop Yield
RAIA	Rayon Agro-Industrial Association
RY	Actual Crop Yield
SANIIRI	Central Asian Irrigation Research Institute
SIC	Scientific-Information Center
TPCS	Technological Process Control System
YH	Farm Yield
YP	Yield Programming
WUA	Water User Association
WUFMAS	Project “The Water Use and Farm Management Survey”

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Introduction to edition 2015

Given publication was prepared and published in 1987 for the first time and was based on the results of research carried out at the SANIIRI Institute's Laboratory for programming of crop yield as part of the Program, named "Programming of Yield" and initiated by the USSR State Committee for Science and Technology and the USSR Ministry for Water Resources.

In subsequent years, this technique was widely spread in the Soviet Union as part of the so-called passportization of fields on an area of more than 100,000 ha in Hunger Steppe (S.A. Nerozin, G.V. Stulina) and further on applied in a number of projects implemented in Central Asia for improvement of land and water productivity.

Specifically, such technique was applied in the World Bank's Project "Best practices" and in number of projects implemented by SIC ICWC with the support of the Swiss Development and Cooperation Agency (e.g. IWRM-Fergana, Water Productivity Improvement at Plot Level).

Present publication contains additional section of case-studies carried out by Dr. G.V. Stulina and Dr. S.A. Nerozin.

The aim of the present publication is to create a basis for application of this technique in practice as part of the research project LaVacca, which is undertaken under coordination of Wurzburg University in German (Prof. C. Conrad), with participation of SIC ICWC (Dr. G.V. Stulina), for assessment of dynamics of land productivity and degradation and for identification of management drivers and mechanisms.

Although description in the first part of the publication was made for Soviet context of agricultural production in former large collective and state farms (*kolkhozes* and *sovkhozes*, respectively), it was left without changes so that the reader could understand the logics of the whole systems approach and its further transformation under present agricultural re-structuring. This process of re-structuring, which proceeds in two directions, is not completed yet: enlargement of farms in Uzbekistan and partly in Turkmenistan and Kazakhstan, on the one hand; and, small-size land use (mainly, family type) in Kyrgyzstan and Tajikistan, on the other hand. Nevertheless, this systems approach can be adapted to the future established pattern of agricultural production, with account of local administrative and legal conditions.

It is also vital that factor-based approach applied in YP virtually may be used for agricultural risk management to prevent, propose appropriate solutions for and mitigate these risks.

This version adds Chapter 9, which is prepared by Eng. G.F. Solodkiy as our vision of further development of software support for extension services that seems to be key to the future.

Prof. V.A. Dukhovniy

Introduction

Large-scale application of the crop yield programming technique is proposed as part of efficient solutions for generation of high and regular crop yields in irrigated land.

Yield programming (YP) involves a set of agronomic and reclamation measures, efficient implementation of which in due time ensures production of design yield, while reclaiming soil fertility and improving environmental conditions. The yield programming technique proceeds from the premise that for each specific field a certain level of yield can be planned and achieved through account of all soil-climatic factors, differentiation of agronomic and soil reclamation methods, and making optimal use of physical and human resources.

Numerous scientific experimental data, research results, and best practices give evidence that fields in the Central Asian countries can produce 40-50 centner/ha of raw cotton, 180-200 centner/ha of alfalfa, 80-100 centner/ha of corn, and 55-65 centner/ha of rice. However, significant gap between experimental and real-life yields indicates that scientific achievements have not been applied yet in full. This is caused by extraordinary diversity of soil and other natural conditions, as well as by specific technical, economic, and social characteristics of each particular farm. Moreover, analysis of farms indicates to breach of technological process, i.e. dates and rates of seeding, application of fertilizes, quality of irrigation, inter-row cultivation, etc. The yield programming technique is to make the work in this area more focused, ensure more effective utilization of soil-climatic resources, water, chemicals, machines, and improve revenues of agricultural producers and economy as a whole.

Later on not only theoretical dimension of YP was developed but YP research results were translated in practices in CAR and the Russian Federation. International practices (GDR, Bulgaria, Netherlands, US, Federal Republic of Germany) also proved high effectiveness of YP technique.

In this context, as early as in 1985 the Agroindustry Commission at the USSR Council of Ministers made a decision to put the yield programming technique into Soviet agricultural practices on an area of 3.34 Mha. By 1990, the YP technique was introduced on 556,000 ha in Uzbekistan, of which: 200,000 ha – cotton; 210,000 ha – maize; 13,000 ha – rice; 30,000 ha – alfalfa; and, 3,000 - vegetables.

However, practical implementation of YP is a complex task as it requires taking into consideration multifactor dynamic situation in agricultural production. This includes, but no limited by poorly predictable weather, complex and largely uncertain plant responses to environmental factors, and economic aspects.

Yield programming does not imply, as many practitioners thought, generation of the highest possible yield in given conditions only due to the fact that given plots, schemes or even whole regions were included into the country-wide programming campaign. Such narrow understanding has caused that many organizations believed that great results could be achieved only through inclusion into this campaign without a need for great deal of difficulty and money.

These hopes failed. Commonly fictious "results of work in programmed plots over the period 1985-1989" demonstrated their unreality despite the records showing astronomical figures of areas covered by programming or effects as compared to "non-programmed" plots. Any expert familiar with programming knew that such groundless efforts under umbrella of this large-scale campaign were not what was really needed for programming of yield.

YP implies development and implementation of the automated control system (ACS) of technological processes in crop farming. Moreover, first, the technological process control system in general is very important as this system enables an enough qualified team to have a program of actions in case of any deviations in natural, economic and institutional conditions from optimal ones, as well as the clear operations sequence, schedules and timelines in order to deal with all encountered difficulties with minimum productivity losses. Furthermore, such system can serve like a comprehensive collection of 'know-how' for farming and helps less qualified personnel to master needed skills through the instructions for technological process control system (TPCS) rather than by trial and error.

It is clear that at a stage of TPCS, programming will help to increase real chances for improved soil fertility and crop yields, depending on natural conditions that vary in time and space, on the one hand, and on degree of observance of technological process, availability of inputs, skills of personnel, etc., on the other hand.

Important advantages of technological process ACS is that it requires self-discipline from both its developers and all members of the technological process, including production men, encourages higher performance standards and qualifications among personnel in farms and production enterprises.

In the present context, yield programming may extend the sphere of its influence to all elements of *rayon* (district level) institutions in agroindustry.

In USSR, yield programming went any further, first of all, in research of I.S. Shatilov, Kh.G. Tooming, N.F. Bondarenko and the team of Agrophisical Institute (S.V. Nerpin, R.A. Poluektov, V.A. Platonov, I.A. Uskov and others) and in works of M.F. Kayumov, O.D. Sirotenko, Ye.P. Galyamin and many others.

The systems of yield programming should not be confused with the problem related to control of plant development factors, which was studied in details for the purposes of plant management. Models developed in the course of this work were to find effects of various natural and anthropogenic factors on plant behavior. Undoubtedly, some components of this work may and should be used for the YP problem; however, the main task of yield programming is to produce the highest possible and economically feasible yield under natural conditions characterized by certain heterogeneity and in conditions where all technological process operations cannot be performed simultaneously and strictly in due time, taking into account multiple stochastic factors. Despite all complexities of this problem, to a large degree the modern farming can control most of these factors. First of all, this concerns crop varieties and types, ways and processes of crop growing. Besides, irrigated farming allows controlling water-air and, in part, thermal regimes of the surface layer of the atmosphere and the soil through irrigation and drainage. Moreover, land reclamation enables farmers to control long-term soil fertility and this should be taken into account when developing the system of yield programming in reclaimed land.

Yield programming as part of the automated agricultural production control system, which manages crop growing process, is a combination of organizational, technical, information, and managerial measures aimed at achievement of the highest possible and economically feasible productivity of given crop under specific soil-climatic conditions and with certain inputs, including labor resources.

Yield programming will help to transfer to ACS of farm technological process on a farm scale, to ACS of farming practices of Rayon Agro-Industrial Association (RAIA) on a rayon scale and so on.

Systems approach, which considers crop production process in light of large system control, is used as a methodological basis for programming. V.A. Platonov and A.F. Chudnovskiy [11] justify this solution in light of the following key characteristics of agricultural production management:

- impossibility to describe the whole system with formal mathematical models;
- need to describe a part of the system by special methods;
- lack or unclear knowledge of numerous control criteria;
- presence of people in the system, who have freedom of actions within the scope of their powers;
- numerous barriers and minor details;
- impossible experimental reconstruction of all probable situations and responses to them.

In this context, the following stages are envisaged for development of “yield programming” as a complex system:

1) determining boundary of the study system and its place in the general problem;
2) identifying the system elements and the links between them;
3) aggregating the elements and building hierarchy of subsystems and blocks, etc.;
4) analyzing and classifying tasks to be solved on different time scales;
5) identifying subsystems composition and interrelations;
6) preparing a set of models;
7) building optimal control options on each scale.

1. Crop Yield Programming

1.1. Boundary of the Yield Programming Subsystem and its Place in the General Problem of Agricultural Production Effectiveness

YP is one of leading subsystems in the automated agricultural production control system or farm ACS. Naturally, as any ACS of agricultural entity it consists of subsystems that cover all spheres of activity of this entity. In this context, we should distinguish eight (and, in future consideration, nine) subsystems to cover main farm services (Figure 1.1, Table 1.1).

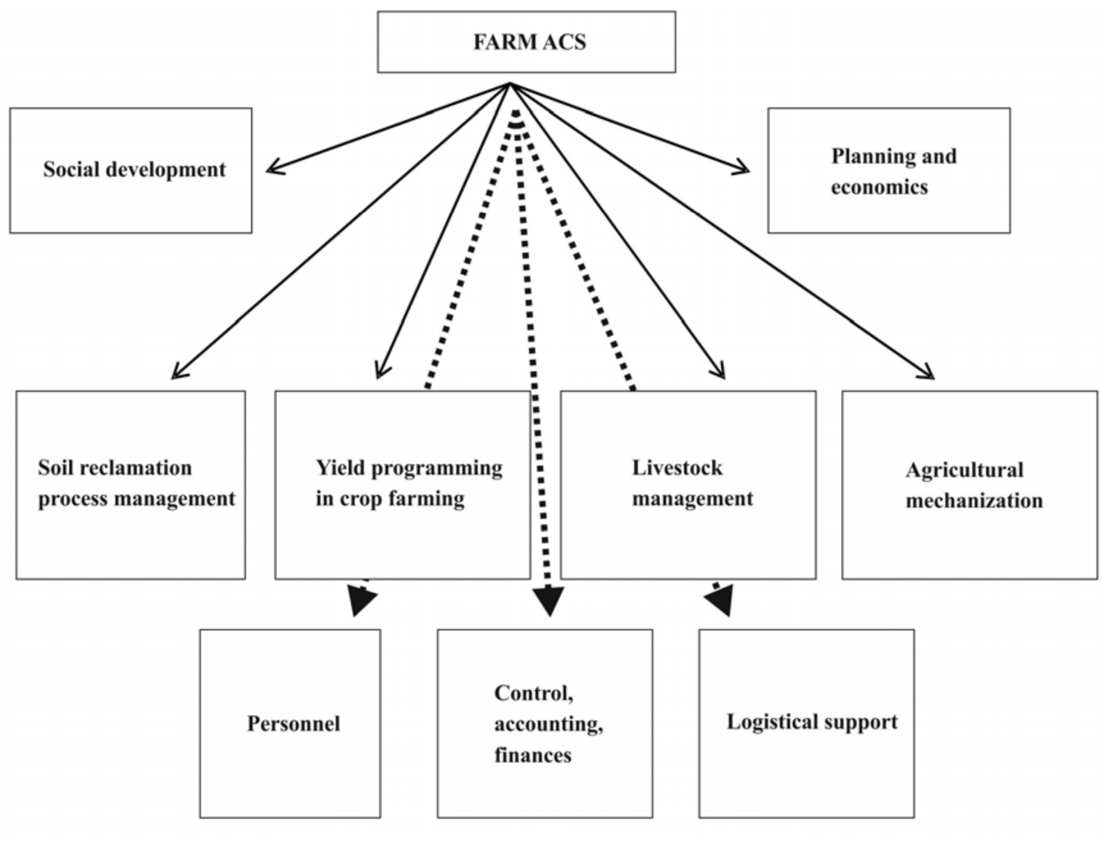


Figure 1.1. Subsystems of farm ACS

Table 1.1

Main objectives of ACS subsystems

Subsystem	Objective	Responsible unit
YP in crop farming	Efficient management of crop production and generation of high yields	Chief agronomist services
Livestock management	Achievement of planned livestock production	Chief animal technician services
Agricultural mechanization and transport	Technological process supported with necessary equipment and transport	Chief mechanical engineer service
Soil reclamation process management	Ensuring of required water-air and water-salt soil regimes and systematic improvement of soil fertility through reclamation measures	Reclamation engineer and soil service
Logistical support	Supply with all necessary materials, fertilizers, farm machinery, etc.	Procurement divisions, chief mechanical engineer services and deputy director on general affairs
Personnel	Recruitment, training of personnel	Personnel division
Planning and economics	Establishing bottom-up planning systems in order to improve effectiveness of agricultural production	Chief economist
Control, accounting, finances	Financing and control over all services	Chief accountant, operations control service
Social development	Creation of conditions for social welfare of staff	Director, Deputy Director on extraoccupational affairs, labor union

Subsystem "Yield programming in crop farming" is connected with all other subsystems through requirements, constraints, supply and technological process links. For example, subsystems "YP in crop farming" and "Livestock management" are linked with each other through fodder requirements and manure application to the soil. The main subsystem – YP - places demand on subsystem "Soil reclamation process management" for provision of crops with moisture and good conditions of soil and determines potential soil fertility and measures for improvement. These subsystems set requirements to subsystems of personnel, logistical support, mechanization and transport, finances, etc.

Yield programming as an integrated soil fertility management process aimed at high yields is not limited by programming itself in crop farming but covers soil reclamation, mechanization, technological, economic and even financial aspects controlled in other relevant subsystems.

Determination of subsystem elements and detailed links between them will enable us to set more clearly boundary of programming process in all ACS subsystems.

At the same time, the proposed structure of farm ACS predetermines the pattern of connection with RAIA ACS (Figure 1.2) and its 14 main subsystems with which functional or subordinate or supply links are established.

Note to the new edition

Although under present market conditions it seems strange to have RAIA (Rayon Agro-Industrial Associations) as the upper organization in ACS which was assumed a superior coordination body in the agricultural sector in the socialistic system, the current approaches that took shape as a result of implementation of IWRM in irrigated agriculture (IWRM-Fergana Project, SIC ICWC-IWMI-SDC)[1] make provision for water supply management by hydrographic boundaries and water demand management by administrative boundaries. Administrative boundary-based management established a structure coordinated at the regional level by regional authority that included all those bodies that, per se, were involved in RAIA ACS. These are bodies responsible for finance and control (bank, tax administration), fertilizers, machinery, reclamation services, plant protection and seed breeding, energy, communication and so on. The system of interactions in the current management patterns differs from that in socialistic management pattern on priority of contractual and economic relations, as well as on the role of local authorities. Whereas the composition of essential components, employment and welfare in the rural cluster have remained the same as assumed within RAIA. However, in the present settings RAIA functions supposedly will be fulfilled by rayon Water-Land Commissions.

[1] GWP Publication "IWRM in Central Asia", Dukhovniy V.A., Sokolov V.I., Ziganshina D.R.

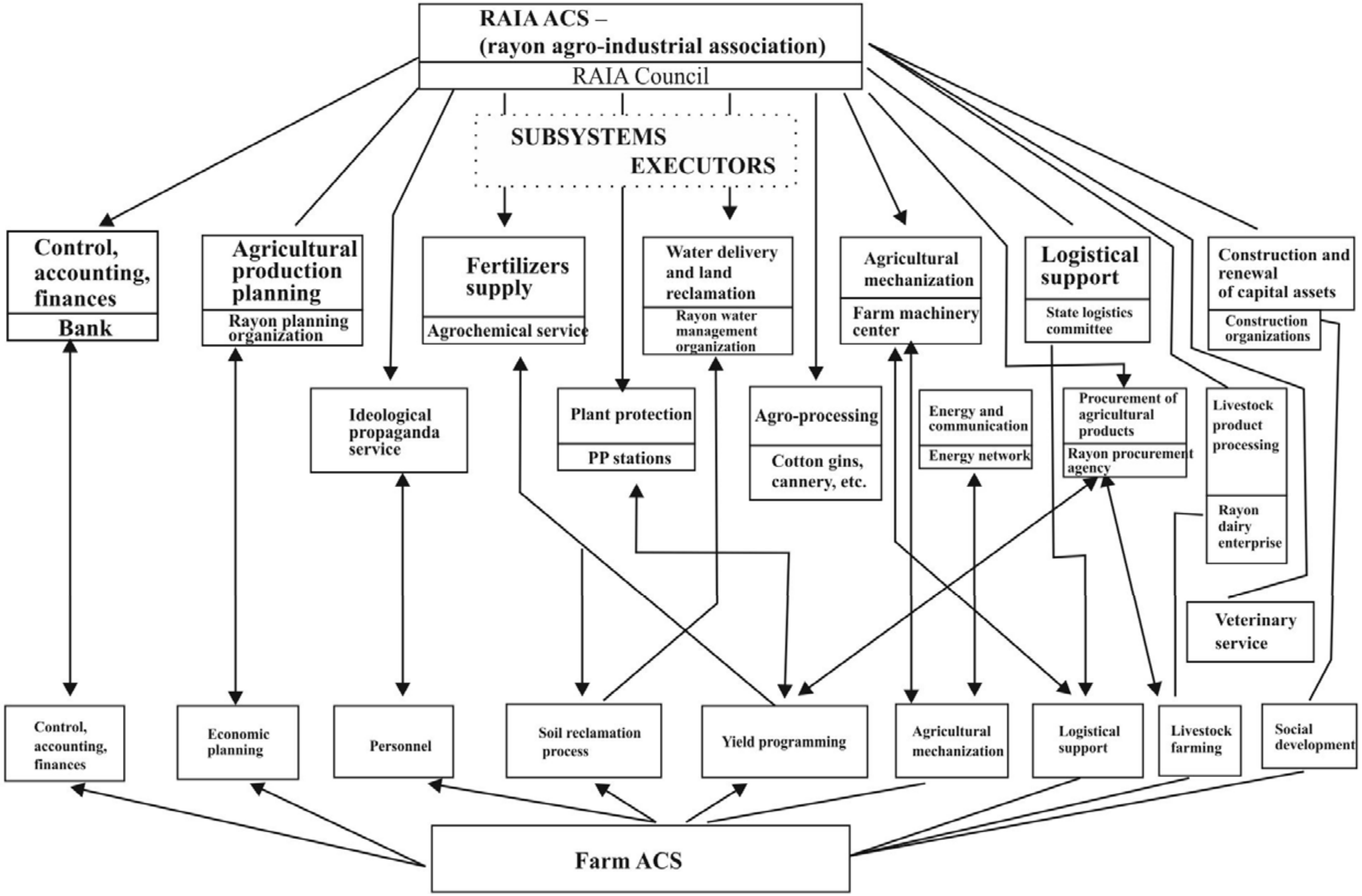


Figure 1.2. Composition of RAIA ACS subsystem

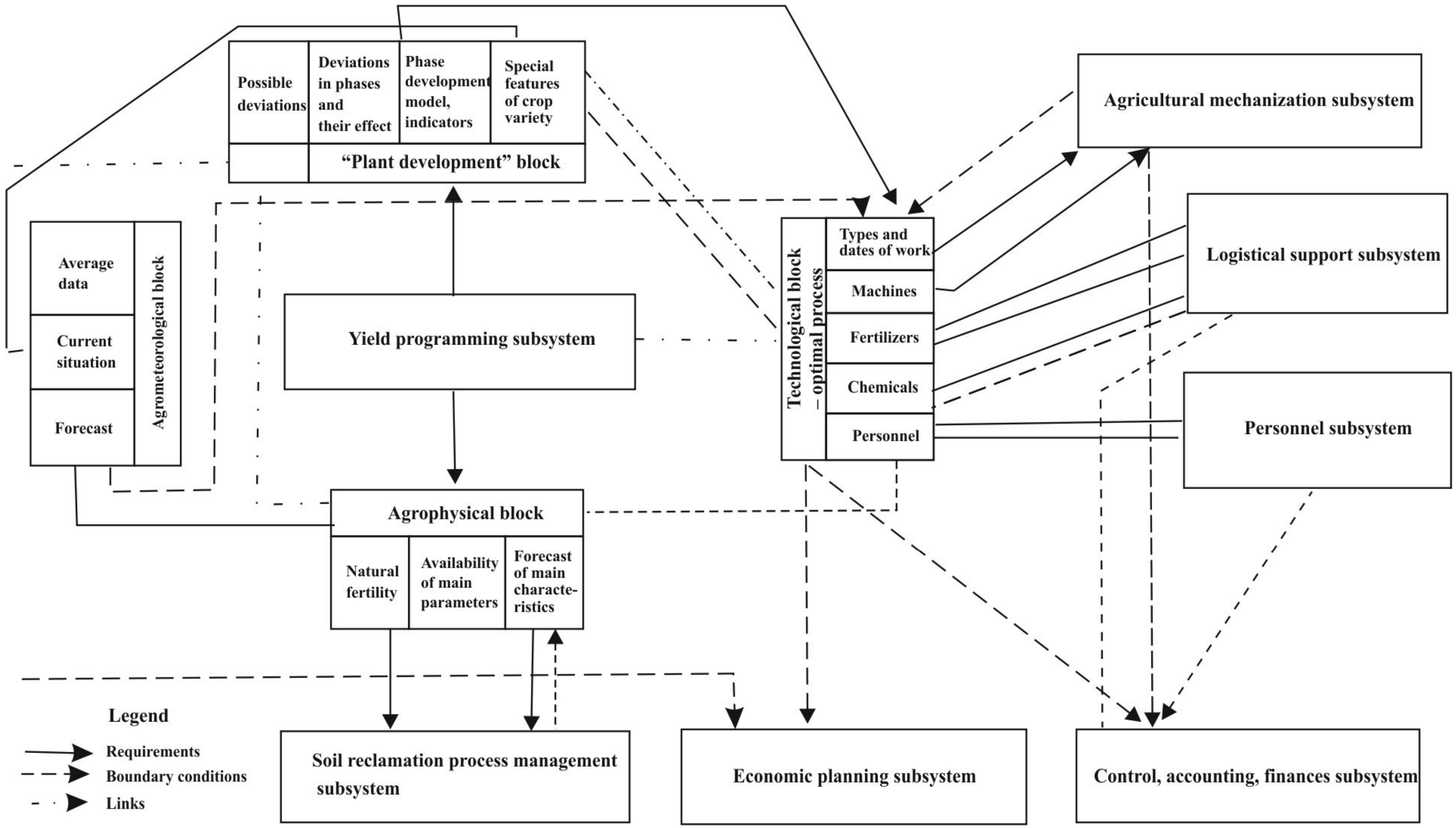


Figure 1.3. "Yield programming" subsystem

1.2. Structure of Subsystem Elements and Links between Them

As mentioned above, yield programming process covers several ACS subsystems.

For assessment of structure and relationships between all subsystems we will use the methodology of I.S. Shatilov and A.F. Chudnovskiy [23], who take as the basis three – agrometeorological, agrophysical, and agrotechnical – aspects that cover mainly the tasks of “Technological process ACS in crop farming”. Here they considered technological processes against the changing agrometeorological situation, which impacts the agrophysical conditions of soil, surface air and plant.

In our opinion this approach is true for current (given year) assessment of technological process ACS but it does not take into account long-term changes in soil fertility. Besides, programming with account of the above three aspects assumes that all control actions are taken in relation to technological processes and their optimization, together with adaptation to and, in some degree, modification of agrometeorological conditions through reclamation measures. In addition, long-term selection of crops and their combinations for adaptation to climatic conditions serve as an important tool for soil fertility management.

For correct building of subsystem “Yield programming in crop farming”, we should think about the control object in this subsystem. This is the combination of plant-soil-environment, where as dynamic processes progress in time and space, the most favorable conditions are created for maximal generation of yield under limited inputs.

Environment is less controllable element (poor control of climate and larger control of hydrological and hydrogeological conditions through drainage and irrigation) in the above combination. To a certain extent, some corrections can be made to soil temperature regime, etc. The plant is enough controllable element in terms of selection of plant type and variety and its direct control by various agronomic methods (thinning, topping and so on). However, the main object to control is the soil and its fertility. V.V. Yegorov [7] defines fertility as the ability of the soil to meet materiel and energy needs of plants.

Indeed, mineral elements (NPK, humus, microelements) are required for plant in strictly necessary quantities in order to generate yield through photosynthesis. However, this is possible only with energy potential, which the soil and plant receive from solar radiation in case of certain moisture content. According to V.R. Volobuyev, the soil energy is equal to:

$$Q_n = R \cdot e^{-0.47\frac{1}{Kn}}, \tag{1.1}$$

where

R is radiation balance;

K_n is coefficient of moistening; e is the natural logarithmic base.

In addition, energy potential determines development of biota, velocity of moisture fluxes in plant and soil, and, consequently, income of nutrients, carbon-oxygen exchange, decomposition of fertilizers for their uptake by plant, etc. Herewith, water transforms all matters in soluble form, takes part in photosynthesis, regulates plant temperature and so on.

Yield depends on both biological abilities of plant and its varieties and on ability of soil to meet plant needs in time and space on regular basis. First, the soil should be a filter, through which all external inputs, such as radiation, substances, moisture, “pass” before reaching the plant. Second, the soil should be a damper, which through soil buffer capacity and inertness mitigates abrupt changes in external environment (e.g. temperature, moisture content and salinity, etc.). Third, the soil is a pool, from which plants and the soil itself can uptake gradually moisture, heat, and nutrients over the longer periods of time in-between their income. The soil also a reactor, which transforms the thermal energy of sun into the kinematic energy of fluid movement or into the energy of cell growth. Eventually, the soil is a giant and full-time ‘kitchen’, where a ‘physiological solution’ is cooked that feeds plants and maintains biota, which in essence is a ‘condiment’ and, at the same time, a producer of this ‘food’. The soil fulfills all these functions depending on its texture, structure, agrochemical and agrophysical properties, salinity, humus content, etc. Therefore, the aim of the technological process ACS consisting in production of the highest possible yield with limited or cost-effective inputs is to be achieved by managing efficiently energy and other inputs to plants through the soil, while ensuring continuous control over soil conditions by appropriate reclamation measures.

Subsystem “Yield programming in crop farming” is divided into the following blocks: “Plant development”, “Agrophysical block”, “Agrometeorological block”, and “Technological block” (Fig. 1.3). “Plant development” block describes quasi ‘reference’ crops for given field. This block should contain characteristics of crop and its variety, special aspects of plant development phases and estimate effects of possible deviations in external (weather) and anthropogenic conditions on the development phases and, finally, on yield. Based on the information in this block, requirements for “Technological block” are formulated and links that determine an impact of the above characteristics and deviations on control actions are formed. “Agrometeorological block” contains characteristics of average long-term and extreme probable deviations of weather conditions for given locality, assesses the current situation and produces forecasts. Characterization of the current situation impacts on the assessment of standard plant development phases and their deviations in the “Plant development” block, as well as in “Agrophysical block” and these two blocks help to formulate requirements in the “Technological block” for “Agricultural mechanization”, “Logistical support”, and “Personnel” subsystems, each of them having feedback as whether these requirements can be met or not as constraints. These constraints again impact on “Technological block”, through this block on “Agrophysical block” and “Plant development” block, thus requiring assessment of the situation, which is formed with such constraints, when initial requirements can be met only in part. If alternative solution to meet these requirements is impossible to find, the resulting yield is corrected.

"Agrophysical block", which interacts mainly with "Soil reclamation process management" subsystem, gives assessment of natural fertility and possible measures for its improvement in the long-term, contains information on status of the soil-plant-atmosphere system, taking into account land reclamation measures (irrigation, drainage) from the "Soil reclamation …" subsystem, and forms information for the "Plant development" block, requirements for fertilizers, agronomic practices, etc.

Finally, "Technological block" together with "Soil reclamation …" subsystem determines composition of standard costs in the "Planning and economics" subsystem, while the "Plant development" block determines amount of plausible ultimate yield, its quality, probable reduction or increase given the level of natural fertility. "Control, accounting, finances" subsystem regularly receives information about all costs incurred in the farm and its units, about deviations from the costs planned in "Planning and economics" subsystem and on the need (or possibility) to take measures to put them in order.

"Technological block" should describe technological process (seeding, fertilizer application, irrigation, cultivation, top cutting, etc.) in such a way so that the process fully corresponds to requirements of the "Plant development" block. Here, three special aspects of technological process should be taken into account:

- Each technological process is rational as long as it corresponds to optimal range of conditions, for which it was developed initially. Moreover, extra advance or delay in process elements or simple difference between planned and actual conditions of the process can worsen, rather than improve, plant development. For example, delay in last application of water to cotton till 25 August – 5 September leads to aftergrowth of leaves, unnecessary accumulation of vegetation mass, breach of defoliation effect, prolongation of fruit formation phase, and, eventually, to reduction of yield. Whereas early irrigation worsens aeration, breaks photosynthesis and some biotic processes, and causes outflow of fertilizers, humus and other substances from the root zone.
- Some technological processes have both positive and negative effects. Farmers should know about such negative effects and prevent them. For example, deep real tillage (to 45 cm) leads to deepening of active layer, improvement of aeration and structure, reduces weeding, and attracts gypsum to this zone. This process is very important for loess gypsum-bearing soils. However, at the same time, such tillage abruptly worsens microbiologic activity, surface layer structure, and reduces fertility of the upper horizon. This is not good for meadow and sand-desert soil.
- Any technological process is costly; therefore, its choice is an optimization problem on how to minimize costs and maximize productivity.

Hence, in the "Technological block" we should have answers to the following questions:

1. What are optimal conditions, time, and intensity of one or another process and what is the range of deviations that impact plant development and what effect these deviations have on final productivity?
2. What are possible negative functions and consequences of each technological process, how are they formalized?
3. What is the spending function of technological process?

We should bear in mind that in real-world farms deviations in each technological process are already known through the size of temporal and spatial stohastism when performing agricultural operations, and this also should be considered by the link between the "Technological block" and "Agricultural mechanization and transport" subsystem.

Particular place in yield programming is taken by "Soil reclamation process management" subsystem, which involves:

- Assessment of natural fertility and development of long-term measures for its improvement;
- Creation of optimal soil conditions to meet requirements of the "Agrophysical block" in terms of moisture and salinity through appropriate reclamation measures (irrigation and drainage).

Thereupon, we set requirements for overall reclamation, as well as for annual agronomic and reclamation measures, for irrigation, drainage maintenance and other operations.

1.3. Main Levels of Productivity, Aggregating the Elements and Building Programming Hierarchy

According to the theoretical provisions of I.S. Shatilov, A.F. Chudnovsky, V.A. Platonov, and R.A. Poluektov, we have considered the following main levels of land productivity:

MVY – the highest possible crop yield that can be achieved only in ideal soil and climate, and production and managerial conditions;

PY – potential crop yield, where long-term indicators of zonal and soil fertility are taken into account;

DVY – actual-possible crop yield, which assumes the highest possible technical crop yield under conditions of a specific climatic year and under effect of controllable factors;

Farm yield (YH) – crop yield of a farm, which in essence is a possible yield achieved under the impact of actual conditions of plant development phases in given year;

RY – actual crop yield achieved taking into account all technological and management actions, operations actually performed in given year and deviations from the optimum.

The objective of yield programming can be reduced to the following expression:

$$RYL_{im} \rightarrow YHL_{im} \rightarrow DVYL_{im} \rightarrow PY \rightarrow MVY$$

In such statement, the problem of yield management is disintegrated into long-term activities determining PY, medium-term activities determining DVY, activities carried out in given year and determining YH, and operational and organizational activities, the result of which is RY. Accordingly, information and management parts of the system (including norms and current information) should be built for every level of land productivity.

$$MVY = \frac{\sum Q_{PAR}}{q} \cdot \eta_F \cdot K \qquad (1.2)$$

where

$\sum Q_{PAR}$ - mean annual influx of photoactive radiation over the growing season (kcal/cm^2);

q - yield caloricity;

η_F - photosynthetic efficiency;

K - coefficient of conversion from phytomass to yield.

The photoactive radiation is determined by direct measurement by photopyranometer or can be computed using conversion coefficients. Based on data of E.D.Cholpankulov and A.Yu.Kratenko (1991) and by processing numerous experimental data, the following relationship was derived for daily and monthly sums of PAR for Central Asian conditions:

$$\sum Q_{PAR} = 0.42 \sum S' + 0.60 \sum D \tag{1.3}$$

where

Q_{PAR} – direct photoactive radiation;

S' – direct solar radiation;

D – diffused solar radiation.

If the total radiation is known, a simplified formula is used:

$$\sum Q_{PAR} = 0.5\ Qc \tag{1.4}$$

where Qc – total radiation.

To calculate a potential yield, the following formula is used:

$$PY = MVY \cdot K_b \tag{1.5}$$

where

K_b – coefficient of soil bonitet, which is calculated using the formula:

$$K_b = Kocn \cdot Kgum \ ,$$

where

K_{ocn} – main bonitet score, which takes into account type of soil formation, thickness of fine grained soil, granulometric composition and automorphy of soil;

K_{gum} – reduction coefficient for humus content in soil.

Before turning to detailed consideration of the automatic control system of technological processes, we will describe stages of land productivity formation. In doing so one should bear in mind that at the level of agricultural enterprise, as per I.C. Shatilov and A.F. Chudnovsky, “routine” standard tasks take 40%, structured ones (for mass service and optimization) – 26%, poorly structured – 24%, extra difficult, unforeseen ones, which are impossible to be structured - 10%. Thus, we can rely on formalization of only two thirds of all technological process management tasks. It should be noted that just some part of tasks at different levels would match together.

Intensive application of manure along with adoption of crop rotation on the basis of permanent grasses is required to increase humus content in the soil; for improvement of soil structure, tillage, addition of sand, slotting, chemicalization and other operations along with application of manure are needed also.

As the basis for the correction of bonitet, recommendations of UzNIIP [11] are used taking into account the methodology developed by GIZR, in which factors, which can be improved during a year, are selected.

Hence, a plan of long-term actions is made to increase PY in given farm or zone. They should include measures to increase soil bonitet and photosynthetic efficiency.

As I.S. Shatilov and A.F. Chudnovsky [23], pp. 77 – 79 stated fairly, for assessing potential land productivity, of great importance is the selection of crops for rotation, which allows maximal use of PAR in given zone and production of the highest possible phytomass in given conditions.

It is known that every kilogram of dry organic matter accumulates 4,000 kcal on average. For every zone, the total radiation *S*, as well as PAR are known and the latter is derived from the simplified relationship: $Q_{PAR} = 0.5 \cdot S$. Certain quantity of PAR in each phase of plant development gives some increase in phytomass. Every crop variety, depending on degree, to which agrophysical conditions are met, absorbs different percents of PAR – from 1 to 3.

Hence, phytomass on average is:

$$FM = \frac{\sum Q_n}{q} \tag{1.6}$$

Thus, if PAR achieves 7 bln kcal/ha (80 kcal/cm^2) in Central Asia, then in accumulating 3% of PAR, yield of grasses (dry weigh) will be

$$\frac{8 \cdot 10^9 \cdot 3 \cdot 10^{-2}}{4 \cdot 10^3} = 600 \text{ centner/ha.}$$

To take full advantage of radiation, it is necessary to select plants with the highest accumulation of PAR (corn, sorghum, etc.), which allows for highest yields under optimal conditions. For example, according to Cooke G.W. [25], the following figures of highest yields (cent./ha) are registered in the world: corn – 222; wheat – 145; sorghum – 215; rice – 144; barley – 114; soybeans - 56.

It should be kept in mind that not the entire amount of radiation over the growing season, but only the amount, which is needed for plant should be seemingly considered in PAR assessments. Otherwise, the amount of heat, which causes moisture overuse, excessive intensity of transpiration mechanism and even depression of plants, would be counted as the positive properties of the area. But it is known that even heat-loving plants, such as cotton and grapes, cease normal development at certain temperature.

DVY describes the possibility to get a yield limit under conditions of given year. This should include indicators of heat provision, as well as the following factors of yield, which can be significantly changed by preventive or current operations:

- salinity (can be changed by current, more rarely capital leaching and artificial drainage) - (K_c);
- weeding (can be changed by mechanical or chemical removal of rhizomes, for example, sodium or copper trichloracetate together with fall plough; deep plowing, etc.) – (K_{sor});
- mineral elements available – K_{NPK};
- infestation with pests and diseases - (K_{bol}, K_{vr});
- uniformity of land, which depends on leveling of the project area - (K_f).

$$DVY = PY \cdot K_c \cdot K_{sor} \cdot K_{NPK} \cdot K_{bol} \cdot K_{vr} \cdot K_f \cdot \frac{\sum Q_n}{\sum Q_{PAR}} \qquad (1.7)$$

where

PY – potential yield;

K_c, K_{sor}, K_{NPK}, K_{bol}, K_{vr}, K_f – coefficients of influence on the yield: salinity, weeding, mineral elements availability, crop infestation with diseases and pests, uniformity of land, respectively;

$\sum Q_n$ – total actual PAR;

$\sum Q_{PAR}$ – total mean long-term PAR.

Analysis of literature sources or the results of special experiments should serve as the methodological basis for the assessment of the above coefficients ranging from 0 to 1.

The ratio $\sum Q_n / \sum Q_{PAR}$ shows PAR availability for particular crop in given year as compared to average long-term data. When $Q_n > Q_{PAR}$, the ratio should be taken equal to one.

The main document, which provides an array of information to determine the indicators of PY and DVY, is the agro-reclamation field passport designed by the SANIIRI Institute. Its data divided into two groups - properties determining long-term fertility and properties characterizing controllable factors on annual basis – help to plan and perform operations for improvement of basic land productivity.

YH, farm yield, is an achievable productivity of crop in the farm. The actual farm yield is calculated without reference to a particular crop. Here, only organizational and production losses and weather-related losses are taken into account.

$$YH = DVY \cdot P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot P_5 \qquad (1.8)$$

where

P_1 –labor (human) resources;

P_2 –equipment and transport;

P_3 - quality of technological operations and deviation from the zonal technology recommendations;

P_4 –fertilizers, chemicals, seeds (resource provision)

P_5 – water availability.

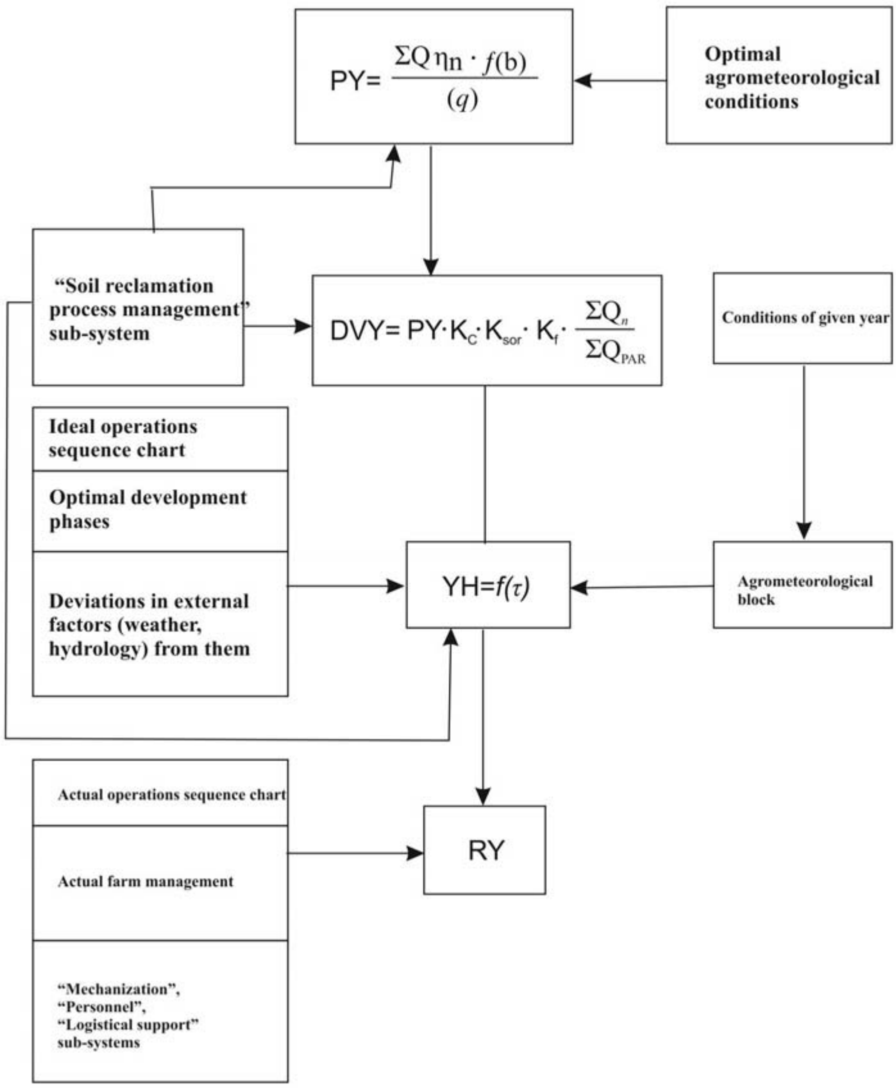


Figure 1.4. Diagram of yield assessment

Variability of external natural (because of the probabilistic nature of climatic and hydrological factors in given period) and organizational (under effect of various logistical factors, such as provision with fertilizers, equipment, etc.) conditions in each year creates a need for assessment of a quasi highest possible crop yield under particular conditions, provided that the whole farm staff works perfectly and follows operations sequence charts and work standards (Fig. 1.4).

The main thing here is the optimal plant development phases under given conditions, and compliance with both control parameters at the end of each phase and the phase duration. For example, the following phases are characteristic for cotton:

- from sowing to formation of two - three real leaves;
- from formation of the third leaf to budding;
- from budding to flowering;
- from flowering to fruiting;
- from fruiting to maturing;
- from maturing to end of harvesting.

For each phase agrotechnicians should establish (in the "Plant development" block):

a. optimal conditions of moisture, temperature, mineral nutrition;
b. duration of each phase (days) and the effect of deviations from the optimum on it;
c. final indicators of normal, maximum permissible output of each phase (e.g., sprouts - number of plants per hectare not less than 120 thousand, if the number of sprouts is lower, yield decreases respectively, etc.);
d. effect of deviations during each phase and in the total duration on final indicators of the item "c".

As mentioned already, at this stage, the main thing is to establish the right sequence of various reclamation and agronomic operations in order to ensure normal development of plants and avoid yield losses. This can be done on the basis of operations sequence chart prepared in form of a flexible flowchart of the process according to particular climatic conditions. Given that weather conditions is a probabilistic process, possible deviations from the average range of the main agro-meteorological indicators and appropriate differentiated agronomic operations should be determined.

It is necessary to identify required capacities of machinery and other facilities and the amount of fertilizers to compensate for possible deviations of climatic and weather conditions and somewhat to "catch up" with the backlog of the technological process or undertake proactive actions if there is deviation from the optimum.

If it is impossible to compensate for deviations, such technological (or operational) controls need to be developed that will help to reduce yield losses to a minimum with limited inputs.

We will illustrate these particular features of the technological process by the example of crop growing. Optimal conditions for growth of seeds are known as:

$$\begin{gathered} t_{S^o} \geq \lfloor t_{S^o} \rfloor \\ [\theta_{\min}] \leq \theta_{0-10} \leq [\theta_{\max}] \\ \theta_{0-10} = f_2\left(\theta_{oit^o}\,;\tau\,;R\right) \end{gathered} \tag{1.9}$$

where

t_S^o - soil temperature,

$\theta_{0\text{-}10}$ - soil moisture in the layer 0-10 cm,

θ_0 – initial soil moisture,

t – air temperature,

τ - period from the beginning of observation,

R – radiation balance.

It is known that the period from sowing to sprouting (τ_{vsh}) can be estimated by the method of phenological forecasts [15].

$$\tau_{VSH} = \frac{A}{t_{sr}^0 - B} \tag{1.10}$$

where

A- total effective temperatures (^{0}C) in given development phase under normal conditions of moisture for given crop variety;

t_{sr}^0 - average temperature in given period, ^{0}C;

B – development threshold or minimum effective temperature (in this case, sprouts), ^{0}C.

Since during the days when $t^0 \leq B$ the plant is not developed, it is more reliable to determine this period with the following expression:

$$\sum_{\substack{\Delta\in\tau_{VSH}\\(t^0\geq B)}} t^0 - \tau_{VSH} \cdot B \geq A \tag{1.11}$$

where the total temperature is taken only as the total of days with daytime values higher than the minimum effective temperature.

As mentioned already, the conditions for sprouting depend not only on temperature but also on moisture regime (optimal moisture is considered to be 0.8-1.0 FC in the layer 0-10 cm; sprouts slow down when moisture varies between 0.6 and 0.8 FC, and sprouts do not emerge when moisture is somewhat below the wilting point).

By constructing the curve of air temperature variability based on meteorological data and the curve of soil moisture variability based on moisture regime calculations (e.g., using the program “Progwat” by Baklushin, Dukhovniy, Dudko), one can estimate how to choose the dates of sowing τ_{cc} in such a way so that the range of soil temperatures and moisture in the layer 0-10 cm be optimal during the period from τ_{cc} до $\tau_{cc} + \tau_{sowing} + \tau_{vsh}$. Hence, the probability of sprouting P_v is as follows.

$$P_j = f_3 \left\{ t^0_{S\tau} ; \theta_{S\tau} \Big|^{\tau_{cc} + \tau_{sowing} + \tau_{VSH}} \right\} \rightarrow \max \tag{1.12}$$

The control parameters for this technological process are τ_{cc} and τ_{sowing}. The sowing date per se is a function of equipment and crop regime. If it is impossible to choose such sowing date that would probabilistically ensure optimal conditions for sprouts, then one should set recharge irrigation as a factor of creating optimal moisture in the soil or shorten τ_{vsh} by selecting a crop variety, which gives the earliest sprouts or by special treatment of seeds (hydroactivation, unipolar, magnetic, etc.).

Thus, under real-world conditions and using some control factors (water, technology, mechanization, fertilizers, and plant protection agents) the process of yield generation, which ultimately consists in producing YH, which is close to DVY, should overcome likely deviations in weather, climatic, economic conditions with minimal yield losses and inputs (Fig. 1.5). Hence, the objective splits into the two main directions: assessment of the optimal crop development under average conditions for particular plot (farm); and, gradual overcoming of all deviations, including economic (not only natural) deviations from the optimum.

Division into phases and real conditions of different plant development phases, depending on the basic background (“Agrophysical” block), conditions of the “Agrometeorological block”, reclamation measures (“Soil reclamation process management” subsystem), and technological processes (“Technological” block) is taken as the basis for “Plant development management”.

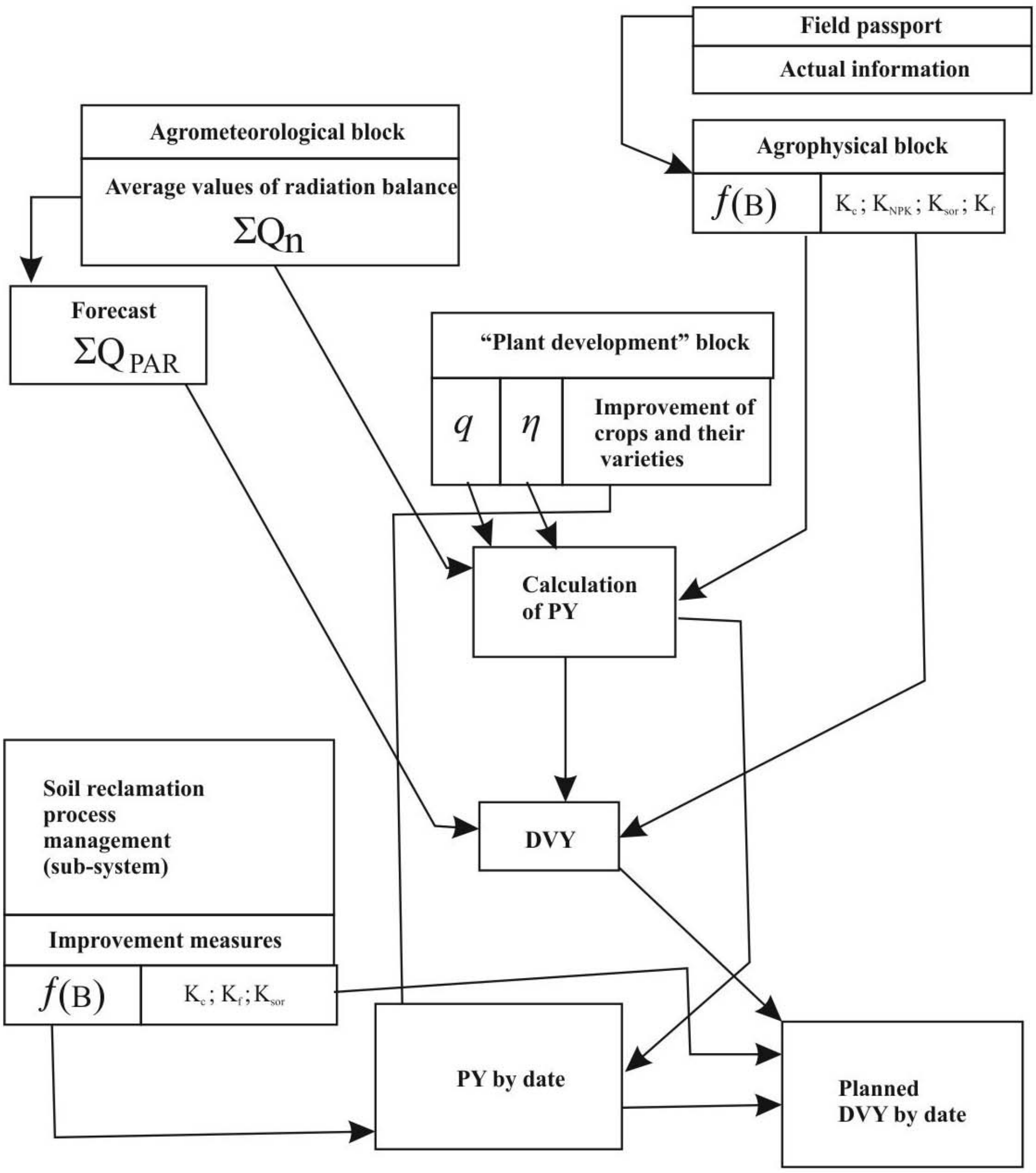


Figure 1.5. Assessment of PY and DVY and possibilities of their increase

There are various ideas concerning consideration of phases and their impact on ultimate yield:

- the duration and effectiveness of each phase is the result of completion of all preceding phases:

$$T = \sum_{\tau \in nF} t_\tau ; t_\tau = f_1^t (S_{t-1}; R; i; t^0; \theta) \qquad (1.13)$$

$$Y_\tau = Y_0 \cdot f''\left(\sum_{\tau \in nF} t_\tau - \langle t_\tau \rangle\right) \qquad (1.14)$$

or

$$Y_\tau = Y_0 \cdot f_1(\tau_1) \cdot f_2(\tau_2) \ldots f_n(\tau_n) \qquad (1.15)$$

$$Y_\tau = \underset{\tau \in nF}{Y_0} \; P f_i(\tau_i) \qquad (1.16)$$

- the duration and effectiveness of each subsequent phase depends only on output of the preceding phase and factors that impact on given phase (Fig. 1.6):

$$t_\tau = t_{\tau-1} + f'''\tau_n(i\,; R\,; t^0\,; Q_S\,, \ldots) \qquad (1.17)$$

$$Y_\tau = Y_0 \cdot S_{t-1} \cdot f''''\tau_n(i; R; t^0; Q_S, \ldots) \qquad (1.18)$$

The first part of this expression is similar to that adopted by V.A. Platonov and A.F. Chudnovsky [11] but they considered only the temperature effect as the basis for each phase. However, we fix the results of each phase (S_{t-1}) and plan to reduce primary yield losses based on deviations in the results of phases from the norm. Therefore, the latter option is taken. Hence, the second objective of the sub-system is to form the set of reference output data and their permissible deviations.

Here, requirements for other sub-systems are established in terms of minimizing deviations from the norm.

Assessment of optimal crop development should include forecasting of plant (variety) development phases based on the optimal moisture conditions and average climatic conditions, identification of normal water requirements and abilities to meet them throughout the whole area in order to be able to scale up from a reference plot to farm, taking into account parameters of irrigation network.

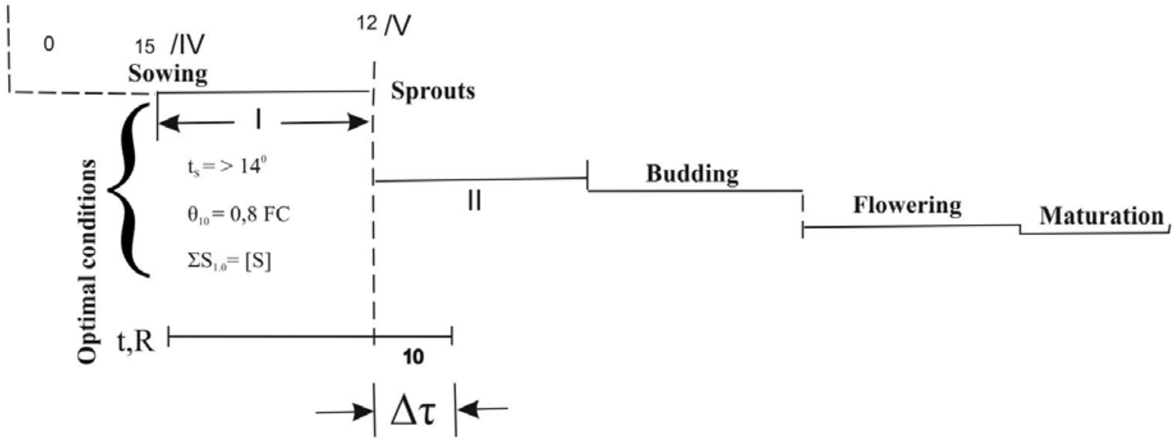


Figure 1.6. Phases of biological development

Further, we should make assessment of plausible deviations in weather parameters (90% occurrence) and economic conditions (staffing in view of qualification and experience, mechanization, available chemicals, etc.) and of the impact of these deviations (also including deviations in water consumption and other physical processes from the optimum) on the normal development of plants.

To prevent deviations, as shown earlier, estimated reserve capacity can be formed or proactive agronomic operations can be performed and this also should be forecasted. Supplementing of all these relations and inputs by economic indicators, actual for each field, will allow transforming the system of yield forecast into economically reasonable one linked with self-sufficiency and optimized production.

Stochastic simulation of "Plant development" block allows you to select crop variety, which is best adapted to temperature, humidity characteristics of climate, including probability of precipitation, frost, etc. This is very important, for example under conditions of early rains and frost (Karakalpakstan and Khorezm province in Uzbekistan), where high-yielding cotton varieties often do not ripen, and early-season varieties are not sown because of their lower yields.

Actual land productivity is formed under effect of any deviations already at the stage of RY. The difference between RY and YH shows, in fact, what is the degree of timely management improvement in this farm, branch or unit. At this stage, besides data on the effect of deviations accumulated in the “Plant development”, it is important to have information on the effect of organizational arrangements on mentioned deviations.

To this end, in the “Planning and economics” subsystem it is advisable to create an array of information in the farm about labor, material and other resources and compare them with data on deviations, which were obtained during analysis of development phases. As a result, by using the multiple regression method, it is possible to identify the effect of these deviations in provision of organizational factors on phases. Hence, a possibility is created to optimize the use of resources under their deficit in order to overcome abnormal flow of phases.

For this purpose, we developed respective formula. It seems possible to process the obtained data in the following form:

$$\frac{\tau_\xi - \langle \tau_\xi \rangle}{\langle \tau_\xi \rangle} = a_\xi \Lambda_\tau + b_\xi P_{ni} + C_\xi P_{oi} + d_\xi P_{yi} + g_\xi T_{pi} \tag{1.19}$$

or similarly derive the relationship between yield reduction in each phase and these factors:

$$\frac{Y_\xi}{Y_\xi - 1} = a'_\xi \Lambda_i + b'_\xi P_{ni} + C'_\xi P_{oi} + d'_\xi P_{yi} + g'_\xi T_{pi} \tag{1.20}$$

where

τ and $< \tau >$ - actual and optimal time of the phase, respectively;

Λ_i - provision with human resources of each production unit, as unit fraction;

P_{ni} ; P_{oi} ; P_{yi} – provision of each production unit with equipment during soil preparation, crop treatment and harvesting;

T_{pi} - provision with transport;

a'_ξ ; b'_ξ ; c'_ξ ; d'_ξ ; g'_ξ - matrix coefficients of indicators showing provision with resources for particular period of time;

a_ξ ; b_ξ ; c_ξ ; d_ξ ; g_ξ - matrix coefficients of the impacts of provision with resources on relative yield reduction;

$\frac{Y_\xi}{Y_\xi - 1}$ – relative yield reduction in each phase:

$$\left. \begin{array}{l} a'_\xi + b'_\xi + c'_\xi + d'_\xi + g'_\xi \\ a_\xi + b_\xi + c_\xi + d_\xi + g_\xi \end{array} \right\} = 1 \tag{1.21}$$

Such reference data collected in farm allow, taking into account current situation in the farm, forecasting possible deviations in the dates of operations, and hence, development phases and crop yield, or assessing the amount of needed reserve of equipment, transport and other resources to compensate possible failures.

Here, in the future, we can add some optimization not only of distribution of scarce resources, but also of formation of necessary reserves at farm and maybe RAIA level to compensate the deficit created by organizational “noises” in the farm.

The proposed four-step approach to formation of yields allows for differentiating costs and the unit cost of production, depending on causes of their emergence, and taking measures to reduce unit cost and, at the same time, increase productivity of agricultural production; thus, yield programming involves economic assessment and options for planning of scope and profitability of production.

Based on the proposed approaches, all main tasks (besides financial, economic and statistical ones) can be systematized, regardless of distribution among sub-systems and blocks (Tables 1.1, 1.2). They are divided into information tasks and control actions. In doing this, information tasks are divided into two sub-groups – reference (norms) and check information.

At the same time, one should bear in mind that, in view of our proposals on the basis of the previously mentioned suggestions by I.S. Shatilov and A.F. Chudnovsky [23], all information tasks relate mainly to “Agrophysical”, “Agrometeorological”, and “Plant development” blocks, which give characteristics of the object of regulation - “soil - plant – atmosphere”, while the regulators are the “Agrotechnical” block and the “Soil reclamation process management” sub-system.

Table 1.2

The hierarchy of tasks in yield programming according to the four-step approach

Type of task	MVY - PY	DVY	YH	RY
Reference base (norms)	1. Characteristics of varieties and crops in terms of their needs for radiation, their coefficients of efficiency	Impact on DVY	1.Optimal conditions for development phases and permissible deviations	1.Standard technology
	2. Average long-term radiation	a) degree of weeding;	2. Factors influencing on phases:	2. Need for equipment in each field
	3. Impact on bonitet:	b) level of salinity;	a) agrometeorologic al;	a) under normal conditions;
	a) structure;	c) uniformity of land (or degree of system operability);	b) technological;	б) taking into account possible deviations
	b) humus content	d) NPK	c) pests;	3. Equipment available

Type of task	MVY - PY	DVY	YH	RY
			d) NPK;	4. Staffing and personnel reserves
			e) moisture	
			3. Indicators of phase completion	
			4. Average agrometeo-rological indicators	
Check base	1. Indicators:	1. Measures to improve agricultural background:	1. Actual information on state of fields	1. Technological control
	a) humus content;	a) removal of weeding;	2. Control of meteorological factors, NPK content, soil	2. Fulfillment of operative tasks
	б) soil structure;	b) salinity reduced, drainage improved;		
	2. Possible measures to increase bonitet score for the next five-year period	c) leveling improved;		
	3. Data on actual performance to increase bonitet	d) NPK application		
		2. Control data on implementation of measures proposed		
Control actions	Long-term measures to improve fertility:	1. Plan of activities for weed control through application of herbicide and chiseling	Organizational and technical measures in current year	Operational measures

Type of task	MVY - PY	DVY	YH	RY
	- Adoption of crop rotation;	2. Measures to improve operation of drainage, organize current land leaching	1. Plan of crop sowing	1. Operative tasks for agronomic operations
	- long-term plans for chemical reclamation and improvement of soil water and physical characteristics;	3. Plan of current leveling	2. Plan of agronomic operations	2. Operational plan for preparation and arrangement of equipment
	- plan of capital leveling;	4. Plan for application of manure and mineral fertilizers	3. Plan for irrigation and irrigation technique	3. Operational plan for transport operation
	- selection of varieties and crops most appropriate to natural conditions;	5. Plan for repair and operations in irrigation network	4. Need for equipment by date as per the schedule of operations for given year	4. Operational plan for personnel development
	- plan for adoption of perfect irrigation technique in order to achieve uniform moistening of the soil;		5. Plan of new technique and its experimental adoption	5. Measures to create necessary technological and material capacity
	- assessment of possible fertility increase		6. Plan of logistical support	
			7. Plan of staff training	

Table 1.3

Scheme for recording deviations of planned and actual inputs, $\frac{plan}{actual}$

No.	Field	Staffing, Λ_i	Deviations from technology			Transport, T_{pi}
			Preparation activities, P_{ni}	Soil cultivation, P_{oi}	Harvesting, P_{yi}	
		A_1	A_2	A_3		A_4
1.						
2.						
3.						
...						

1.4. Sub-System Composition and Interrelations

Let us consider the proposed structure of farm ACS in the interests of yield programming, taking into account subsystem and block composition.

The basic “Yield programming” subsystem at the first temporal stage of objectives (assessment and increase of PY and DVY) consists of one-time tasks - once a year (see Figures 1.5, 1.6). PY is calculated on the basis of the task “Average long-term radiation balance” from the “Agrometeorological” block, the relevant tasks for estimation of q and η for a variety and crop, and the assessment of soil bonitet using the “Field passport”. By inputting respective corrections for PAR forecasted for given year and the coefficients reducing plant productivity through weeding, salinity, etc., we will get DVY.

Further, the “Soil reclamation process management” sub-system assesses measures to increase bonitet score and the “Plant development” block determines feasible improvement of crop or variety. Thereupon, the forecast of PY increase is given according to schedule of long-term measures.

For assessing the appropriateness of a crop or variety we can apply the method recommended by I.S. Shatilov, A.F. Chudnovsky [23] on taking full advantage of radiation. The coefficient of radiation utilization is calculated as:

$$m = \frac{R_H}{R} = \frac{R_H}{R_H + Rn} \to 1 \tag{1.22}$$

where

R – total radiation ($R_H + R_n$);

R_H – radiation utilized in layer H (height of plant);

R_n – radiation utilized by soil.

Taking into account that $R_n + R_H = Q \cdot K_R$, the function (1.20) of the maximal utilization of radiation in given area can be formulated as follows:

$$\frac{R_H}{Q} \to \max \tag{1.23}$$

To assess step-by-step increase in DVY, measures to increase coefficients K_c, K_f, etc. should be introduced from the “Soil reclamation process management” sub-system according to the plan of measures for improvement of soil fertility, control of weeds, and application of manure. Unlike one-time assessment of PY and DVY (once a year), all factors - both natural and anthropogenic ones - contributing to productivity should be regularly monitored when determining YH and RY.

In doing so, the following statements by I.S. Shatilov and A.F. Chudnovsky [23] on the need to take into account the basic laws of farming and crop production should be considered:

- about equal significance and irreplaceability of life factors (heat, water, light, nutrition, etc.);
- about the minimum – yield is controlled by the availability of the scarcest resource (limiting factor);
- about the optimum - best development is achieved under the optimal ratio of factors;
- about return - nutrients taken from the soil must be restored;
- about crop rotation, especially taking into account southern crops;
- that the plant itself is a “complicated natural and climatic system”, which responds to changes in external environment and adapts (within its capabilities) to them; this property is of particular importance as it creates a range of deviations from the design narrow choice of optima, which is set for plants generally.

For calculation of YH, the main block in the PY sub-system is that of “Plant development”, which focuses on the assessment of the process of yield generation for a “reference plant” that characterizes the state of all crops in the plot. The “Plant development” block seems to be oriented towards 75% occurrence for the total area of field (and in the future - 90%).

The goal of this block is as follows:

- establish normal development (without any distortions) of plants for given conditions, based on the average long-term weather conditions (perhaps, for two levels of climatic parameters occurrence - 10 and 90%). To this end, it is advisable to choose a year-analogue and calculate normal development of plants, without any agronomic, organizational and reclamation negative impacts, except for climate and weather;
- collect phenological information on the actual development of plants in particular years and with deviations;
- regularly submit information on the state of crops with comparative assessment to governing bodies;
- develop a model of crop development and relationships between development phases and deviations;
- provide material for forecast of productivity at the stage of YH.

The block diagram for current assessment of YH is given in Figure 1.7.

For each phase, the “Plants development” block determines requirements for natural conditions in terms of heat, light, wind activity, etc. For the conditions of normal year, average and extreme reference parameters for agricultural phases are set. Then, based on assessment of the current situation and long-term records, forecast of agrometeorological factors is made. Assessment of the state of crops during preceding phase is made on the basis of the “Plant development” block and the possible development of the next phase is predicted using the data from the “Agrophysical” block (moisture, soil temperature, soil solution salinity, mineral nutrition). Hence, requirements for the “Soil reclamation process management” sub-system and the “Technological” block are formulated. Depending on the capabilities to meet them, forecast for the phase is corrected, measures to overcome backlogs are planned or correction for ultimate yield is made.

The “Agrophysical” block” should be based on the laws of interactions in the system “soil (aeration zone) - plant - surface layer” that were developed by S.V. Nerpin and A.F. Chudnovsky [10] (Fig. 1.8).

The “Soil, ground and other constants” task should contain information about invariable indicators of water-physical and physical-chemical soil properties (unit weight and bulk density, Peclet and Fick parameters, full field capacity, filtration coefficient, etc.). Along with the aggregate composition, humus and microorganisms content, the “Long-term transformation indicators” task can also include indicators from the previous task, if measures for improvement of water-physical properties, texture, etc. are planned based on the information from the "Soil reclamation process management" sub-system.

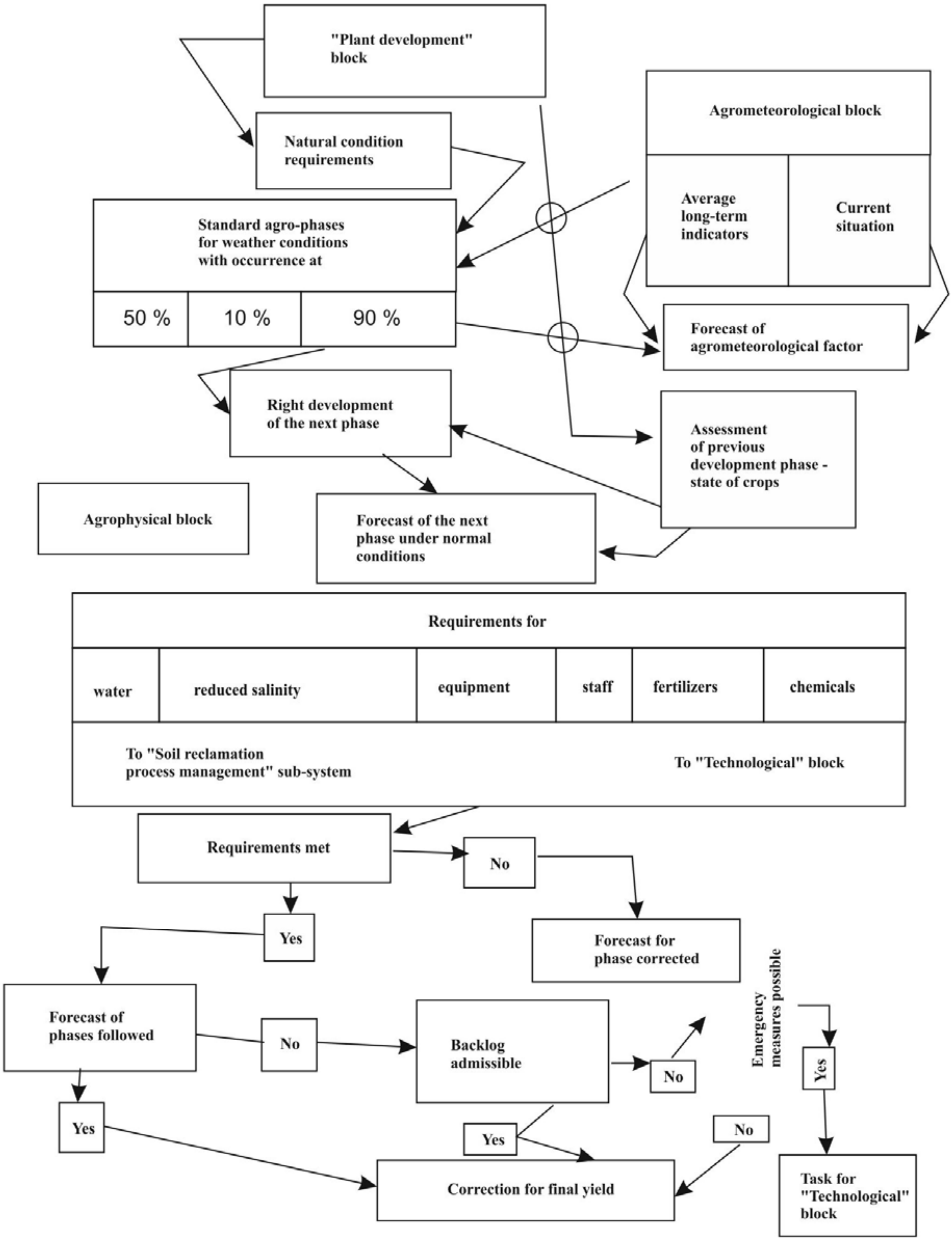


Figure 1.7. Block diagram of the model of current productivity YH

Based on the models of moisture transfer and heat exchange, S.B. Nerpin and A.F. Chudnovsky [10], dynamics of soil moisture, temperature, salinity of soil solution, salt accumulation, etc. can be regularly recorded. By comparing changes in these indicators with the requirements for the soil in the "Plants development" block, requirements are formulated in the "Agrophysical" block for the "Soil reclamation process management" sub-system in terms of irrigation, drainage and leaching and for the "Technological" block for NPK.

The "Technological" block ("Technology of agricultural production") as per the definition of V.A. Platonov [11] is aimed to:

- plan a set of agronomic measures in each field to produce design yield, including dates, volumes, workflow, etc.;
- provide a set of technological recommendations in the case of emergence of non-standard conditions;
- help to calculate, for any period of time, requirements for other sub-systems, including, for example, issues related to logistical support and organizational measures, identification of bottlenecks, etc.;
- provide check parameters for technological operations;
- calculate calendar dates for crop treatment operations with account of changed external and current conditions;
- keep online records of dates and quality of operations.

The PY sub-system puts requirements through this block for the "Soil reclamation process management" sub-system which should give an apparatus for optimization (and pre-classification) of all proposed technological processes.

The main documents of this subsystem are as follows:

- field characteristics record;
- input parameters from other sub-systems;
- operations sequence chart that takes into account stationary processes and those depending on both the current characteristics of the field and on the meteorological and organizational conditions.

The operations sequence chart contains the following data: name of the process, dates, management parameters, labor inputs, list of mechanisms, unit cost of operations, total costs, etc., as well as tasks for the next set of operations in the field. This enables to form an array of information about completed and planned activities in the state farm (*sovkhoz*), branch or even smaller technological units.

At the same time, the data of this subsystem dictate requirements for the "Plant development" block by assessing the state of crops and further controllability of agricultural production. In addition, the main document here should be a report on completion of given tasks.

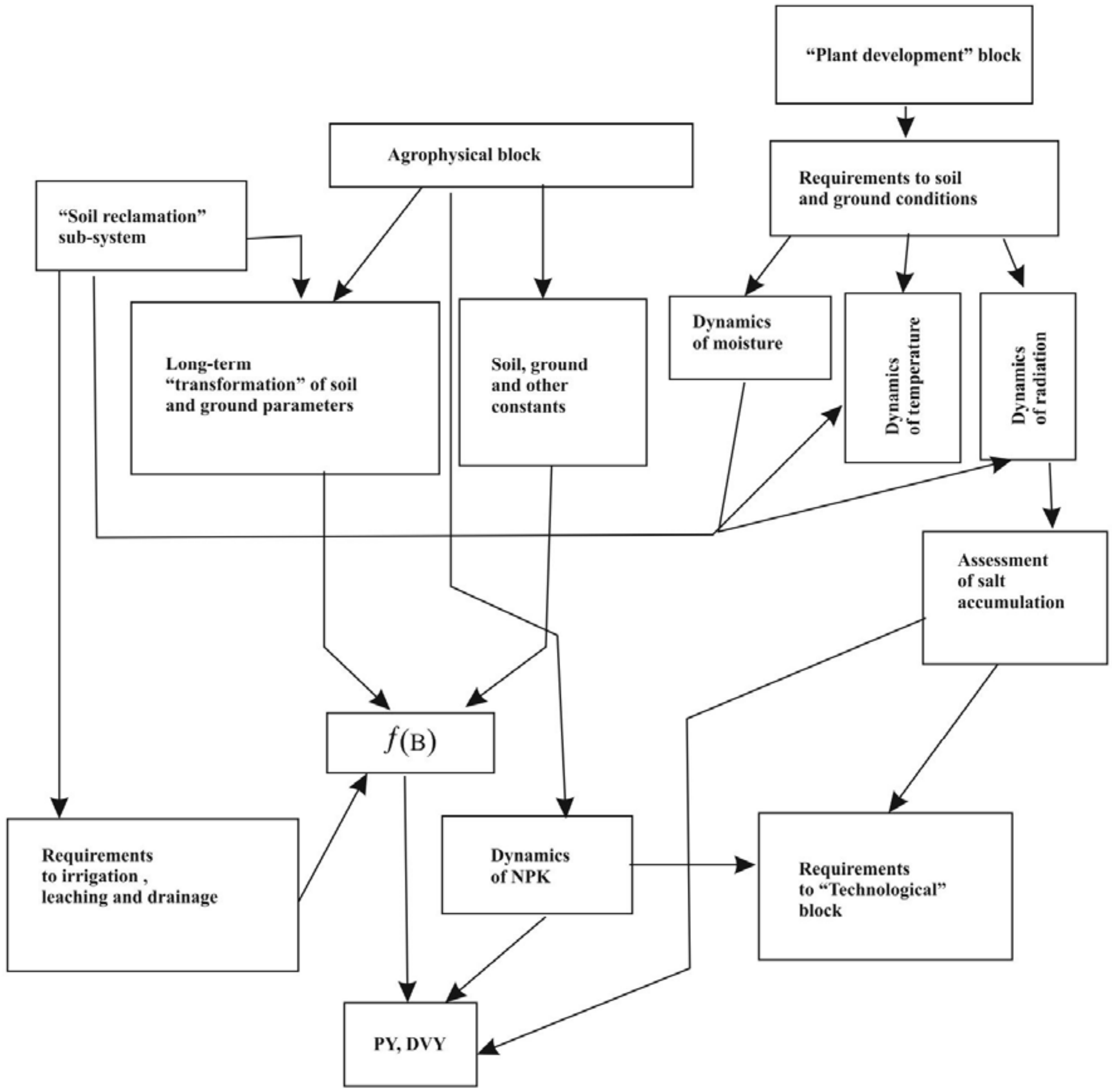


Figure 1.8. Tasks and interactions in the Agrophysical block

One can use recommendation of V.A. Platonov [11] to decide whether undertaken measures should be adjusted or not, based on the requirements from the "Plant development" block.

"Soil reclamation process management" subsystem should help to develop measures for improvement of land productivity (long-term plans) and creation of appropriate conditions (moisture and salt contents) for generation of high yield. This subsystem also involves measures for planning and fulfillment of capital and agronomic operations. Therefore the subsystem seems to divide into two parts: long-term and current measures (Fig.1.9).

A set of engineering and agronomic operations aimed at gradual long-term improvement of soil fertility should be determined by analyzing soil-formation process and correspondence of maintained soil conditions to it. We recommend using for these purposes the flow chart from [17].

Assessment of possible measures for improvement of fertility in different fields and plots allows identifying, with the use of optimization tools, the priority sites that could show highest effectiveness if irrigation systems are also reconstructed or not reconstructed, i.e. only through these fertility improvement measures. Consequently, a plan for long-term measures should be prepared and include engineering and other reclamation operations plus a plan for medium-term measures consisting of current leveling, weed control, leaching irrigation, intensified drainage or improved performance of irrigation and drainage systems.

Another part of the subsystem covers maintenance of the required moistening and desalination regimes. Moisture availability for seeds is estimated regularly using the data from “Agrometeorological block”, “Agrophysical block”, and “Plant development” block. To this end, we developed a task block “Water requirement prediction”. This block uses somewhat unique method for estimation of moisture availability, which differs from all other methods.

The UkrNIIGiM Institute (I.V.Ostapchuk) uses moisture dynamics in representative points (one point per 500-1,000 ha) as the basis for information-advisory systems. Accuracy of such estimation is very low in our conditions.

I.S.Shatilov, A.F.Chudnovskiy [1] recommend another indicator – relative moisture content.

$$n = \frac{(E_t + U) + C_b + F}{\sum \theta + Oc + F} \qquad (1.24)$$

where

$E_t + U$ - evapotranspiration;

C_b – surface outflow;

F - infiltration;

θ - deposit of moisture in the soil;

O_c - rainfall.

This is the ratio of the sum of evapotranspiration plus surface outflow and infiltration to rainfall, infiltration, and initial moisture content.

Tooming [19] proposes to use the following indicator as a criterion of water availability

$$\beta = \frac{E_t + U}{E_0} \tag{1.25}$$

where E_o – reference evapotranspiration.

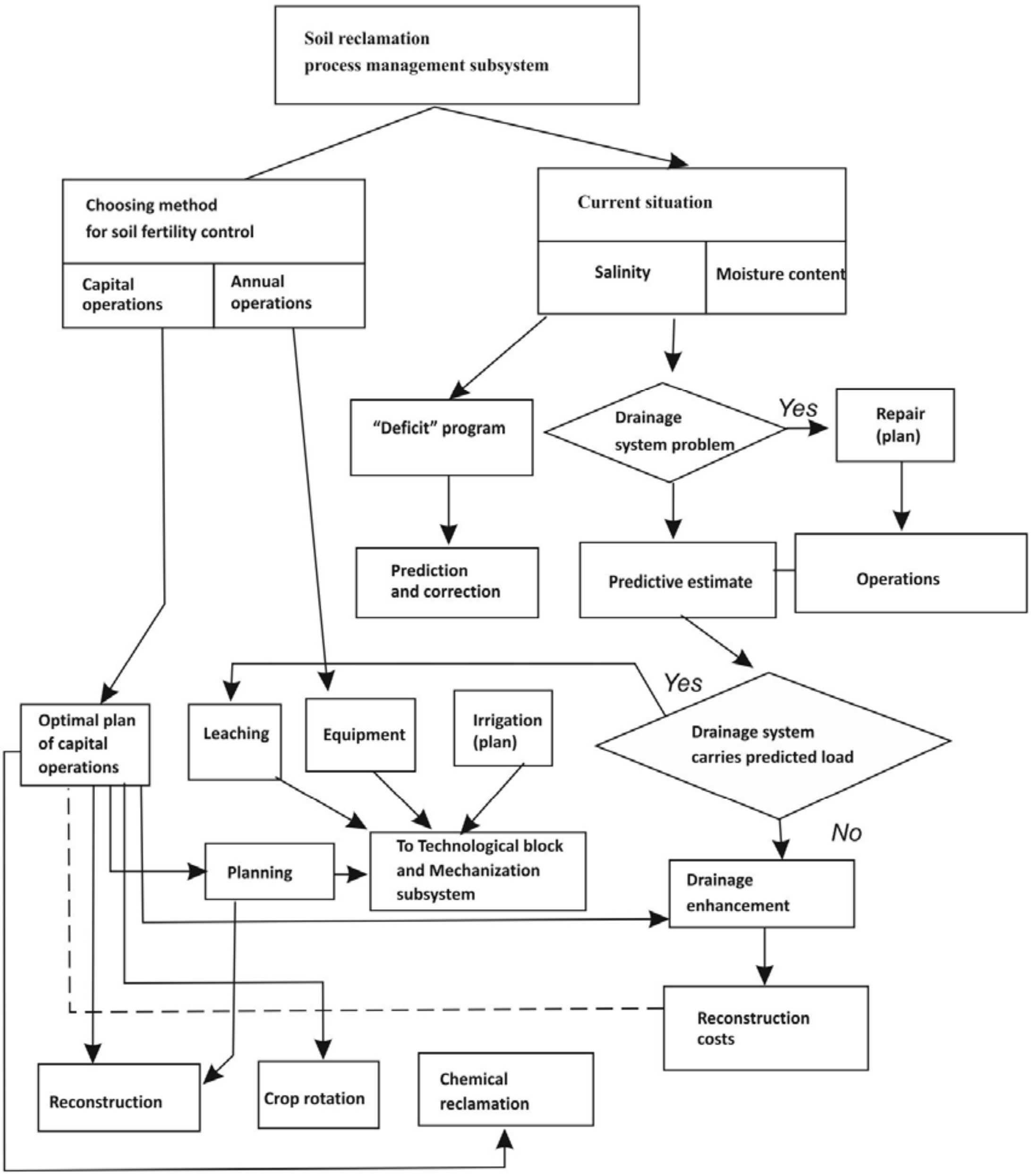


Figure 1.9. "Soil reclamation process management" subsystem

Evaporation capacity is the highest possible evaporation, while we are interested in ensuring required water nutrition at minimum water inputs through optimization of soil water regime. We demonstrated [6] that groundwater evaporation requirement for optimal soil water regime equaled approximately 0.65 E_o. Therefore, if one considers stability of moisture availability, it would be more correct to estimate it from the deficit of effective moisture in the aggregated balance of moisture availability during each development phase.

$$D \Big|_{\tau_1}^{\tau_2} = (\theta - \theta_{b3})_z \Big|_0^{\delta} + (E_t + U)_2 + O_c(1-\alpha) + O_p \eta_{mn} - (E_t + U) \qquad (1.26)$$

where

θ - initial moisture varying within θ_{mn} - θ_{b3};

θ_{mn} and θ_{b3} – field capacity and wilting point, respectively;

$(E_t + U)_2$ - evaporation from groundwater;

O_c – rainfall;

$(1 - \alpha)$ – their effective part;

O_p – irrigation water;

η_{mn} – irrigation technique efficiency.

Then, the coefficient of water availability is

$$n = 1 - \frac{\sum_{f=0}^{F} \sum_{t_{n\pm1}}^{t_n} D_{tf}}{\sum_{f=0}^{F} \sum_{t_{n-1}}^{t_n} (E_T + U)} \qquad (1.27)$$

where

f - area of single plot;

t_{n-1} - t_n - period of time, when moisture demand is maximum.

The point is that for us of importance is availability of water for the whole area during certain period of time. An overall estimate of moisture deficit may smooth over acute deficit points for plant development though exactly these points strongly affect yields. The program developed according to our algorithm for the "moisture deficit" block helps to determine short-term irrigation regime and, simultaneously, estimates deficit that occurs at any time of the growing season.

By using this program, one may calculate plan for water applications in the farm after calculation of irrigation regime. Predicted and current water balance is used for calculation of salt accumulation and leaching requirements. Other output from this part of the subsystem is improvement of drainage and optimization of repair and operation. Accordingly, irrigation schedule sets requirements for "Technological block".

Without entering into other supportive subsystems, let us consider the main points in the "Planning and economics" subsystem.

Profitability of one hectare in the farm (or its unit) can be estimated in general as

$$\overline{D}_j = \Pr ice_j \cdot RY \pm (\overline{Z}_j^c + \overline{Z}_j^d + \overline{Z}_j^0) \tag{1.28}$$

where

D_j – profitability from crop *j*,

$\overline{Z_j^c}$ and $\overline{Z_j^d}$ – constant (independent of fertility factors – transition from PY to DVY and from DVY to YH) and variable costs of yield production, respectively;

$\overline{Z_j^0}$ – unscheduled costs related to increased quantity of work, including elimination of programmed yield lags.

Thus, the cost per unit will be

$$CC_j = \frac{\overline{Z}_j^c + \overline{Z}_j^d + \overline{Z}_j^0}{RY} \tag{1.29}$$

or

$$D_j = (\Pr ice_j - CC_j) \cdot RY \tag{1.30}$$

Removal of factors preventing DVY from approaching to PY should increase resulting RY and, at the same time, reduce variable costs, although these costs can be higher in some periods of time.

Consequently, it seems real to estimate probable changes in profitability of programmed yield.

$$\Delta D_j = \lfloor \Pr ice_j - (CC_j - \Delta CC_j) \rfloor (RY + \Delta RY) - (\Pr ice_j - CC_j)\, RY =$$
$$= (\Pr ice_j - CC_j)\, \Delta RY + \Delta CC_j\, (RY + \Delta RY)\,, \tag{1.31}$$

where

ΔCC_j – change in cost per unit yield;

ΔRY – change in actual yield.

It is easy to show that

$$\Delta CC_j = \frac{\overline{Z}_j^c + \overline{Z}_j^d + \overline{Z}_j^0}{RY} - \frac{\overline{Z}_j^c + (\overline{Z}_j^d \pm \Delta Z_j) + \overline{Z}_j^0}{RY + \Delta RY} =$$

$$= \frac{\overline{Z}_j^c \cdot \Delta RY + \overline{Z}_j^d \cdot \Delta RY \pm \overline{Z}_j^d \, RY + \overline{Z}_j^0 \Delta RY}{(RY + \Delta RY)\, RY} \quad ; \tag{1.32}$$

$$\Delta D_j = \Pr ice_j \, \Delta RY \pm \Delta \overline{Z}_j^d + \overline{Z}_j^0 - \frac{2\,(\overline{Z}_j^c + \overline{Z}_j^d + \overline{Z}_j^0)}{RY} \cdot \Delta RY \tag{1.33}$$

Thus, programming assumes economic context and approaches an indicator of effectiveness of agricultural production.

Hence, we have the following tasks for given subsystem:

- evaluation of gross production in every field and underproduction when affected by factors of fertility deterioration;
- possible improvement of land productivity by each factor, its monetary evaluation and effectiveness;
- distribution of costs among technological process items, depending on area and harvest, and among additional work items to remove factors that reduce productivity, such as weeding, salinity, ground non-uniformity;
- assessment of an impact of provision with staff, equipment, machines, fertilizers, and capital assets on final product – crop yield.

Solution of the above mentioned tasks will help to determine more accurately the relation between reduction of the gap between RY and PY and the increase of land productivity, on the one hand, and the decrease of costs, on the other hand, and estimate optimal inputs to avoid yield reduction due to organizational reasons.

Systematic accounting of all cost items allows having the “Planning and economics” subsystem, which identifies all relations between production cost and productivity improvement from RY to PY.

1.5. Determining Factors Affecting Crop Yield

Proceeding from the above mentioned, it is easy to establish a relationship between factors that reduce yield from PY to RY:

$$\frac{DVY}{PY} = 1 - (a_1\ K_{sor} \cdot a_2\ K_c \cdot a_3\ K_N \cdot a_4\ K_P \cdot a_5\ K_K \cdot a_6\ K_F) \quad ; \qquad (1.34)$$

$$\frac{YH}{DVY} = \left[1 - \left(\frac{D}{E_T + U} \right)^{\lambda} \right] \quad ; \qquad (1.35)$$

$$\frac{YH}{DVY} = (a_7\ \Lambda_t + a_8\ P_t + a_9\ T_p)\ S_{\Lambda} \quad , \qquad (1.36)$$

where

$a_1, a_2, a_3, a_4, a_5, a_6$ – matrix coefficients reflecting influence of weeding, salinity, *NPK* content, and land uniformity (all factors expressed in unit fractions in form of decreasing functions);

D – deficit of cumulative moisture;

λ - crop coefficient;

a_7, a_8, a_9 – matric coefficients of provision with personnel, mechanisms, and transport, respectively;

and Λ_t ; P_t ; T_p – provision (in unit fractions) with personnel, mechanisms, and transport, respectively.

Hence, it follows that

$$RY = YH\ (a_7\ \Lambda_t + a_8\ P_t + a_9 T_P)\ S_{\lambda} \quad ; \qquad (1.37)$$

$$YH = DVY \left[1 - \left(\frac{D}{E_T + U} \right)^{\lambda} \right] \quad ; \qquad (1.38)$$

$$DVY = PY\left[1-(a_1\,K_{sor}\cdot a_2\,K_c\cdot a_3\,K_N\cdot a_4\,K_P\cdot a_5\,K_K\cdot a_6\,K_F)\right] \quad (1.39)$$

when

$$\Lambda_t = 1\,;\, P_t = 1\,;\, P_T = 1$$

$$RY = S_\Lambda\,y_h$$

where

S_Λ - factor of subjective management.

By using these relationships, we will have

$$RY = PY\left[1-(a_1\,K_{sor}\cdot a_2\,K_c\cdot a_3\,K_N\cdot a_4\,K_P\cdot a_5\,K_K\cdot a_6\,K_F)\right]\,x \quad (1.40)$$

$$x\;\left[1-\left(\frac{D}{E_T+U}\right)^{\lambda}\right]\cdot(a_7\,\Lambda_t + a_8\,P_t + a_9\,T_P)$$

While knowing for each field the values of the above factors, we can determine impact of these factors on yield reduction by multiple regression method using the matrix coefficients.

Analysis of productivity levels carried out in different farms in the Fergana Valley using the data from the IWRM-Fergana Project (Nerozin S.A., Methodological approaches to assessment of irrigated land productivity with the purpose of more efficient usage of such land: IWRM-Fergana case-study, 2010) can serve as an example.

One should bear in mind that total revenues in agricultural cluster, with account of processing, taxes, and various earnings, are much higher that direct benefits from produced crop. Based on data of the AFMAS Project, which studied the value chain of irrigated agriculture, Figure 1.11 shows that given the average return from cotton of 1849 $/ha in this rayon, the total revenue with account of processing, textile production, taxes and fees increases as much as 20 times. That is why irrigated agriculture is a strong driver of human wellbeing, economic development and employment.

Analysis of shortfalls in crop production allows focusing on those aspects in controllable agro-technological and agro-physical processes that can be corrected by management mechanisms in order to generate higher yield and economic productivity.

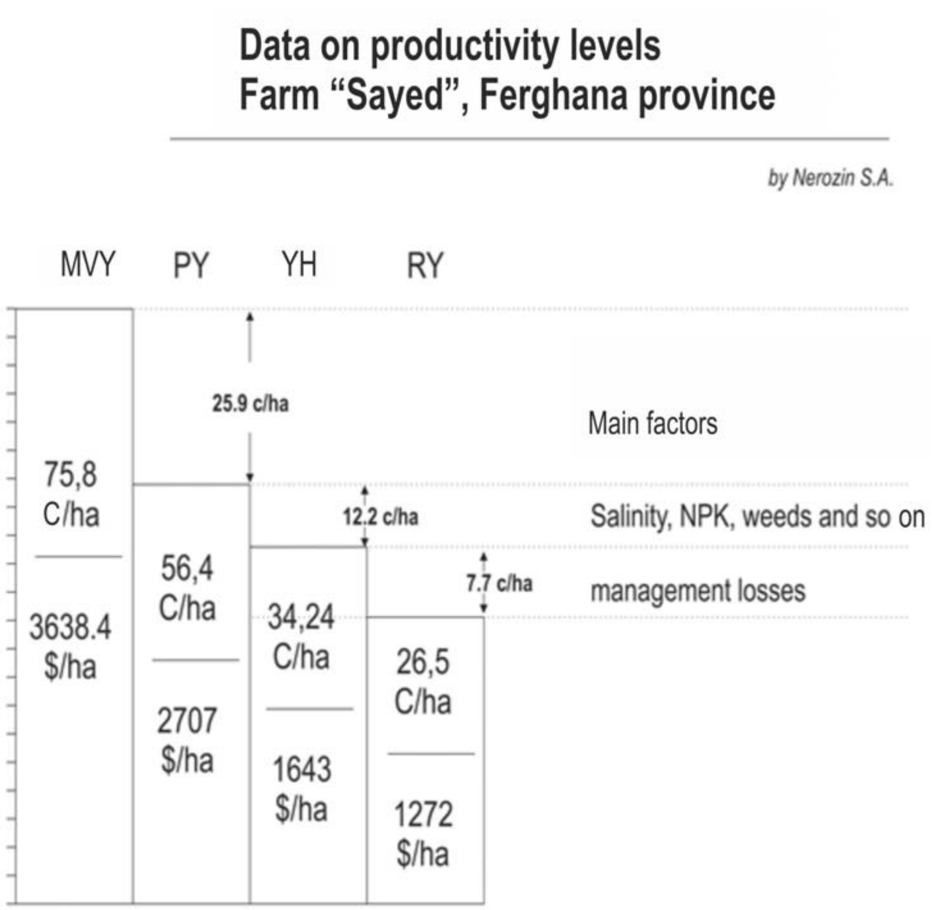


Figure1.10. Difference between levels of productivity vis a vis expenses for reduction of losses

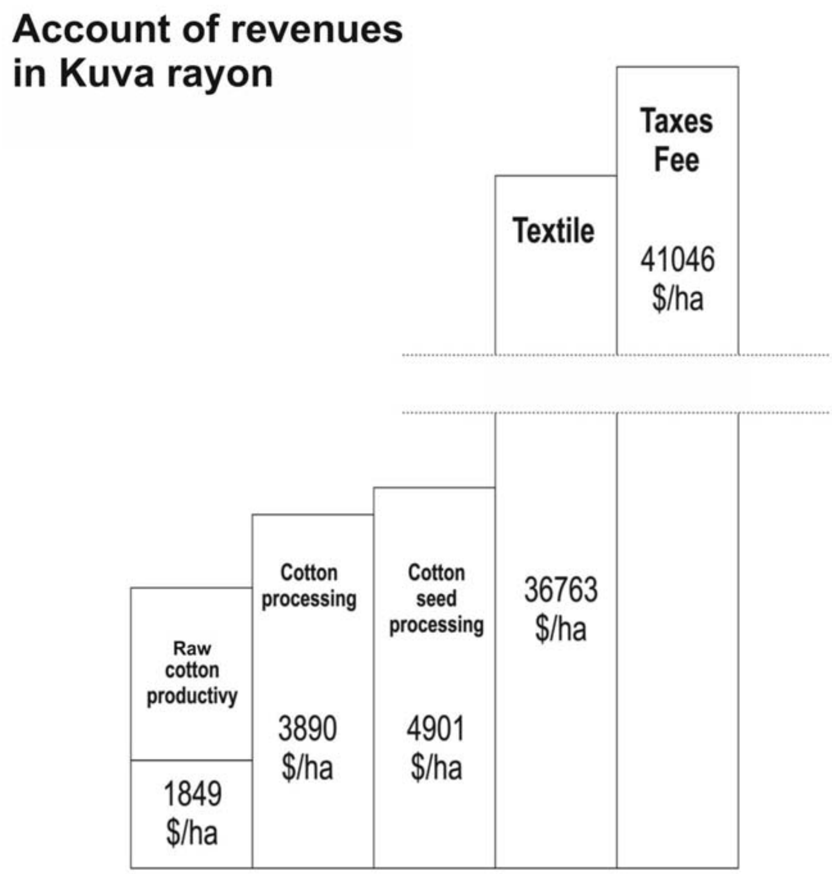


Figure1.11. Direct and non-direct benefits

1.6. Developing and Applying Yield Programming in Agricultural Production (Experience and Lessons Learnt)

The YP method is distinguished by accounting of special characteristics of each specific field and differentiation of agronomic operations depending on weather conditions. This is the major difference between YP and conventional technology, which is designed usually for “average” field and average long-term agrometeorological conditions.

As part of work on this problem, the SANIIRI Institute proposed a prototype of field passport containing agronomical documentation for particular plots and specific reference data, norms and recommendations, which are necessary for arranging scientifically sound measures for crop production in particular field. The agro-reclamation passport can be used during a 10-year period for recording actual characteristics of given plot and particular observations for the purposes of unbiased analysis of plot conditions and agricultural production dynamics and for improvement of cotton growing technology. The field passport contains information on plot layout, physical conditions of collector-drainage network (CDN), soil map, maps of humus, phosphorus, and potassium contents, data on salinity and weeding of the field, plant diseases and pest infestation, actual water delivery, groundwater level, information for assessment of cost-effectiveness of agricultural production, and data on crop yields.

The knowledge of the basic soil-reclamation characteristics of particular plot helps the farmer to apply appropriate quantities of fertilizers, improve cropping patterns, schedule effectively irrigation and leaching of salinized land, choose best dates for soil treatment, use efficiently agricultural machines and equipment, and, finally, improve crop yields. Passportization costs approximately 1.5 $/ha, whereas its annual economic effect is 80-140 $/ha. The SANIIRI Institute has covered with passportization 23 thousand hectares on contractual basis. The method guidelines on soil-reclamation passportization of fields were developed. A computer-based version of the field passport was developed as well.

For large-scale application of this new method, a computing center on the basis of computers of that period was organized in the G.Gulyam state farm “1a” located in Il’ichevsk district, Syrdarya province. In addition, a range of tasks under the Technological block was solved and relevant software was installed and started to be used by cotton-growing teams (on an area of 2,000 ha) in this state farm. These included the “Resource limit card” and the “Mechanized direct cost accounting” per team.

Adoption of the resource limit cards, cheque system, and mechanized direct cost accounting enabled the farm to arrange accurate and open accounting and control of the use of funds, reduce 5 positions in staff, avoid distortions in consumption of materials, and decrease by 16% direct costs of agricultural production.

Moreover, a simplified method was developed for generation of «field individual operations sequence chart» coupled with already applied in the farm the short-term water use prediction software.

The algorithm developed at the SANIIRI Institute determined the total moisture stock for plants, taking into account all elements in water balance. Calculation and prediction of water use (PROGWAT software) were organized in the following sequence:

1) for early growing season, initial moisture is determined for each layer from aeration zone to water table;
2) the total moisture deficit is calculated for particular time slot (ten-day);
3) predicted moisture deficit for ten-days is calculated;
4) beginning date of irrigation, irrigation norm and irrigation requirements are determined.

All planned work in this direction was not finished because of termination of research programs at the State Committee for Science and Technology and the Ministry of Water Resources in the former Soviet Union. However, at present, with rapid development of information technologies and wider application of computation tools and given the future need for searching optimal conditions for yield generation at minimum water inputs and finding the most efficient combination "costs-net profit", establishment of comprehensive focused programs for agricultural risk management in sync with those past developments in yield forecasting that were made 25-30 years ago would be ever more important. Even now G.V. Stulina and G.F. Solodkiy from SIC ICWC have developed the water requirements planning program – REQWAT – which calculates irrigation water requirements and corrects them, depending on the current climatic and water situations. Progressive installation of weather stations in sites of water-management organizations and WUAs will boost this work through better availability of actual local data as is the case in Italy, Spain, USA and other countries all over the world.

A.G. Sorokin and T.V. Kadirov from SIC ICWC have developed a program, which optimized cropping patterns, with account of the future water-related, socio-economic and food supply conditions. Hence, we believe that the past research and developments should not be undervalued and should be adapted to current realities of agriculture and its challenges.

2. Cotton Productivity Assessment Algorithm

2.1. Methodology and Example of Computation of the Highest Possible Yield (MVY) for Cotton

The highest possible cotton yield (MVY) computation methodology was described in Chapter 1 (formula 1.2), where we used A.A.Nichiporovich's formula and added to it the coefficient for conversion from phytomass to yield.

MVY for known PAR (52 kcal/cm^2) per 1 hectare of cotton area is computed as follows:

$$MVY = \frac{52 \cdot 10^8 \cdot 3.5 \cdot 0.20}{4.8 \cdot 10^5 \cdot 10^2} = 75.8$$ centner/ha

where:

$52 \cdot 10^8$ – influx of PAR per 1 ha of area (or per 100,000,000 cm^2) during growing season, kcal/ha;

3.5 % - photosynthetic efficiency;

0.20 - coefficient of conversion from phytomass to yield;

$4.8 \cdot 10^5$ - yield caloricity per centner, kcal/centner.

(Cotton yield caloricity is 4,800 kcal/kg; coefficient of conversion from phytomass to yield is 0.20; photosynthetic efficiency is 3.5).

The recommended photosynthetic efficiency for cotton computations is 3.5.

Monthly sums of PAR were computed for 44 locations in CIS, based on direct and diffused radiation observations collected by a network of actinometric stations.

We selected data on PAR from the stations located in Uzbekistan. Table 2.1 shows the average indicators for PAR.

Table 2.1

Values of photosynthetically active radiation (kcal/cm^2) in Uzbekistan

Commonalities	Months												Period	
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	>5º	>10º
Transient	1.0	3.3	5.0	6.7	8.9	8.9	8.9	7.8	6.0	4.3	2.3	1.8	48.1	43.2
Thermal	2.4	3.3	4.8	6.6	8.2	8.9	9.1	8.2	6.5	4.6	2.7	2.0	57.3	52.0
Subtropical	2.8	3.7	5.3	6.8	8.8	9.3	9.3	8.8	6.6	5.3	3.3	2.5	66.0	54.0

2.2 Methodology and Example of Computation of the Potential Yield (PY) for Cotton under Climatic Conditions of Given Year

The potential cotton yield (PY) computation methodology was described in Chapter 1 (formula 1.5), where we used A.A.Nichiporovich's formula and added to it the coefficient for conversion from phytomass to yield.

To compute a **potential yield** for particular area, the following formula is used:

$$PY = MVY \cdot K_b \tag{2.1}$$

where

K_b – coefficient of soil bonitet, which is computed for particular area using the formula: $K_b = K_{ocn} \cdot K_{gum}$, where K_{ocn} – main bonitet score, which takes into account type of soil formation, thickness of fine grained soil, granulometric composition and automorphy of soil. K_{ocn} is chosen from the soil bonitet scale (Table 2.2). K_{gum} is the reduction coefficient for humus content in the soil (Table 2.3).

Table 2.2

Irrigated soil bonitet scale in the cotton growing area

Thickness of fine-grained layer, cm	**Desert zone**						**Sierozem belt**					
	Granulometric composition, K_{ocn}						**Granulometric composition, K_{ocn}**					
	sand	**loamy sand**	**light loam**	**medium loam**	**heavy loam**	**clay**	**sand**	**loamy sand**	**light loam**	**mediu m loam**	**heavy loam**	**clay**
Automorphic soil												
< 30	0.10	0.20	0.30	0.35	0.40	0.40	-	-	0.20	0.30	0.35	0.35
31-50	0.25	0.30	0.40	0.45	0.50	0.60	-	-	0.40	0.45	0.55	0.60
51-70	0.45	0.50	0.55	0.60	0.65	0.70	-	-	0.55	0.65	0.75	0.70
71-100	0.50	0.70	0.85	0.80	0.75	0.75	-	-	0.80	0.90	0.85	0.75
> 100	0.70	0.90	1.00	0.95	0.85	0.70	-	-	0.90	1.00	0.90	0.80
Hydromorphic soil												
< 30	0.20	0.25	0.30	0.35	0.40	0.40	0.20	0.25	0.35	0.40	0.35	0.30
31-50	0.35	0.40	0.50	0.55	0.60	0.50	0.30	0.40	0.50	0.50	0.55	0.60
51-70	0.60	0.70	0.80	0.70	0.65	0.60	0.40	0.60	0.70	0.75	0.70	0.65
71-100	0.80	0.90	0.95	0.80	0.75	0.65	0.50	0.70	0.80	0.90	0.80	0.60
> 100	0.85	1.00	1.00	0.90	0.80	0.60	0.50	0.85	0.90	1.00	0.85	0.60

Table 2.3

Values of the reduction coefficient for humus content (K_{gum})

Humus content, t/ha	K_{gum}
< 30	0.60
30-45	0.65
46-65	0.70
66-85	0.80
> 85	1.00

The reduction coefficient for humus content (K_{gum}) was computed as the average for soil phase in t/ha:

a) the arithmetic average of humus content (%) is computed by point of soil sampling in layers 0-30 cm and 30-50 cm:

$$A_1 = \frac{a_1 + a_2 + a_3 + ...a_P}{P} \quad (2.2)$$

a_1, a_2, a_P - humus content (%) in 0-30 cm layer;

P - number of soil sampling points.

Similar calculation is made for 30-50 cm layer (A_2)

b) humus content in % is converted into t/ha:

$$B_{1,2} = \frac{A_{1,2} \cdot d_{1.2} \cdot h_{1.2} \cdot 10000}{100} \quad (2.3)$$

$A_{1,2}$ - arithmetic average of humus content in 0-30 cm and 30-50 cm

$h_{1,2}$ - thickness of layer (m), i.e. for layers 0-30 cm and 30-50 cm;

$d_{1,2}$ - bulk density in layers 0-30 cm and 30-50 cm;

h_1 = 0.3 m for 0-30 cm layer;

h_2 = 0.2 m for 30-50 cm layer.

c) total humus content in the 0-50 cm layer is determined by summing up B_1 and B_2

$$B = B_1 + B_2,$$

where

B_1 and B_2 are humus contents (t/ha) in layers 0-30 cm and 30-50 cm, respectively.

The coefficient of soil bonitet for project area or particular field (K_b) from PY formula is determined as the weighted average of the coefficients of soil phase bonitet using the following expression:

$$K_b = \frac{K_{b1} \cdot S_1 \cdot K_{b2} \cdot S_2 + ... + K_{bP}}{S_{field}} \tag{2.4}$$

S_{field} - field area, ha;

$K_{b1,2}$ - data for one soil phase;

$S_{1,2}$ - area of soil phase.

Table 2.4

Example of potential cotton yield (PY) computation
(G. Gulyam farm, Syrdarya province, Republic of Uzbekistan)

MVY centner/ha	K_{ocn}						K_{gum}				losses for K_b centner/ha	PY centner/ha
	soil type	texture	Automorph	thickness of fine grain soil	K_{ocn}	losses for K_{ocn} centner/ha	%	humus, t/ha	Red. coef	losses for K_{gum} centner/ha		
75.6	sierozem	light loam	semi-automorph	> 100	0.90	7.0	0.50	31.1	0.65	24.3	31.3	44.3

2.3. Methodology and Example of Computation of the Actual-Possible Yield (DVY) for Cotton under climatic Conditions of given Year

The next level of yield, DVY - the actual-possible yield under conditions of given climatic year $\left(\frac{\sum Q_n}{\sum Q_{PAR}}\right)$ - depends on controllable factors and is computed by formula:

$$DVY = PY \cdot K_c \cdot K_{sor} \cdot K_{NPK} \cdot K_{bol} \cdot K_{vr} \cdot K_f \cdot \frac{\sum Q_n}{\sum Q_{PAR}} \quad (2.5)$$

where

PY – potential yield, center/ha;

K_c - coefficient of salinity influence on yield;

K_{sor} - coefficient of weeding influence on yield;

K_{NPK} - coefficient of nitrogen, phosphorus and potassium availability influence on yield;

K_{bol} - coefficient of crop disease influence on yield;

K_{vr} - coefficient of pest infestation influence on yield;

K_f - coefficient of land uniformity (leveling) influence on yield;

$\sum Q_n$ - total actual photoactive radiation PAR for given year;

$\sum Q_{PAR}$ - total mean long-term PAR.

K_c is determined from Tables 2.5, 2.6 and 2.7.

Table 2.5

Reduction coefficient for salinity, %
(no field leaching)

Degree of contour salinity	Type of salinity			
	sulphate	sulphate-chloride	chloride - sulphate	chloride
Non-saline	1.00	1.00	1.00	1.00
Slightly saline	0.97	0.95	0.94	0.92
Moderately saline	0.83	0.82	0.77	0.70
Highly saline	0.63	0.57	0.51	0.45
Very highly saline	0.45	0.49	0.40	0.30

Table 2.6

Reduction coefficient for salinity, %
(field leaching with optimal leaching norms against the background of operational drainage)

Degree of contour salinity	Type of salinity			
	sulphate	sulphate-chloride	chloride - sulphate	chloride
Non-saline	1.00	1.00	1.00	1.00
Slightly saline	1.00	1.00	1.00	0.99
Moderately saline	0.99	0.96	0.95	0.94
Highly saline	0.97	0.94	0.92	0.90
Very highly saline	0.95	0.93	0.90	0.88

Table 2.7

Reduction coefficient for salinity, % (field leaching with rough norms against the background of poor operating drainage)

Degree of contour salinity	Type of salinity			
	sulphate	sulphate-chloride	chloride - sulphate	chloride
Non-saline	1.00	1.00	1.00	1.00
Slightly saline	0.98	0.96	0.95	0.92
Moderately saline	0.97	0.94	0.90	0.86
Highly saline	0.94	0.90	0.87	0.80
Very highly saline	0.90	0.87	0.85	0.77

Residual toxic effect of salts in the soil and also conditions of water and salt transport during growing season are taken into account in the coefficients shown in Tables 2.6 and 2.7.

K_{sor} is determined by Tables 2.8 and 2.9.

Table 2.8

Reduction coefficients for weeding, %
(no weed control)

Group of weeds	Degree of weeding, %		
	poor	moderate	heavy
Annual and biennial monocotyledonous	0.96	0.92	0.83
Annual dicotyledonous	0.95	0.90	0.80
Perennial rhizome plants	0.92	0.83	0.65

Table 2.9

Reduction coefficients for weeding, %
(weed control following recommendations provided in individual operations sequence chart for given field)

Group of weeds	Degree of weeding, %		
	poor	moderate	heavy
Annual and biennial monocotyledonous	1.00	0.98	0.96
Annual dicotyledonous	1.00	0.97	0.95
Perennial rhizome plants	0.98	0.96	0.93

The above coefficients help to estimate losses by contour, then sum up losses for the whole field, and dividing them by field hectares gives average losses per hectare.

K_N is taken from Table 2.10.

Table 2.10

Reduction coefficient for initial nitrogen content in the soil (N-NH_3), %

Availability	Content of N-NH_3 in the soil, mg/kg	Reduction coefficient, %
Very low	< 20	0.80
Low	20-30	0.90
Average	30-50	0.98
Increased	50-60	1.00
High	> 60	1.00

Table 2.11

Reduction coefficient for initial phosphorus content in the soil (P_2O_5), %

Availability	Content of P_2O_5 in the soil, mg/kg	Reduction coefficient, %
Very low	< 15	0.85
Low	16-30	0.93
Average	31-45	0.97
Increased	46-60	1.00
High	> 60	1.00

Information about *P* availability is given in input data by field's contour in the "nutrient map".

The above coefficients are used if the soil was not prepared in autumn to achieve the average *P* content, with application of phosphorus according to individual operations sequence chart. If phosphorus content is at average level, the reduction coefficient K_P will equal 1 in all cases.

Table 2.12

Reduction coefficient for initial potassium content in the soil (K_2O), %

Availability	Content of K_2O in the soil, mg/kg	Reduction coefficient, %
Very low	< 100	0.93
Low	101-200	0.97
Average	201-300	0.98
Increased	302-400	1.00
High	> 400	1.00

Information about *K* availability is given in input data by field's contour in the "nutrient map".

The above coefficients are used if the soil was not prepared in autumn to achieve the average *K* content. If potassium content is at average level, the reduction coefficient K_K will equal 1 in all cases.

K_{bol} is determined from Table 2.13.

Table 2.13

Reduction coefficient for cotton diseases, %

Disease	Disease rate, %		
	low	moderate	heavy
Wilt	0.87	0.65	0.40
Gummosis	0.95	0.83	0.68
Root rot	0.98	0.85	0.75

In DVY forecasts, K_{bol} is taken equal to 1 provided that preventive measures for disease control are undertaken.

K_{vr} is determined from Table 2.14.

Table 2.14

Reduction coefficient for cotton pests, %

Pests	Infestation rate, %		
	low	moderate	heavy
Spider mite	0.96	0.88	0.77
Aphid	0.97	0.92	0.85
Cotton moth	0.95	0.85	0.75
Cutworm moth	0.95	0.85	0.78

In DVY forecasts, if preventive measures for pest control are taken, K_{vr} is taken equal 0.98.

K_f is determined from Table 2.15.

Table 2.15

Reduction coefficient for level uniformity, %
(field leveling)

Land uniformity	Deviation from '0' ground level, cm	Reduction coefficient, %
High (optimal)	0	1.00
Good	± 3 - ± 5	0.99
Average	± 5 - ± 10	0.95
Poor	± 10 - ± 15	0.88
Very poor	± 15 - ± 25	0.80

Finally, DVY is computed by formula 2.5.

Table 2.16

Example of the actual-possible cotton yield (DVY) computation

PY centner/ha	K_c (salinity)			K_{sor} (weeds)		K_N (nitrogen)		K_P (phosphorus)	
	salinity type	degree of salin	Red coef	weeding	Red coef	Availa bi lity	Red coef	Availa bi lity	Red coef
44.3	sulpha-te	slightly	1.0	poor	0.98	high	1.0	avera-ge	0.98

K_K (potassium)		K_{bol} (diseases)		K_{vr} (pests)		K_f (leveling)		$\frac{\sum Q_n}{\sum Q_{PAR}}$	DVY centner/ha
availa bility	Red coef	diseas e rate	Red coef	infesta tion	Red coef	relief	Red coef		
high	1.0	low	0.99	low	0.95	good	1.0	1.0	40.2

Thus, DVY losses expressed in center/ha have a form of factor-based reduction of productivity:

$$DVY = 44.3 - (0.0 + 0.80 + 0.0 + 0.80 + 0.0 + 0.40 + 2.01 + 0.0 + 0.0) =$$
$$= 40.2 \text{ centner/ha}$$

$$DVY = 44.3 - 4.01 = 40.2 \text{ centner/ha}$$

where

PY = 44.3 centner/ha,

yield losses = 4.01 centner/ha.

2.4. Methodology and Example of Computation of the Actual Cotton Yield of a Farm (YH) under Climatic Conditions of Given Year

The basic expression for the actual yield (YH) is as follows

$$YH = Y_{DVY} \cdot P_1 \cdot P_2 \ldots P_i \tag{2.6}$$

where

YH – is predicted (design) yield for a plot;

Y_{DVY} – actual-possible yield in the plot computed using the methodology in section 2.3;

P_i – reduction coefficient characterizing an impact of factor X on productivity;

$P_i = f(X_i)$ is considered as a function of X_i, $i = 1, 2 \ldots, \ell$.

Proceeding from this expression, we consider a problem of yield forecast based on indicators characterizing the agricultural production. This problem is solved using the following formula:

$$YH = Y_{DVY} \cdot f(X_1) \cdot f(X_2) \ldots f(X_i) \tag{2.7}$$

where:

X_1 – provision with labor resources;

X_2 – provision with equipment and transport;

X_3 – quality of technological operations and efforts;

X_4 – quality of seeds, provision with chemicals and fertilizers;

X_5 – provision with water.

Table 2.17

Example of the actual farm cotton yield (YH) computation

DVY centner/ha	P_1 manual labor		P_2 mechanized labor		P_3 efforts		P_4 fertilizers, chemicals, fuel	
	availability	red coef	availability	red coef	availability	red coef	availability	red coef
41.1	normal	0.98	normal	0.96	normal	0.98	low	0.94

P_5 water		RY centner/ha
availability	red coef	
normal	1.0	34.8

$$YH = DVY - (0.8 + 1.5 + 0.8 + 2.3 + 0) = 34.8 \text{ centner/ha}$$

$$YH = 40.2 - 5.4 = 34.8 \text{ centner/ha}$$

2.5. Cotton Irrigation Regime and Yield Losses Depending on Water Availability During Growing Season

One of the main factors of irrigated land productivity is water availability for crops during the growing season. If water availability falls below the optimal level, yields of almost all crops decrease.

In case of optimal water availability for irrigated crops, the reduction coefficient for water factor is not applied as a priori it equals 1. Water regime should be optimized and controlled based on recommendations of a water duty zoning (the so called “hydromodule zoning”) and crop irrigation schedule (G.V. Stulina, 2010).

Table 2.18

Cotton irrigation schedule for VI hydromodule zone

Crop	Irrigation norm, m³/ha	No. of irrigation event	Irrigation depth, m³/ha	Irrigation dates		Irrigation interval, days
				beginning	end	
Cotton	5,100	1	1,300	28.5.09	26.6.09	30
		2	1,300	27.6.09	20.7.09	24
		3	1,300	21.7.09	15.8.09	26
		4	1,200	16.8.09	5.9.09	21

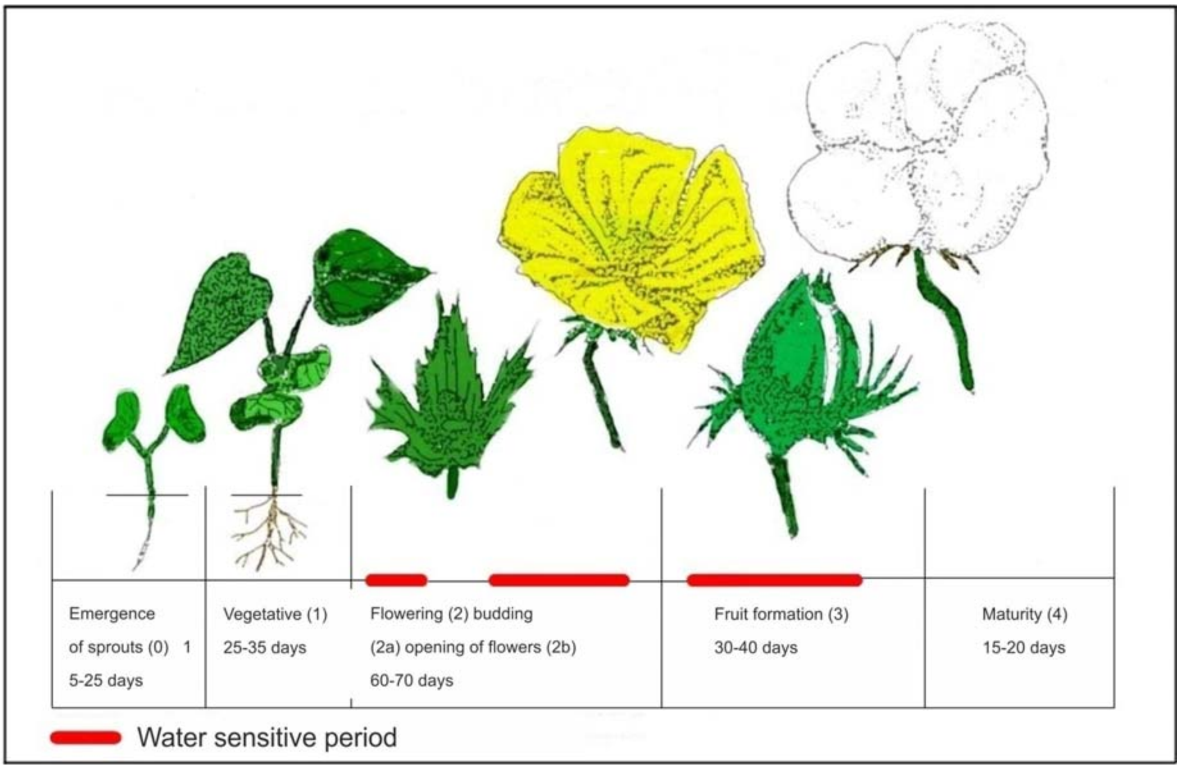


Figure 2.1. Cotton development stages

Table 2.19

Number and distribution of irrigation events and irrigation norms for cotton

Type of soil and groundwater depth	Number of irrigatio n events	Distribution of irrigation events			Irrigation norm (m3/ha)
		before flowering	flowering and fruit formation	maturing	
Thin soil with closely bedded pebbles and sand and deep groundwater	8-12	2-3	4-6	2-3	6,000-8,400
Sierozem with groundwater bedded at 3-4 m and deeper	5-9	1-2	3-5	1-2	5,200-7,800
Sierozem-meadow soil - with groundwater bedded at 2-3 m	4-7	1-2	3-4	0-1	4,200-6,500
Meadow soil with groundwater bedded at 1-2 m	3-5	1	2-4	0	3,000-5,000
Meadow-boggy soil with groundwater bedded at a depth less than 1 m	2-3	0	2-3	0	2,000-3,200

Based on CROPWAT computations, Table 2.20 shows the average values of probable yield losses, depending on water availability for cotton during its development phases and the growing season in general [22].

Table 2.20

Yield losses during the growing season and by development phase depending on water supply to cotton (with orientation to optimal supply) [22]

Water supply, %	Fractional yield losses				
	Growing season	1	2	3	4
90	0.10	0.02	0.02	0.03	0.02
80	0.16	0.04	0.05	0.05	0.04
70	0.23	0.05	0.06	0.07	0.05
60	0.29	0.07	0.08	0.09	0.06
50	0.35	0.08	0.09	0.11	0.08

Note: 1 – sowing – sprouting; 2 – sprouting - budding; 3 – budding - flowering; 4 – flowering - maturing.

Using the data from Table 2.20, one may chose the most appropriate time of cotton growing when irrigation norms can be reduced, while resulting in minimum yield losses.

3. Winter Wheat Productivity Assessment Algorithm

According to Voskresenskaya N.P. (1965), Ross U.K. (1975), and Tooming H.T. (1977), plant productivity is linked with radiation regime via the photosynthetically active radiation (PAR).

PAR designates the spectral range of solar radiation from 0.38 to 0.71 μm that can be used in the process of photosynthesis and, as a result, organic matter constituting ≈ 95% of dry biomass is formed. The photoactive radiation is taken into account in the yield programming theory and serves as the main indicator for computation of the highest possible yield in Nichiporovich's formula.

3.1. Methodology and Example of Computation of the Highest Possible Yield (MVY) for Winter Wheat

For computation of winter wheat MVY we used the Nichiporovich's formula (see Chapter 1, formula 1.2) added by a factor for conversion from phytomass to yield:

where:

$\sum Q_{PAR}$ – total average long-term influx of PAR during growing season, kcal/cm^2;

Q – winter wheat yield caloricity = 4500 kcal/kg;

η_f – photosynthetic efficiency = 2.5 %; (3.1)

K – coefficient of conversion from phytomass to yield = 0.46.

Section 2 (Table 2.1) gives data on monthly photoactive radiation observed in Uzbekistan with reference to climatic commonality. We used these data for computation of total PAR influx during crop growing in order to assess efficiency of PAR in the selected experimental plot.

Values of the coefficient of conversion from winter wheat phytomass to yield are shown in Table 3.1.

Table 3.1

Yield caloricity and coefficients of conversion

Crop	Caloricity, kcal/kg	Coefficient of conversion from phytomass to yield		
		air-dry weight	grain standard moisture regain	grain ovendry weight
Winter wheat	4,500	-	0.46	-

Values of photosynthetic efficiency for different conditions of crops in terms of their productivity are listed in Table 3.2.

Table 3.2

Photosynthetic efficiency

No.	Crop conditions	Efficiency
1	Bad	0.50
2	Usually observed	0.5-1.5
3	Good	1.5-3.0
4	Record-breaking	3.0-6.0
5	Theoretically possible	6.0-8.0

The recommended photosynthetic efficiency to be used in computations for winter wheat is 2.5.

Example of the highest possible winter wheat yield (MVY) computation

Table 3.3

Computed values of the highest possible winter wheat yield

Climatic commonality	K_{PAR}		PAR	Dry matter yield, centner/ha	Grain yield, centner/ha
	class	efficiency, %			
Transient	I	7 (6-8)	44.8	697	324
	II	4.25 (3.5-5)		423	197
	III	2.25 (3-1.5)		224	104
	IV	1.00 (1.5-0.5)		99.6	46.4
	Y	< 0.5		49.8	23.2
normally used		**2.5**		**249**	**116**
Thermal	I	7 (6-8)	45.8	712	331
	II	4.25 (3.5-5)		436	203
	III	2.25 (3-1.5)		229	107
	IV	1.00 (1.5-0.5)		102	47
	Y	< 0.5		50.9	23.7
normally used		**2.5**		**254**	**118**
Subtropical	I	7 (6-8)	49.8	775	360
	II	4.25 (3.5-5)		470	219
	III	2.25 (3-1.5)		249	158
	IV	1.00 (1.5-0.5)		111	52
	Y	< 0.5		53.3	25.7
normally used		**2.5**		**277**	**129**

According to the computed highest possible yield values, MVY for winter wheat is 107 centner/ha in the selected site in Andizhan province (Uzbekistan).

3.2. Methodology and Example of Computation of the Potential Yield (PY) for Winter Wheat under Climatic Conditions of Given Year

PY characterizes a possibility to achieve maximal yield under climatic conditions of given year. To calculate a potential yield, the following formula is used:

$$PY = MVY \cdot K_b \tag{3.4}$$

where

K_b – coefficient of soil bonitet, which is calculated using the formula:

$$K_b = K_{ocn} \cdot K_{gum} \tag{3.5}$$

where

K_{ocn} – main bonitet score, which takes into account type of soil formation, thickness of fine grained soil, granulometric composition and automorphy of soil (see Chapter 2, Table 2.2);

K_{gum} – reduction coefficient for humus content in soil (see Chapter 2, Table 2.3).

The reduction coefficient for humus content (K_{gum}) was computed as the average for soil phase in t/ha (see Chapter 2, formulas 2.2 - 2.4).

Table 3.4

Example of potential winter wheat yield (PY) computation

MVY centner/ha	K_{ocn}						K_{gum}			losses for K_b centner/ha	PY centner/ha
	soil type	texture	Auto morph	thickness of fine grain soil	K_{ocn}	losses for K_{ocn} centner/ha	humus, t/ha	Red. coef	losses for K_{gum} centner/ha		
107.0	sierozem	medium loam	semi automorphic	100	0.89	10.8	41.0	0.65	34.3	45.1	61.9

3.3. Methodology and Example of DVY Computation for Winter Wheat

The next level of yield, DVY - the actual-possible yield under conditions of given climatic year $\left(\frac{\sum Q_n}{\sum Q_{PAR}}\right)$ - depends on controllable factors and is computed by formula:

$$DVY = PY \cdot K_c \cdot K_{sor} \cdot K_{NPK} \cdot K_{bol} \cdot K_{vr} \cdot K_f \cdot \frac{\sum Q_n}{\sum Q_{PAR}} \tag{3.6}$$

where

PY – potential yield, center/ha;

K_c - coefficient of salinity influence on yield;

K_{sor} - coefficient of weeding influence on yield;

K_{NPK} - coefficient of nitrogen, phosphorus and potassium availability influence on yield;

K_{bol} - coefficient of crop disease influence on yield;

K_{vr} - coefficient of pest infestation influence on yield;

K_f - coefficient of land uniformity (leveling) influence on yield;

$\sum Q_n$ - total actual photoactive radiation (PAR) for given year;

$\sum Q_{PAR}$ - total average long-term PAR.

K_c is derived from Tables 3.5, 3.6 and 3.7.

Table 3.5

**Reduction coefficient for salinity, %
(no field leaching)**

Degree of contour salinity	Type of salinity			
	sulphate	sulphate-chloride	chloride - sulphate	chloride
Non-saline	1.00	1.00	1.00	1.00
Slightly saline	0.96	0.94	0.92	0.90
Moderately saline	0.81	0.75	0.71	0.63
Highly saline	0.62	0.56	0.50	0.45
Very highly saline	0.43	0.36	0.32	0.25

Table 3.6

**Reduction coefficient for salinity, %
(field leaching with optimal leaching norms against the background of operational drainage)**

Degree of contour salinity	Type of salinity			
	sulphate	sulphate-chloride	chloride - sulphate	chloride
Non-saline	1.00	1.00	1.00	1.00
Slightly saline	1.00	1.00	1.00	0.99
Moderately saline	0.97	0.95	0.93	0.90
Highly saline	0.95	0.93	0.89	0.86
Very highly saline	0.93	0.90	0.88	0.85

Table 3.7

Reduction coefficient for salinity, % (field leaching with rough norms against the background of poor operating drainage)

Degree of contour salinity	Type of salinity			
	sulphate	sulphate-chloride	chloride - sulphate	chloride
Non-saline	1.00	1.00	1.00	1.00
Slightly saline	0.98	0.97	0.96	0.90
Moderately saline	0.95	0.92	0.88	0.83
Highly saline	0.90	0.87	0.84	0.76
Very highly saline	0.86	0.84	0.81	0.72

Residual toxic effect of salts in the soil and also conditions of water and salt transport during growing season are taken into account in the coefficients shown in Tables 3.6 and 3.7.

The reduction coefficients for weeding, % are listed in Table 2.8. (for cases with no weed control) and in Table 2.9 (for cases when weed control follows the recommendations provided in individual operations sequence chart for given field).

The above coefficients help to estimate losses by contour, then sum up losses for the whole field, and dividing them by field hectares gives average losses per hectare.

K_N is determined from Table 3.8.

Table 3.8

Reduction coefficient for initial nitrogen content in the soil ($N\text{-}NO_4$), %

Availability	Content of $N\text{-}NO_4$ in the soil, mg/kg	Reduction coefficient, %
Very low	< 20	0.83
Low	20-30	0.92
Average	30-50	0.99
Increased	50-60	1.00
High	> 60	1.00

K_P is determined from Table 3.9

Table 3.9

Reduction coefficient for initial phosphorus content in the soil (P_2O_5), %

Availability	Content of P_2O_5 in the soil, mg/kg	Reduction coefficient, %
Very low	15	0.95
Low	16-30	0.98
Average	31-45	0.99
Increased	46-60	1.00
High	> 60	1.00

The above coefficients are used if the soil was not prepared in autumn to achieve the average *P* content, with application of phosphorus according to individual operations sequence chart. If phosphorus content is at average level, the reduction coefficient K_P will equal 1 in all cases.

K_K is determined from Table 3.10.

Table 3.10

Reduction coefficient for initial potassium content in the soil (K_2O), %

Availability	Content of K_2O in the soil, mg/kg	Reduction coefficient, %
Very low	< 100	0.97
Low	101-200	0.99
Average	201-300	1.00
Increased	302-400	1.00
High	400	1.00

The above coefficients are used if the soil was not prepared in autumn to achieve the average K content. If potassium content is at average level, the reduction coefficient K_K will equal 1 in all cases.

K_{bol} is determined from Table 3.11.

Table 3.11

Reduction coefficient for wheat diseases, %

Disease	Disease rate, %		
	low	moderate	heavy
Root rot	0.88	0.75	0.65
Rust	0.92	0.80	0.70
Powdery mildew	0.95	0.85	0.75

In DVY forecasts, K_{bol} is taken equal to 1 provided that preventive measures for disease control are undertaken.

K_{vr} is determined from Table 3.12.

Table 3.12

Reduction coefficient for wheat pests, %

Pests	Infestation rate, %		
	low	moderate	heavy
Aphid	0.97	0.92	0.85
Lema	0.95	0.90	0.80
Ground beetle	0.95	0.90	0.80

In DVY forecasts, if preventive measures for pest control are taken, K_{vr} is taken equal 0.98.

The reduction coefficient for land uniformity (K_f), % or field leveling is derived from Table 2.15 (Chapter 2).

Table 3.13

Example of the actual-possible winter wheat yield (DVY) computation

PY centner /ha	K_c (salinity)			K_N (nitrogen)		K_P (phosphorus)		K_K(potassium)	
	salinity type	degree of salin	Red coef	Availa bi lity	Red coef	Availa bi lity	Red coef	Availa bi lity	Red coef
61.9	sulph-chlorid e	slightly	0.95	high	1.0	aver	0.98	norm	1.0

K_{sor} (weeds)		K_{bol} (diseases)		K_{vr} (pests)		K_f (leveling)		$\frac{\Sigma Q_n}{\Sigma Q_{PAR}}$	DVY centner/ha
weeding	Red coef	disease rate	Red coef	infestation	Red coef	relief	Red coef		
aver	1.0	low	1.0	low	0.96	good	0.99	1.0	54.8

$$DVY= 61.9 – (3.0 + 0.0 + 1.2 + 0.0 + 0.0 + 0.0 + 2.4 + 0.6 + 0.0) = 54.8 \text{ centner/ha}$$

$$DVY = 61.9 – 7.1 = 54.8 \text{ centner/ha}$$

where: PY = 61.9 centner/ha, yield losses = 7.1 centner/ha.

3.4. Methodology and Example of Computation of the Actual Winter Wheat Yield of a Farm (YH) under Climatic Conditions of Given Year

The basic expression for the actual yield (YH) is as follows

$$YH = Y_{DVY} \cdot P_1 \cdot P_2 \ldots P_i \qquad (3.7)$$

where

YH – is predicted (design) yield for a plot;

Y_{DVY} – actual-possible yield in the plot computed using the methodology in section 2.3;

P_i – reduction coefficient characterizing an impact of factor X on productivity;

$P_i = f(X_i)$ is considered as a function of X_i, $i = 1, 2 \ldots, \ell$.

Proceeding from this expression, we consider a problem of yield forecast based on indicators characterizing the agricultural production. The actual farm yield (YH) is calculated without reference to a particular crop. Here, only organizational and production losses and weather-related losses are taken into account.

$$YH = Y_{DVY} \cdot f(X_1) \cdot f(X_2) \ldots f(X_i) \quad (3.8)$$

where:

X_1 – provision with labor resources;

X_2 – provision with equipment and transport;

X_3 – quality of technological operations;

X_4 – quality of seeds, provision with chemicals and fertilizers;

X_5 – provision with water.

Table 3.14

Reduction coefficients for organizational and production factors

Factor		Deviation from the norm, %			
		low (A) to 15 %	**average (B) to 25 %**	**high (C) to 40 %**	**0**
P_1	Provision with labor resources	0.98	0.92	0.85	1.0
P_2	Provision with equipment and transport	0.96	0.90	0.80	1.0
P_3	Quality of technological operations, deviation from the zonal technology recommendations	0.95	0.85	0.70	1.0
P_4	Provision with chemicals, fertilizers and water	0.92	0.80	0.65	1.0
P_5	Provision with water	0.99	0.95	0.70	1.0

Table 3.15

Example of actual farm yield (YH) computation

DVY centner/ha	P_1 K_{labor}		P_2 $K_{equipment}$		P_3 $K_{technology}$		P_4 $K_{fert,}$ chemicals, fuel		P_5 K_{water}	YH centner/ha
	avail	red coef	avail	red coef	avail	red coef	avail	red coef	norm	
54.8	norm	0.99	aver	0.96	norm	0.98	low	0.91	1.0	46.4

$$YH = 54.8 – (0.5 +2.2+1.0+4.7) = 46.4 \text{ centner/ha}$$

$$YH = 54.8 – 8.4 = 46.4 \text{ centner/ha}$$

where:

54.8 centner/ha - DVY;

8,4 centner/ha – yield losses through organizational and production factors.

We will show as an example of yield losses for main crops the results of the research carried out in the pilot farm “Azizbek” located in the Fergana Valley.

MVY in the fields of this farm amounted to 75.5 centner/ha for cotton and 110 centner/ha for winter wheat. Potential yield (PY) was determined by the difference between MVY and yield losses through slowly changing physical soil properties and humus content. The actual possible yield (DVY) was derived from the difference between PY and losses through controllable factors of agricultural production (salinity, content of macroelements in the soil, weeding, disease rate, infestation by pests, and field leveling). Quantitative values of each factor determined ultimate yield losses (reduction coefficients for each factor were estimated on the basis of analysis of numerous literature and experimental data). The results of computations listed in Tables 3.16 - 3.19 visualize yield losses in pilot plots through agricultural production factors for the year 2003.

Table 3.16

Losses of cotton and wheat yield (centner/ha) in pilot plots through major agricultural production factors (2003)

Farm	MVY	Losses through physical soil proper-ties	Losses through lack of humus	PY	Losses through salinity	Losses through lack of P_2O_5	Losses through lack of K_2O	Losses through weeding	Losses through disease	Losses through pests	Losses through poor leveling	DVY	Organiz ational losses	Actual yield
Cotton														
Azizbek	75.5	5.8	7.2	62.5	3.3	7.0	2.6	2.9	1.6	4.2	1.2	39.7	8.7	31.0
Wheat														
Azizbek	110.0	8.0	12.0	90.0	4.0	9.0	4.2	4.8	4.7	3.9	4.1	55.3	6.7	48.6

MVY – highest possible yield; PY – potential yield; DVY – actual-possible yield.

Table 3.17

Organizational and technological yield losses (center/ha) in pilot plots (2003)

Farm	Losses through water stress	Losses through lack of equipment	Losses through lack of labor resources	Losses through poor quality seeds	Losses through reduction of seeding amount	Losses through deviation from zonal technology	Poor quality of technological operations	Losses during harvesting	Total organizational and technological losses
Cotton									
Azizbek	1.6	0.0	1.0	0.0	0.0	2.6	3.5	0.0	8.7
Winter wheat									
Azizbek	1.3	0.5	1.4	0.0	0.0	1.5	0.9	1.1	6.7

Table 3.18

Computation of productivity levels in G. Gulyam farm 1a (Syrdarya province, Uzbekistan)

No. field	Plot	Crop	Area, ha	K_{gum}			K_b						K_c			
				%	humus t/ha	Red coef	Soil type	texture	Auto-morphism	Thickness Fine grained soil	Red K_{ocn}	K_b	Cℓ - %	Type of salinity	degree	Red coef
01	U-50a	cotton	4.8	0.54	33.7	0.65	sieroz	l.loam h.loam	Semi automorph	100	0.95	0.62	0.02	Sulphate	non-saline	1.0
02	U-50	w.wheat	6.0	0.56	35.0	0.65	sieroz	l.loam		100	0.90	0.59	0.015	Sulphate -chloride s/h	non-sal	1.0
03	U-48	cotton	16.0	0.50	31.1	0.65	sieroz	l.loam		100	0.90	0.59	0.025	s/h	non-sal	1.0
04	U-47a	cotton	5.4	0.48	30.0	0.65	sieroz	l.loam		100	0.90	0.59	0.045	s/h	moderately	0.83
05	U-46	w.wheat	8.0	0.54	33.7	0.65	sieroz	l.loam		100	0.90	0.59	-	s/h	non-sal	1.0
06	U-45	cotton	8.84	0.40	26.0	0.60	sieroz	m.loam		100	1.00	0.60	0.06	s/h	modera-tely	0.9
07	U-1	w.wheat	4.8	0.44	27.5	0.60	sieroz	l.loam		100	0.90	0.54	-	s/h	non-sal	1.0
08	U-4	w.wheat	10.56	0.74	46.2	0.70	sieroz	l.loam		100	0.90	0.63	-	s/h	non-sal	1.0
09	U-4a	cotton	8.0	0.48	30.0	0.65	sieroz	l.loam		100	0.90	0.59	0.015	s/h	non-sal	1.0
10	U-7	w.wheat	13.0	0.26	16.2	0.60	sieroz	l.loam		100	0.90	0.54	-	s/h	non-sal	1.0

Table 3.18, continued

K_P			K_K			K_{sor}		K_{bol}		K_{vr}		K_f		$\frac{\sum Q_n}{\sum Q_{PAR}}$	$K_{labor\ res}$	
P mg/kg	availa bility	Red coef	K mg/kg	availa bility	Red coef	weeding	Red coef	Rate of disease	Red coef	Infest.	Red coef	apparent micro-relief	Red coef		provision	Red coef
na			na			strong	0.80	0	1.00	0	1.00	aver	0.95	1.00	low	0.98
25	low	0.98	170	low	0.99	strong	0.80	0	1.00	0	1.00	aver	0.95	1.00	low	0.98
21	low	0.98	180	low	0.99	poor	0.95	0	1.00	0	1.00	good	1.00	1.00	low	0.98
16	low	0.98	170	low	0.99	moderate	0.90	0	1.00	0	1.00	aver	0.95	1.00	low	0.98
18	low	0.98	175	low	0.99	poor	0.95	0	1.00	0	1.00	poor	0.88	1.00	low	0.98
26	low	0.98	200	low	0.99	moderate	0.90	0	1.00	0	1.00	poor	0.88	1.00	low	0.98
45	aver	1.00	270	aver	1.00	poor	0.95	0	1.00	0	1.00	aver	0.95	1.00	low	0.98
20	low	0.98	240	aver	1.00	poor	0.95	0	1.00	0	1.00	aver	0.95	1.00	low	0.98
34	aver	1.00	205	aver	1.00	poor	0.95	0	1.00	0	0.95	good	0.99	1.00	low	0.98
31	aver	1.00	190	low	0.99	poor	0.95	0	1.00	0	1.00	aver	0.95	1.00	low	0.98

Table 3.18, continued

$K_{equipment}$		$K_{efforts}$		$K_{fert, chemicals, fuel, water}$		MVY center/ha	PY center/ha	DVY center/ha	RY center/ha	Actual yield, centner/ha		
provision	Red coef	provision	Red coef	provision	Red coef					farm	field	plot
poor	0.96	high	0.75	average	0.80	75.6				10.3	15.8	28.6
poor	0.96	average	0.85	average	0.80	116	68.4	50.4	32.2	20.3	24.0	24.0
poor	0.96	poor	0.95	low	0.92	75.6	44.6	41.1	33.8	18.0	26.9	42.4
poor	0.90	poor	0.95	low	0.92	75.6	44.6	30.7	23.7	18.4	18.4	28.2
poor	0.96	poor	0.95	low	0.92	116	68.4	55.5	45.6	18.3	29.1	22.8
poor	0.96	average	0.85	low	0.92	75.6	45.4	31.4	23.1	13.0	7.3	11.4
poor	0.96	poor	0.95	low	0.92	116	62.6	56.5	46.4	16.2	29.6	28.5
poor	0.96	poor	0.95	low	0.92	116	73.1	64.6	53.1	32.0	42.0	42.0
poor	0.96	poor	0.95	low	0.92	75.6	44.6	39.8	32.7	14.3	12.0	18.8
poor	0.96	high	0.75	low	0.92	116	62.6	55.9	36.3	20.7	21.6	21.9

Table 3.19

Analysis of yield losses, center/ha, for G.Gulyam farm 1a (Syrdarya province, Uzbekistan)

No. field	Plot	Crop	MVY	PY	MVY-PY	DVY	PY-DVY	Losses (field conditions)							RY	DVY-RY	Losses (organizational)			
								salt	P	K	weeds	disease	pests	uniform			labor	equip	efforts	resourc
02	U-50	w.wheat	116	68.4	47.6	50.4	18.0	0	1.3	0.6	12.8	0	0	3.5	32.2	18.2	0.9	1.8	6.6	8.9
03	U-48	cotton	75.6	44.6	31.0	41.1	3.5	0	0.9	0.8	1.8	0	0	0	33.8	7.3	0.8	1.5	1.9	3.1
04	U-47a	cotton	75.6	44.6	31.0	30.7	13.9	6.8	0.8	0.4	1.9	0	2.0	2.0	23.7	7.0	0.6	3.0	1.5	1.9
05	U-46	w.wheat	116	68.4	47.6	55.5	12.9	0	1.4	0.6	3.2	0	0	7.7	45.6	9.9	1.0	1.8	2.4	3.8
06	U-45	cotton	75.6	45.4	30.2	31.4	14.0	4.0	0.8	0.4	4.0	0	0	4.8	23.1	8.3	0.6	1.2	4.2	2.3
07	U-1	w.wheat	116	62.6	53.4	56.5	6.1	0	0	0	3.1	0	0	3.0	46.4	20.1	1.1	2.2	2.7	4.1
08	U-4	w.wheat	116	73.1	43.9	64.6	8.5	0	1.5	0	3.5	0	0	3.5	53.1	11.5	1.2	2.4	3.1	4.8
09	U-4a	cotton	75.6	44.6	31.0	39.8	4.8	0	0	0	2.2	0	2.2	0.4	32.7	7.1	0.7	1.4	1.3	3.1
10	U-7	w.wheat	116	62.6	53.4	55.9	6.7	0	0	0.7	3.0	0	0	3.0	36.3	19.6	1.0	2.0	12.6	4.0

For cotton, the average potential yield amounted to 62.5 centner/ha and the actual possible yield equaled 39.7 centner/ha. Bulk of losses were caused by lack of humus in the soil (7.2 centner/ha), low content of P_2O_5 (7.0 centner/ha), and physical soil properties (5.8 centner/ha). For winter wheat, potential yield amounted to 90.0 centner/ha and the actual possible yield equaled 55.3 centner/ha. Here, yield losses through low organic matter content were well higher as compared to cotton – 12.0 centner/ha, while losses through physical soil properties and content of P_2O_5 reached 8.0 centner/ha and 9.0 centner/ha, respectively. Organizational and technological losses were quite high for cotton – 8.7 centner/ha – and amounted to 6.7 centner/ha during production of wheat, where bulk losses resulted from low quality agronomic operations, deviation from zonal technology and low water availability for crops. Quantitative assessment of yield losses helps to identify factors that largely contribute to lowering of productivity and select agronomic or organizational measures that mitigate their effect.

3.5. Winter Wheat Irrigation Regime and Yield Losses Depending on Water Availability During Growing Season

In case of optimal water availability for irrigated crops, the reduction coefficient for water factor is not applied as a priori it equals 1. Water regime should be optimized and controlled based on recommendations of a water duty zoning (the so called "hydromodule zoning") and crop irrigation schedule (Stulina G.V., 2010).

Table 3.18

Winter wheat irrigation schedule for VI hydromodule zone

Crop	Irrigation norm, m^3/ha	No. of irrigation event	Irrigation depth, m^3/ha	Irrigation dates		Irrigation interval, days
				beginning	end	
Winter	4,600	1	600	29.10.09	11.11.09	14
wheat		2	800	29.3.09	13.4.09	16
		3	800	14.4.09	26.4.09	13
		4	800	27.4.09	7.5.09	11
		5	800	8.5.09	18.5.09	11
		6	800	19.5.09	1.6.09	14

Table 3.19

Recommended soil wetting zones for winter wheat watering

No. of irrigation event	Irrigation dates with reference to crop development stages	Wetting zone (cm)
0	Recharge irrigation (before sowing)	100-110
1	Tillering	40-45
2	Before earing	70-80
3	Flowering	80-100
4	Grain filling	100-110

Table 3.20

Approximate dates for recharge and growing season irrigation of winter grain crops

Type of irrigation	Republic of Uzbekistan and provinces		
	Kashkadarya, Surkhandarya, Navoiy and Bukhara	Samarkand, Dzhizak, Tashkent, Syrdarya, Fergana, Namangan and Andizhan	Karakalpakstan and Khorezm
.Recharge irrigation	10.10-20.10* / 700-1200	20.09-30.09 / 600-800	10.09-20.09 / 600-900
Autumn irrigation in growing season	25.10-20.11 / 700-900	20.10-10.11 / 500-700	15.10-10.11 / 500-700
3. Spring irrigation during growing season:			
First irrigation (tillering)	20.02-10.03 / 700-800	01.03-20.03 / 600-700	20.03-10.04 / 600-650
Second irrigation (leaf-tube formation)	10.03-30.03 / 750-850	25.03-15.04 / 700-750	15.04-25.05 / 600-650
Third irrigation (earing)	30.03-20.04 / 800-850	15.04-25.04 / 750-800	25.04-10.05 / 650-700
Forth irrigation (milky-wax ripeness phase)	20.04-10.05 / 500-550	01.05-15.05 / 450-500	10.05-25.05 / 400-450

Note: * numerator – irrigation date; denominator – irrigation depth, m^3/ha.

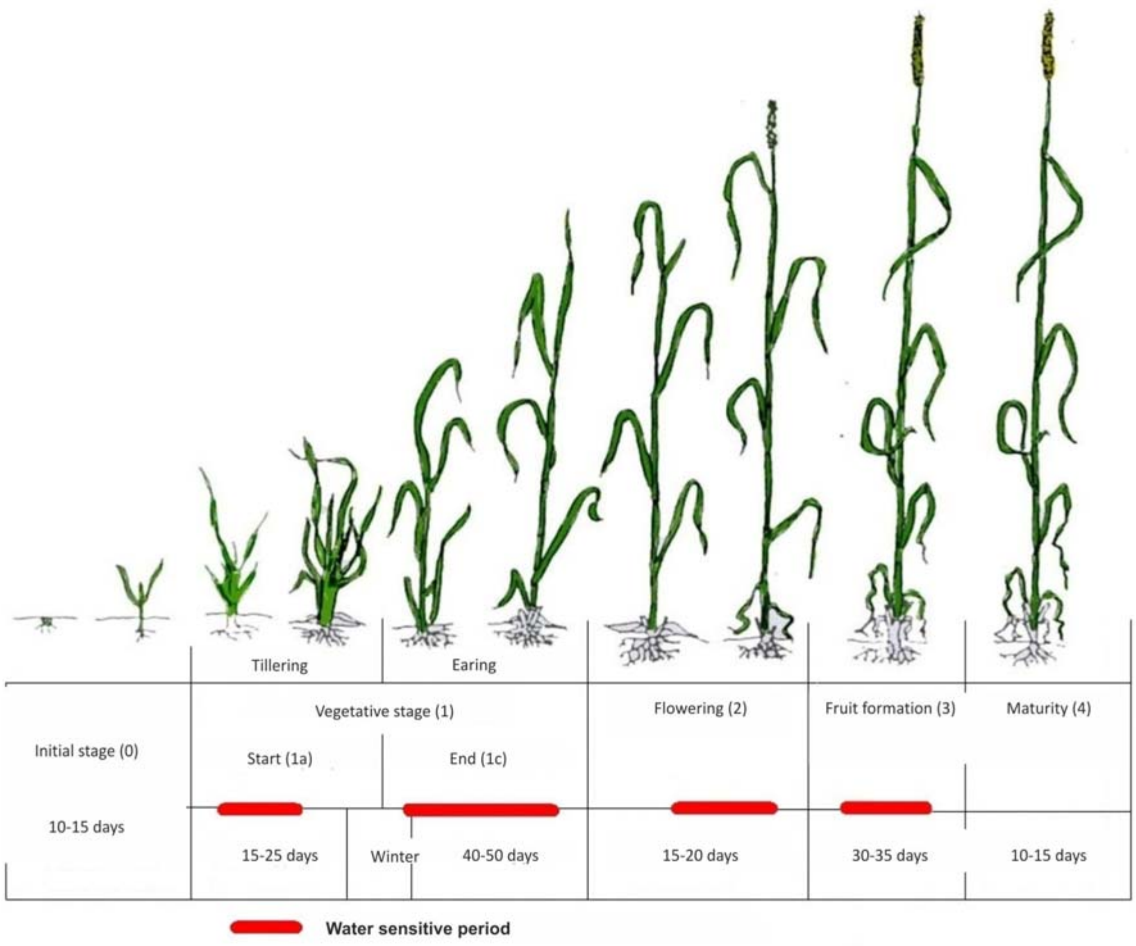


Figure 3.1. Winter wheat development stages

Table 3.21

Average yield losses depending on water supply to winter wheat (with orientation to optimal supply) during growing season [22]

Water supply, %	Fractional yield losses
90	0.04
80	0.15
70	0.27
60	0.38
50	0.49

4. Maize Productivity Assessment Algorithm

Maize is grown for both grain and silage in agriculture. Usually in Uzbekistan, maize for silage is grown as a second crop, which is sown after harvesting of winter cereals in July and mowed down in October. Maize for grain can be sown as first crop in early May and harvested in late September-early October or sown after harvesting of winter cereals in July as a second crop.

4.1. Methodology and Example of Computation of the Highest Possible Yield (MVY) for Maize

The total PAR influx for maize by climatic area is: 38.0 kcal/cm^2 for transient area; 39.1 kcal/cm^2 for thermal area; and, 41.1 kcal/cm^2 for subtropical area. Short-season hybrids ripen at PAR ≈ 28-37 kcal/cm^2 during growing season. Short-season maize hybrids consume ≈ 20-31 kcal/cm^2, while for mid-season hybrids PAR influx is from 31.5 to 35.5 kcal/cm^2. Maximum solar energy (34-36.5 kcal/cm^2) falls on late-season hybrids.

For computation of maize MVY we used the Nichiporovich's formula (see Chapter 1, formula 1.2) added by a factor for conversion from phytomass to yield:

where:

$\sum Q_{PAR}$ – total average long-term influx of PAR during growing season, kcal/cm^2;

Q – yield caloricity (4100 kcal/kg);

η_f – maize photosynthetic efficiency = 1.5-2.5 %; (4.1)

K – coefficient of conversion from phytomass to yield = 0.521.

Chapter 2 (Table 2.1) gives data on monthly photoactive radiation observed in Uzbekistan with reference to climatic commonality.

Values of the coefficient of conversion from maize phytomass to yield are shown in Table 4.1.

Table 4.1

Maize yield caloricity and coefficients of conversion

Crop	Caloricity, kcal/kg	Coefficient of conversion from phytomass to yield		
		air-dry weight	grain standard moisture regain	grain ovendry weight
Maize for grain	4,100	-	0.521	0.448

Values of photosynthetic efficiency for different condition of crops in terms of their productivity are listed in Table 4.2.

Table 4.2

Photosynthetic efficiency, %

No.	Crop condition	Efficiency
1	Bad	0.50
2	Usually observed	0.5-1.5
3	Good	1.5-3.0
4	Record-breaking	3.0-6.0
5	Theoretically possible	6.0-8.0

The recommended photosynthetic efficiency to be used in computations for maize is 2.5 %.

The most objective criterion of maize productivity is the coefficient of solar radiation utilization Given the present level of equipment, capabilities of highly mechanized irrigated agriculture, production of new intensive hybrids, and application of fertilizers and chemicals in sufficient amounts, it is feasible to achieve 3.5-4% of photosynthetic efficiency. However, conducted research has shown that in actual standard working environment photosynthetic efficiency is approximately equal to 1.5-2.5 %. Maize caloricity is 4,000 kcal/kg for leafy mass and 4,100 kcal/kg for grain (the standard ratio between green mass and grain is 55 % to 45 %). The coefficient of conversion (K) from phytomass to yield of dry grain is taken equal 0.448, while that from phytomass to grain of standard moisture regain (14 %) is equal to 0.521. The computation results for the highest possible yield (MVY) are shown in Tables 4.3 and 4.4.

Maize is high productivity crop. Its biologically possible yield (MVY) reaches from 20 centner/ha to 365 centner/ha, depending on growing zone and photosynthetic efficiency. In full-scale growing conditions, MVY for grain of standard moisture regain was estimated as 120 -130 centner/ha.

Table 4.3

Computation of the highest possible yield (MVY) of maize for grain

Climatic communality	K_{PAR}		PAR for growing season, kcal/cm^2	Biomass yield, centner/ ha	Main product yield (ovendry yield), centner/ ha	Main product yield (standard moisture regain 14 %), centner/ha
	class	efficiency, %				
Transient	I	7 (6-8)	38.0	638.8	290.7	338.0
	II	4.25 (3.5-5)		393.97	176.5	205.3
	III	2.25 (3-1.5)		208.6	93.5	108.7
	IV	1.00 (1.5-0.5)		92.7	41.5	48.3
	V	< 0.5		46.35	20.8	24.1
normally used		**2.5**		**231.75**	**103.8**	**120.7**
Thermal	I	7 (6-8)	39.1	667.6	299.1	347.8
	II	4.25 (3.5-5)		405.3	181.6	211.2
	III	2.25 (3-1.5)		214.6	96.1	111.8
	IV	1.00 (1.5-0.5)		95.4	42.7	49.7
	V	< 0.5		47.7	21.4	24.8
normally used		**2.5**		**238.5**	**106.8**	**124.3**
Subtropical	I	7 (6-8)	41.1	701.7	314.4	365.6
	II	4.25 (3.5-5)		425.8	190.7	221.8
	III	2.25 (3-1.5)		225.4	100.97	117.4
	IV	1.00 (1.5-0.5)		100.2	44.9	52,2
	V	< 0.5		50.1	22.4	26.1
normally used		**2.5**		**250.5**	**112.2**	**130.2**

Example of computation of MVY for maize for grain provided that the total PAR influx is 26.1 kcal/cm^2, and photosynthetic efficiency is 1.5-2.5 % for the crops conditionsof which is estimated as below average.

$$MVY = \frac{26.1\ \text{kcal/cm}^2}{4100\ \text{kcal/kg}} \cdot (1.5\text{-}2.5\ \%) \cdot 0.521 \cdot 10^4 = \text{from } 49.7 \text{ centner/ha to } 82.9 \text{ centner/ha}$$

The highest possible yield of maize for silage is shown in Table 4.4.

Table 4.4

Computation of the highest-possible yield (MVY) of maize for silage (second crop)

Climatic communality	K_{PAR}		PAR for growing season	Biomass yield
	class	efficiency, %		
Transient	I	7 (6-8)		434
	II	4.25 (3.5-5)		263.5
	III	2.25 (3-1.5)		139.5
	IV	1.00 (1.5-0.5)		62
	V	< 0.5		31
normally used		**2.5**	**24.8**	**155**
Thermal	I	7 (6-8)		456.7
	II	4.25 (3.5-5)		277.1
	III	2.25 (3-1.5)		146.7
	IV	1.00 (1.5-0.5)		65.2
	V	< 0.5		32.6
normally used		**2.5**	**26.1**	**163.0**
Subtropical	I	7 (6-8)		479.5
	II	4.25 (3.5-5)		291.1
	III	2.25 (3-1.5)		154.1
	IV	1.00 (1.5-0.5)		68.5
	V	< 0.5		34.2
normally used		**2.5**	**28.4**	**171.2**

4.2. Computation of Potential Maize Productivity (PY)

Potential level of crop productivity is the yield that can be reached under specific soil-climatic conditions of given year. PY is computed by formula:

$$PY = MVY \cdot K_b \tag{4.2}$$

where

MVY – the highest possible yield;

K_b – coefficient of soil bonitet, which is calculated using the formula:

$$K_b = K_{ocn} \cdot K_{gum} \tag{4.3}$$

where

K_{ocn} – main bonitet score,

K_{gum} – reduction coefficient for humus content in soil.

K_{ocn} is taken according to the irrigated soil bonitet scale, depending on zonal location of given site, granulometric composition, automorphy or hydromorphy of soil, and thickness of fine grained soil (see Table 2.2).

Maize likes drained, aerated soil, deep groundwater, with pH 5.0-7.0. However, under conditions of desert and sierozemic soil, where initial background is close to neutral, decrease in pH is caused by groundwater rise and entails deterioration of aeration conditions. Analysis of the results received by numerous researchers shows that maximal maize yield was achieved in the soil with pH 7.0-8.0, i.e. requirements for response of the medium are similar to those of cotton. Good aeration of the rooting layer contributes to higher maize yields, e.g. loosening down to 80 cm increases green mass by 114 centner/ha and ears by 48.6 centner/ha.

Despite high degree of chemicals use, soil fertility decreases. Humus content decreased almost one third in the last thirty years. This could be avoided if manure was to be applied sufficiently. The agronomic rate of manure application is 20-30 t per hectare, whereas in real practices only 4-5 t/ha of manure were applied in the recent 10-15 years. Therefore, initial humus content is an important parameter for computation of potential yield.

The scale of irrigated soil bonitet for CAR area is shown in Chapter 2 (see Table 2.2).

The reduction coefficients for humus content (K_{gum}) for maize (%) are similar to K given in Chapter 2 (see Table 2.3).

Table 4.5

Example of computation of potential yield (PY) for maize for grain

MVY centner/ha	K_{ocn}					K_{gum}			PY centner/ha
	soil type	texture	automorph	thickness of fine grain soil	Losses K_{ocn}	humus, t/ha	Red. coef	losses for K_{gum} centner/ha	
117.4	sierozem	medium loam	automorphic	> 100	0.0	35.0	0.65	36.7	80.7

4.3. Assessment of the Actual-Possible Productivity (DVY) for Maize

The actual-possible productivity is a yield, which is formed through such field parameters as salinity, nutrient content, diseases, infestation, weeding, and uniformity of the field.

It is well-known that salts have a negative effect on plants reflecting in an increase in osmotic pressure of soil water making it less available. Here both type and degree of salinity are of importance. Different soils may have the same amount of salts but, depending on their composition, be characterized by different degrees of salinity since various soluble salts differ in their toxic effect on plants.

As in the saline soil these are toxic salts that suppress growth of crops, it is preferably to classify soil in terms of degree of salinity not only by solid residue but also by the sum of toxic salts. As to salt tolerance, maize refers to moderately resistant crops.

Table 4.6 gives degrees of salt tolerance of maize according to FAO and yield potential, depending on electric conductivity of the soil solution.

Table 4.6

Degrees of salt tolerance of maize

Yield potential								
100 %		90 %		75 %		50 %		MAX
ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
1.7	1.1	2.5	1.7	3.8	2.5	3.9	3.9	10

Maize refers to moderately resistant crops.

Table 4.7

Crop requirements for soil (according to FAO)

Crop	Rating of crop tolerance	Demand for fertilizers N, P, K kg/ha for growing season
Maize	Moderately sensitive	100-120, 50-80, 60-100

Table 4.8 shows levels of maize yield depending on soil salinity.

Table 4.8

Maize yield depending on soil salinity

Maize	Yield at given salt content in the soil, % of mass				
	0.1	0.3	0.6	0.9	1.2
Yield, %	100 %	80 %	39 %	15 %	0

The reduction coefficients for salinity are similar to those of cotton (see Chapter 2, Tables 2.5, 2.6 and 2.7).

According to data of Central Agrochemistry and Fertilizer Research Institute (CINAU), 2.5 kg/center of nitrogen is required per unit of maize production, while the ratio of phosphorus to nitrogen for balanced nitration of maize should be 0.4-0.5.

Table 4.9

Soil assessment by degree of availability of nitrogen (N- NH_3) and phosphorus (P_20_5), mg/kg

Availability	Maize N-NH_3	Maize P_20_5
Very low	< 20	< 30
Low	20-30	31-79
Average	30-50	80-150
High	50-80	> 150

Table 4.10

Soil assessment by degree of availability of potassium K_2O (mg/kg)

Availability	Maize, K_2O
Very low	< 30
Low	30-70
Average	70-100
High	> 100

Yield dependence on nitrogen, phosphorus, and potassium contents is considered in computation of the actual-possible yield by adding reduction coefficients for availability of such nutrients.

Reduction coefficients for initial content of nitrogen, phosphorus and potassium in the soil are given in Table 4.11

Table 4.11

Reduction coefficients for availability of nitrogen (N), phosphorus (P) and potassium (K), %

Availability	Reduction coefficient for N, %	Reduction coefficient for P, %	Reduction coefficient for K, %
Very low	0.80	0.85	0.93
Low	0.90	0.93	0.97
Average	0.98	0.97	1.00
High	1.00	1.00	1.00

Diseases, pests and weeds can reduce crop yield substantially. Consideration of those factors in yield programming is particularly important under current lack of plant protection agents.

Reduction coefficients for weeding (K_{sor}) in no weed control case are similar to those of cotton (see Chapter 2, Table 2.8)

Reduction coefficients for weeding (K_{sor}) in weed control case are the same as for cotton (see Chapter 2, Table 2.9).

Table 4.12

Reduction coefficients for disease (K_{bol}) and pests (K_{vr}), %

Infestation	low	moderate	heavy
Disease (K_{bol})	0.92	0.83	0.68
Pests (K_{vr})	0.95	0.85	0.75

Table 4.13

Reduction coefficients (%) land uniformity, K_f

Land uniformity	Deviation from '0' ground level, cm	Reduction coefficient, %
High (optimal)	0	1.00
Good	± 3 - ± 5	0.99
Average	± 5 - ± 10	0.95
Poor	± 10 - ± 15	0.88
Very poor	± 15 - ± 25	0.80

An important factor of crop yield is the uniformity of land. Detailed research carried out in this field allowed identifying an impact of micro- and mesorelief on yields. Reduction coefficients for land uniformity for maize are shown in Table 4.13.

Table 4.14

Example of the actual-possible maize yield (DVY) computation

PY centner/ha	K_c (salinity)			K_{sor} (weeds)		K_N (nitrogen)		K_P (phosphorus)	
	salinity type	degree of salin	Red coef	weeding	Red coef	Availa bi lity	Red coef	Availa bi lity	Red coef
80.7	sulphat	non-sal	1.0	low	1.0	high	0.98	aver	0.93

Table 4.14, continued

K_K(potassium)		K_{bol} (diseases)		K_{vr} (pests)		K_f (leveling)		$\frac{\Sigma Q_n}{\Sigma Q_{PAR}}$	DVY centner/ha
Availabi lity	Red coef	disease rate	Red coef	infestation	Red coef	relief	Red coef		
high	1.0	low	1.0	low	0.95	good	0.97	1.0	67.8

$$DVY = 80.7 – (0.0 + 0.0 + 1.51 + 5.31 + 0.0 + 0.0 + 0.0 + 3.70 + 2.25 + 0.0) = = 67.8 \text{ centner/ha}$$

$$DVY = 80.7 – 12.9 = 67.8 \text{ centner/ha}$$

where:

PY = 80.7 centner/ha, yield losses = 12.9 centner/ha.

4.4. Assessment of Actual Maize Yield (YH) in Farm

The actual crop productivity is assessed in particular field depending on performance quality of technological process and provision with resources (fertilizers, chemicals, personnel).

In order to determine degree of provision with a production factor, one needs to have actual and planned (standard) indicators. Standard indicators of technological process performance are the zonal operations sequence charts for crop production.

Table 4.15

Example of computation of actual maize yield (YH) in farm

DVY centner/ha	P_1 manual labor		P_2 mechanized labor		P_3 performance		P_4 Kfert., chemicals, fuel	
	avail	red coef	avail	red coef	avail	red coef	avail	red coef
67.8	norm	0.98	norm	1.0	norm	0.94	suitable	0.92

Table 4.15, continued

P_5 water		RY centner/ha
avail	red coef	
norm	1.0	57.5

$$YH = 67.8 – (1.3 + 0.0 + 3.9 + 5.2 + 0.0) = 57.5 \text{ centner/ha}$$

$$YH = 67.8 – 10.3 = 57.5 \text{ centner/ha}$$

4.5. Maize Irrigation Regime and Yield Losses Depending on Water Availability During Growing Season

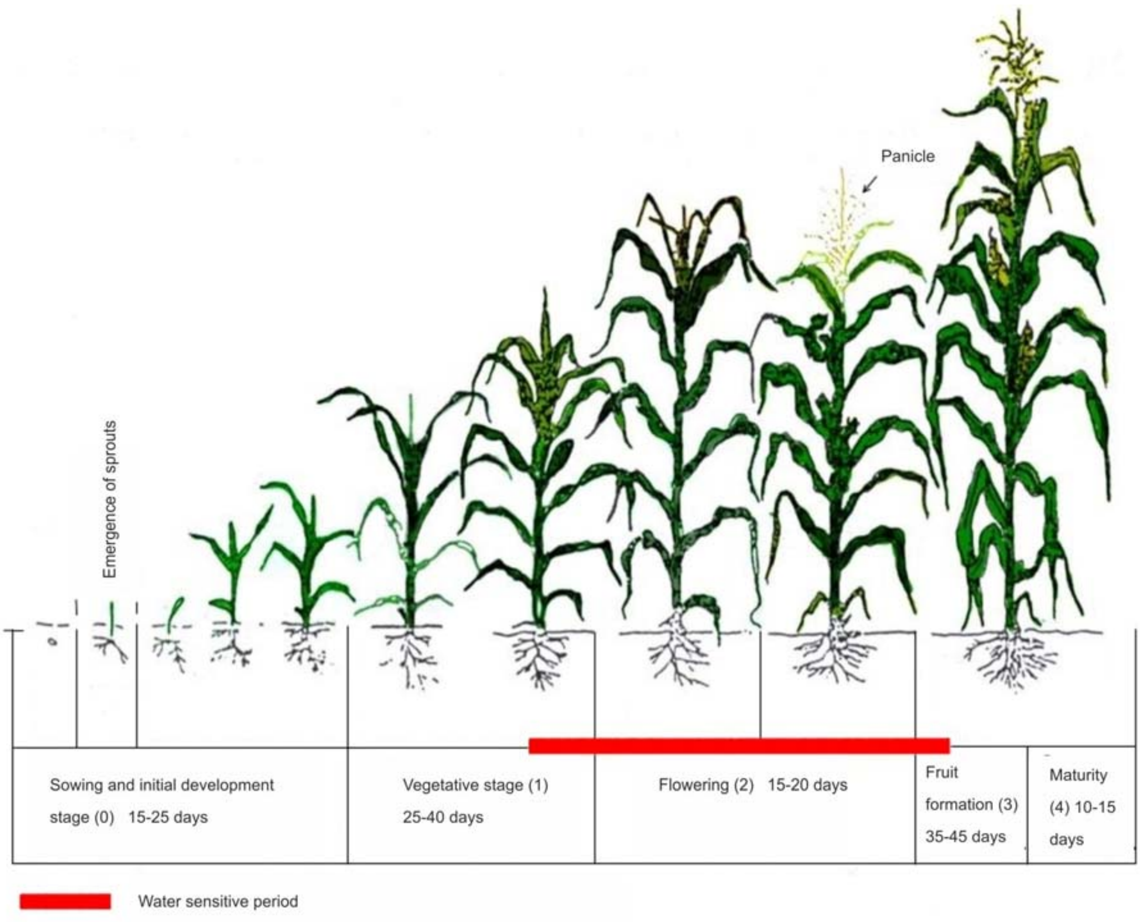


Figure 4.1. Maize development stages

Table 4.16

Recommended soil wetting zone (cm) for maize watering

No. of irrigation event	Development stage	Wetting zone (cm)
0	Recharge irrigation	100-130
1	Formation of 4-5 leaves	45
2	Panicle earing	60-70
3	Flowering	70-85
4	Beginning of fruit formation	85-100
5	Grain filling	100-120
6	Grain ripening	100-120

In case of optimal water availability for irrigated crops, the reduction coefficient for water factor is not applied as a priori it equals 1. Water regime should be optimized and controlled based on recommendations of a water duty zoning (the so called "hydromodule zoning") and crop irrigation schedule (Stulina G.V., 2010).

Table 4.17

Maize irrigation schedule for VI hydromodule zone

Crop	Irrigation norm, m^3/ha	No. of irrigation event	Irrigation depth, m^3/ha	Irrigation dates		Irrigation interval, days
				beginning	end	
Maize for grain	6,600	1	900	14.5.09	8.6.09	26
		2	1000	9.6.09	26.6.09	18
		3	1100	27.6.09	14.7.09	18
		4	1100	15.7.09	1.8.09	18
		5	1000	2.8.09	6.9.09	36
		6	1500	7.9.09	25.9.09	19

Table 4.18

Approximate depths and dates for maize irrigation by development stage

Para-meters	Irrigation event						Num-ber of irrigat events	Irrigat norm, m^3/ha
	0	1st	2nd	3rd	4th	5th		
Developm phase		Formation of 4th leaf	Formation of 10th leaf			Milky-wax ripeness	6	6,300
Dates	Before tillage	In 35-40 days after sowing	In 50-60 days after sowing	In 10-15 days after 2nd irrigation event	In 10-15 days after 3rd irrigation event			
Irrigation depth, m^3/ha	900	1,000	1,000	1,100	1,200	1,100		

Table 4.19

Average yield losses depending on water supply to maize (with orientation to optimal supply) during growing season [22]

Water supply, %	Fractional yield losses
90	0.04
80	0.14
70	0.24
60	0.34
50	0.44

5. Rice Productivity Assessment Algorithm

5.1. Biological Features of the Crop

Anatomically, rice is distinguished in that its tissues have numerous blind pits and air pockets through which air is transported to lower submerged parts of the plant. The root system of rice is well developed and varies structurally depending on available water.

The physiologically active temperature at which the plant's germ occurs is 15 ^{o}C, the optimal temperature is 22-25 ^{o}C, and seeds do not begin to sprout at 40-42 °C.

Fibrous root system of rice has no the highly developed mainroot. All rootlets are similar in form and size and look like fibers. The seminal root serves as the mainroot in the period from sprouting to tillering. Rice is highly capable of tillering: actually, daughter side tillers can emerge from the base of each leaf.

The main stages of organogenesis and development of rice are presented below:

I stage – emergence of young plant from germ. Formation of growing point (tip) and first three leaves: coleoptile, primary leaf and second leaf.

II stage – differentiation of leaves and secondary roots in the junction zone of leaves and downmost part of internodes; initiation of top leaves in the growing point of the main stem.

III stage – intensive development of the growing point (tip), which reaches 0.14 mm and formation of the base for future yield – tissues of buds from which branches of panicle emerge. The longer this stage, the more productive panicle is.

IV stage - formation of secondary and next order branches, emergence of pedicels. In this period of time, the temperature of water layer in the area of tillering node is critical for formation of productive panicle. The optimal water temperature (20 ^{o}C) in the area of tillering node prolongs the process of panicle growth and promotes extensive growth of branches and pedicels.

V stage – formation of spikelets, initiation of lemmas, paleas and flowers.

VI stage – formation of generative tissue in anthers and pistil. Completion of pistil, which consists of ovary, style, and stigma.

VII stage takes place simultaneously with IV stage and differs in intensive growth of panicle organs. This time, glumes, paleas and lemmas, awn and all other organs of flower increase 3-5 times in length.

VIII stage – paniculation, flowering and fertilization.

IX stage – formation of caryopsis.

X stage – accumulation of nutrients in caryopses, milky ripeness.

XI stage - maturity. During this stage, waxy and complete ripeness is distinguished. In complete ripeness endosperm and embryo lose water (get dry) and caryopsis gets mature.

Rice plant growth is divided into the following main phases: germination, seedling, tillering, booting, paniculation (and flowering), maturity.

5.2. Methodology for Assessment of the Highest Possible Rice Yield (MVY)

Khorezm province and Karakalpakstan are the main rice-growing zones in the Republic of Uzbekistan, with minor rice areas in other provinces.

The total photoactive radiation for rice is taken equal to the total PAR during growing season, i.e. from sowing to harvesting. The photoactive radiation designates the spectral range of solar radiation, which is utilized by plants in the process of photosynthesis.

Almost 90% of rice yield is generated through solar radiation and carbon dioxide in the atmosphere. In this context, the task of the farmer is to select crop and variety, by handling total PAR, that would give high productivity in this location. The recommended rice sowing dates are: 25 April -20 May for UzROS variety; and, 10 May – 30 May for other varieties. Taking into account the recommended optimal dates of sowing and harvesting (sowing: early-mid May; harvesting: second and third 10-day of September), the total photoactive radiation during rice growing is 331 kcal/cm^2 for transient zone, 335 kcal/cm^2 for thermal zone, and 351 kcal/cm^2 for subtropical climatic commonality.

The caloricity of dry rice biomass is 4,500 kcal/g. Caloricity is the amount of solar energy that is used for generation of unit biomass. The present high-productive crops utilize solar energy at PAR efficiency equal to 2.3-2.5%.

The recognized varieties are selected for every natural-climatic zone. The input of PAR for rice varieties is as follows: 28-30 kcal/cm^2 for early-season varieties with 90-100 days of growing season; 30-32 kcal/cm^2 for mid-season varieties with 105-115 growing days; and, 32-34 kcal/cm^2 for late-season varieties, with 115-125 growing dates.

The coefficient of conversion from phytomass to rice is 0.5 for dry grain and 0.581 for 14%-moist grain.

The highest possible rice yield for different PAR income zones is computed by A.A. Nichiporovich's formula and shown in Table 5.1.

Table 5.1

Computation of the highest possible rice yield (MVY)

Climatic commonality	K_{PAR} Class	K_{PAR} Efficiency, %	PAR	Biomass yield, centner/ha	Main product (rice) yield, centner/ha	Main product yield (standard moisture regain 14 %), centner/ha
Transient	I	7 (6-8)	33.1	514.9	257.4	299.1
	II	4.25 (3.5-5)		312.6	156.3	181.6
	III	2.25 (3-1.5)		165.5	82.7	96.1
	IV	1.00 (1.5-0.5)		73.5	36.7	42.7
	Y	< 0.5		36.8	18.4	21.3
Normally used		**2.5**		**183.9**	**91.9**	**106.8**
Thermal	I	7 (6-8)	33.5	521.1	260.5	30,7
	II	4.25 (3.5-5)		316.4	158.2	183.8
	III	2.25 (3-1.5)		167.5	83.7	97.3
	IV	1.00 (1.5-0.5)		74.4	37.2	43.2
	Y	< 0.5		37.2	18.6	21.6
Normally used		**2.5**		**186.1**	**93.0**	**108.1**
Subtropical	I	7 (6-8)	35.1	54.6	273	317.2
	II	4.25 (3.5-5)		351	175.5	203.9
	III	2.25 (3-1.5)		175.5	87.7	101.9
	IV	1.00 (1.5-0.5)		78	39.0	45.3
	Y	< 0.5		39	19.5	22.6
Normally used		**2.5**		**195**	**97.5**	**113.3**

The highest possible yield of rice amounts to 273 centner/ha at peak values of coefficient of efficiency. For standard crops, 2.5 is a good indicator of coefficient of efficiency. In this case, the yield of ovendry grain varies from 91.9 centner/ha in transient zone to 97.5 centner/ha in subtropical zone and that of standard moisture grain ranges from 107 centner/ha to 113 centner/ha, respectively.

Example of computation: The highest possible rice yield (MVY) under climatic conditions of the Khorezm province for the fields with average crop conditions is computed by formula 1.2 (Chapter 1),

where:

$\sum Q_{PAR}$ – income of PAR during growing season, 33.1 kcal/cm^2;

η_{ϕ} – photosynthetic efficiency, 2.25 %;

q – yield caloricity, 4500 kcal/kg;

K – 0.581 (conversion from rice phytomass to standard moist grain).

The result of computation for the conditions of Karakalpakstan is as follows:

$$MVY = \frac{33.1\ \text{kcal/cm}^2}{4{,}500\ \text{kcal/kg}} \cdot 2.25\ \% \cdot 0.581 \cdot 10^4 = 96\ \text{centner/ha}$$

Hence, one may say that the biologically possible yield for given conditions is 96 centner/ha.

5.3. Computation of Potential Rice Yield (PY)

Rice differs from other studied crops in physiological process of its growing. He has largely different soil requirements and, therefore, the general algorithm for yield computation cannot be used for rice.

The potential yield (PY) is computed by formula:

$$PY = MVY \cdot K_{ocn} \cdot K_{gym} \quad (5.1)$$

Table 5.2

Example of computation of potential yield (PY) for rice (Karakalpakstan, RUz)

MVY centner/ha	K_{ocn}						K_{gum}				Losses for K_b centner/ha	PY centner/ha
	soil type	texture	automorph	thickness of fine grain soil	K_{ocn}	Losses for K_{ocn} Centner/ha	%	humus, t/ha	Red. coef	losses for K_{gum} centner/ha		
96.0	sierozem	light loam	semi automorph	> 100	0.90	8.8	0.50	31.1	0.65	31.0	39.8	56.2

5.4. Assessment of the Actual-Possible Rice Yield (DVY)

The actual-possible productivity is a yield, which is formed through such field parameters as salinity, nutrient content, diseases, infestation, weeding, and smoothness of the field.

It is well-known that salts have a negative effect on plants reflecting in an increase in osmotic pressure of soil water making it less available. Here both type and degree of salinity are of importance. Different soils may have the same amount of salts but, depending on their composition, be characterized by different degrees of salinity since various soluble salts differ in their toxic effect on plants.

As in the saline soil these are toxic salts that suppress growth of crops, it is preferably to classify soil in terms of degree of salinity not only by solid residue (S.V. Astapov) but also by the sum of toxic salts (Bazilevich-Pankova).

The relative salt tolence of crops can be classified as follows: tolerant crops – barley, sugar beet, cotton; moderately tolerant crops – wheat, oats, sorghum, soybean, alfalfa, sweet clover, rice, maize, sunflower; low tolerant crops - vetch, peas, beans, clover.

Table 5.11 shows degrees of rice salt tolerance according to FAO and yield potential, depending on electric conductivity of soil solution.

Table 5.3

Degrees of salt tolerance of rice (ECe and ECw) and yield potential, %

100 %		90 %		75 %		50 %		MAX
ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	12.0

ECe – electric conductivity of saturation soil extract, mmol/cm;

ECw - electric conductivity of irrigation water, mmol/cm.

The yield potential describes the degree of lowering of the rice field productivity depending on ECe and ECw.

Table 5.4

Rice requirements for soil (according to FAO)

Crop	Rating of crop tolerance	Demand for fertilizers N, P, K kg/ha for growing season
Rice	Moderately sensitive	100-150, 20-40, 80-120

The soil research laboratory of the SANIIRI Institute has made a calibration table for conversion from electric conductivity of soil solution to total salt content.

Opinions on salt resistance of rice vary. Most scholars refer rice to moderately tolerant crops, while others to low tolerant crops.

When speaking about salt tolerance of rice, besides nature and quantity of salts in the soil, it is desirable to consider the soil solution concentration and response of the medium while growing rice using the basin irrigation technique, especially under conditions of poor permeable ground.

Rice is most sensitive to soil salinity during sprouting and flowering. Salts make it difficult for plants to respire and impede photosynthesis.

The threshold concentration at which salinity has no negative effect on rice is 0.06 % for Na_2SO_4, 0.01 % for NaCℓ, and 0.006 % for Na_2CO_3.

Irrigation water reduces initial salinity; therefore, many authors conclude that given the well-operated drainage with timely disposal of drainage water, rice fields produce high yields.

Table 5.13 gives the yield response factor for cation exchange capacity.

According to CINAU's data, 3.2 kg/centner of nitrogen are needed per unit rice production.

The ratio of phosphorus to nitrogen under balanced nutrition should be 0.3-0.45 for rice. Availability of nutrients is estimated for each particular crop, in this context we distinguish:

1) crops of low nutrient removal – cereals;

2) crops of increased nutrient removal – root crops, potato;

3) crops of high nutrient removal – vegetables, fruits, technical crops, alfalfa.

Thus, availability of labile nutrients is assessed based on this classification.

Table 5.5

Yield response factor to cation exchange capacity (K_{ko}), %

No.	Cation exchange capacity, mg-eqv	Yield losses, %
01	0-5	0.84
02	6-10	0.87
03	11-20	0.90
04	21-30	0.92
05	31-40	0.95
06	41-50	0.98
07	51-60	1.00
08	61-80	1.00

The reduction coefficients for initial content of nitrogen, phosphorus, and potassium in the soil are shown in Table 5.14.

Table 5.6

Reduction coefficients for availability of nitrogen (K_N), phosphorus (K_P), and potassium (K_K) in the soil

Availability	Reduction coefficient for K_N, %	Reduction coefficient for K_P, %	Reduction coefficient for K_K, %
Very low	0.80	0.95	0.97
Low	0.90	0.98	0.99
Average	0.97	1.00	1.00
High	1.00	1.00	1.00

Diseases, pests, and weeds may substantially decrease yields and, therefore, these factors are critical in programming rice yield.

Weeds cause considerable damage to rice, with the most harmful being among them *Echinochloa phyllopogon*, barnyard grass (cereals), *Bolboschoenus*, nut grass, mace reed, common reed, rush, and some algae species (sedge family).

The most harmful pest is the *Haplothrips aculeatus*, which is widespread in Central Asia and affects crops everywhere (panicles are 15-20% damaged).

Besides thrips, the main rice pests are *Cricotopus silvestris*, *Ephydra macellaria Egger*, rice leaf miner, and aphid. Worms of *Cricotopus silvestris* damage rice by scraping off the back of rice leaves that are in contact with water. The economic injury level is one worm per plant at seedling stage. *Ephydra macellaria Egger* lays its eggs on young rice plants during germination. Its larvae eat rootlets and leaves, cause suppression, death and sparseness (economic injury level – 5-7 larvae per plant). Larvae of rice leaf miner mine the rice leaves leaving wide strips and the damaged leaves droop (economic injury level – 0.5-1 larva per plant).

Rice blast is a widespread disease. It can affect leaf, collar, node, neck, parts of panicle, and leaf sheath and appears as oval gray spots with red to brownish border. Leaves and tillers die off. If nodes are damaged, the stem inclines and breaks down. If panicle is affected, it dries off and breaks off, grain does not emerge or shrinks.

Bakanae disease of rice is also widespread. It affects the plant at all vegetative stages. Affected seedlings turn yellow and die. Lower leaves of adult plants also turn yellow and die. Distinct or indistinct brown spots may occur on leaves and sheaths. Adult plants do not die but stunt.

Level of weed harmfulness is determined by degree of weeding and floristic composition. Pest population density is estimated in scores or by number of pests per $1m^2$, number of affected plants, and number of accounted plants.

Reduction coefficients for weeding are shown in Tables 5.7 and 5.8.

Infestation by pests and diseases is determined by expertise. Assessment is given for all pests and diseases, and maximal indicators are used in estimations.

Table 5.9 gives reduction coefficients for plant infestation by pests and diseases.

Table 5.7

Reduction coefficients for weeding (K_{sor})
(no weed control), %

Group of weeds	Degree of weeding, %		
	poor	moderate	heavy
Annual and biennial monocotyledonous	0.98	0.95	0.88
Annual dicotyledonous	0.95	0.92	0.80
Perennial rhizome plants	0.92	0.85	0.70

Table 5.8

Reduction coefficients for weeding (K_{sor}) (weed control), %

Group of weeds	Degree of weeding, %		
	poor	moderate	heavy
Annual and biennial monocotyledonous	1.00	0.98	0.96
Annual dicotyledonous	1.00	0.97	0.95
Perennial rhizome plants	0.98	0.96	0.93

Table 5.9

Reduction coefficients for disease (K_{bol}) and pests (K_{vr}), %

	low, %	moderate, %	heavy, %
Disease	0.92	0.83	0.68
Pests	0.95	0.85	0.75

Table 5.10

Reduction coefficients (%) for land uniformity (K_f)

Ground smoothness	Deviation from '0' ground level, cm	Reduction coefficient, %
High (optimal)	0	1.00
Good	± 3 - ± 5	0.99
Average	± 5 - ± 10	0.95
Poor	± 10 - ± 15	0.88
Very poor	± 15 - ± 25	0.80

An important factor of crop yield is the uniformity of land (Table 5.10). Detailed research carried out in this field allowed identifying an impact of micro- and mesorelief on yields. Reduction coefficients for an impact of leveling defects on rice production are shown Table 5.11.

Table 5.11

Yield response factor to leveling defect (K_{ld}) against permissible height of surface (%)

N	Degree of field leveling, ± cm	Yield losses, %
00	0	1.00
01	0-1	0.98
02	1-2	0.96
03	2-3	0.92
04	3-4	0.87
05	4-5	0.80
06	5-6	0.72
07	7-8	0.61
08	8-10	0.50
09	10-12	0.40

The actual-possible yield (DVY) is calculated by:

$$DVY = PY \cdot (K_{ko} \cdot K_N \cdot K_P \cdot K_K \cdot K_{sor} \cdot K_{bol} \cdot K_{vr} \cdot K_f \cdot K_{ld}) \qquad (5.2)$$

Example of DVY computation for Shortanbai farm located in Karakalpakstan:

$$DVY = 56.2 - (2.3 + 0.0 + 0.0 + 2.5 + 0.0 + 1.2 + 0.0 + 3.5 + 2.5 + 0.0) =$$
$$= 44.2 \text{ centner/ha}$$
$$DVY = 56.2 - 12.0 = 44.2 \text{ centner/ha}$$

where:

PY = 56.2 centner/ha, yield losses = 12.0 centner/ha.

The most intensive period of nitrogen consumption by rice is the tillering and booting stages, during which about 75 % of the total nitrogen uptake is utilized.

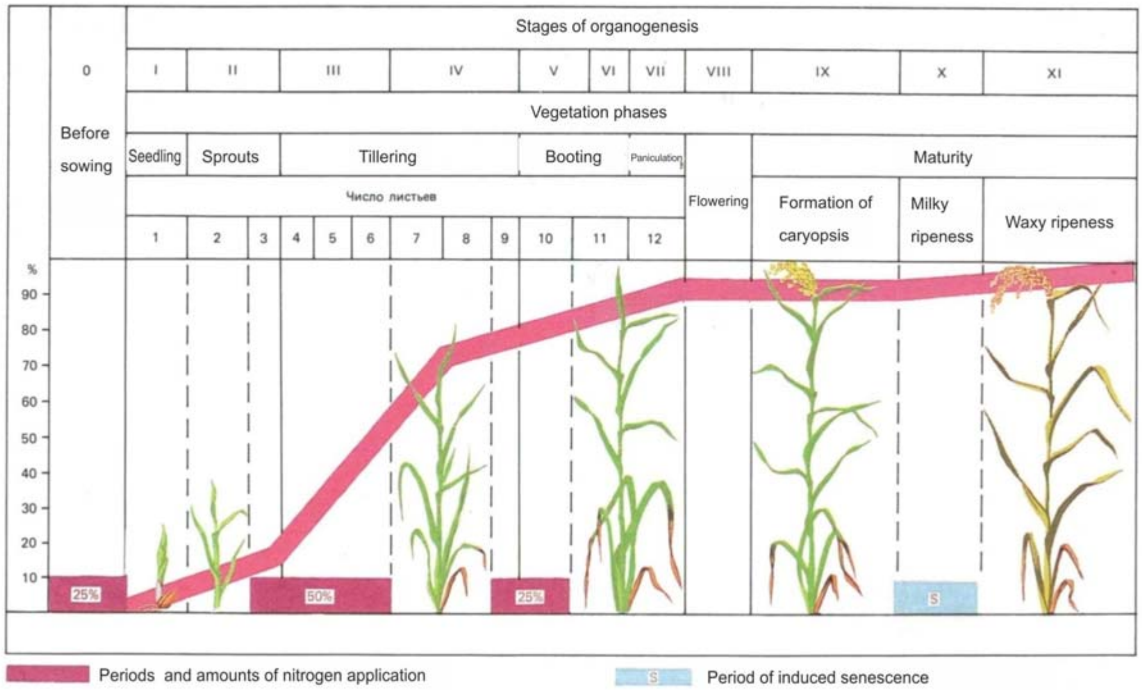


Figure 5.1. Nitrogen consumption by rice per growing stage

Intensive consumption of phosphorus by rice starts from the beginning of germination and seedling and ends during booting, whereafter only 15% of phosphorus compounds are utilized during flowering and maturing.

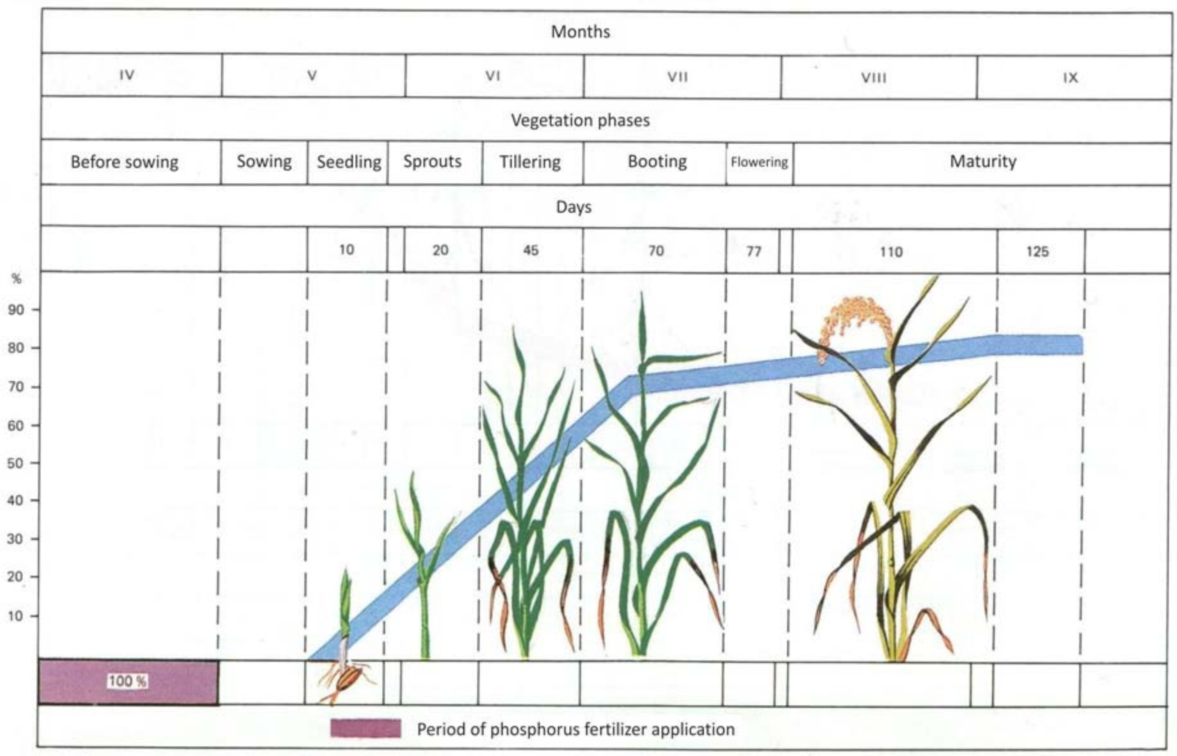


Figure 5.2. Phosphorus consumption by rice per growing stage

Intensive consumption of potassium by rice starts from the beginning of germination and seedling and ends during booting, whereafter only 12% of potassium compounds are utilized during flowering and maturing.

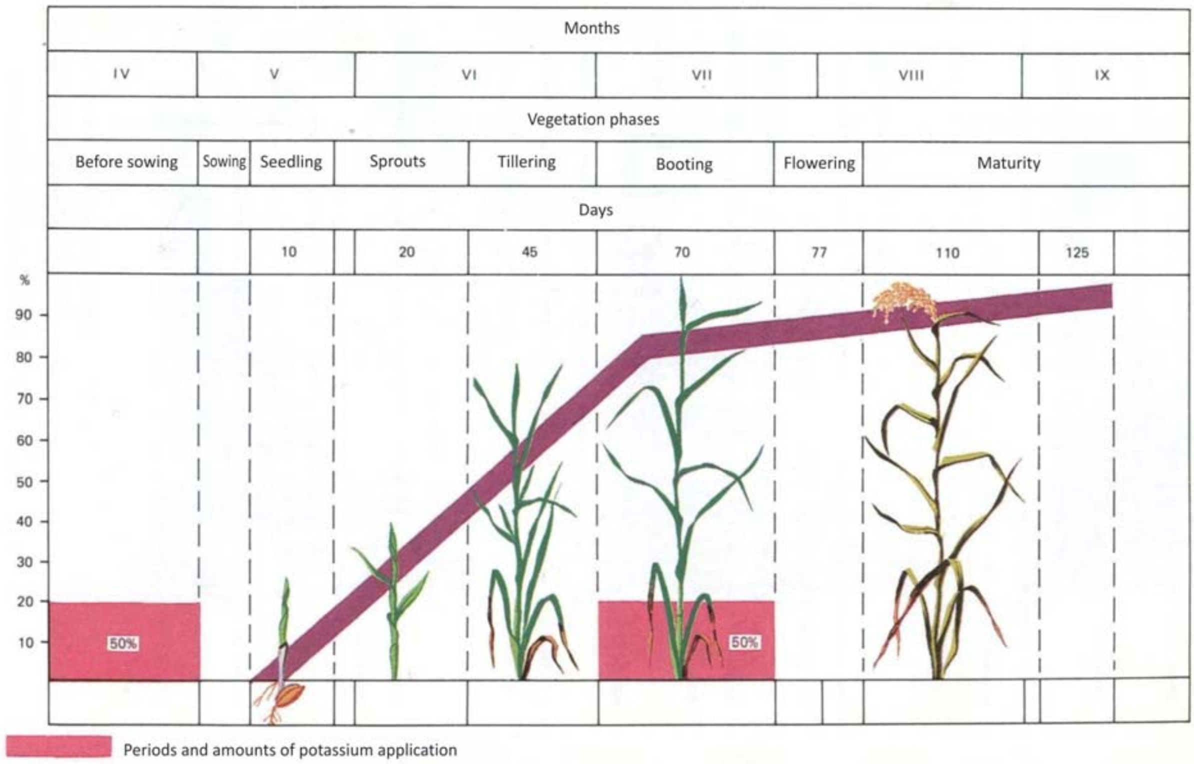


Figure 5.3. Potassium consumption by rice per growing stage

Figure 5.4 shows information on rice protection measures against main diseases, with indication of dates and doses of protecting agents.

Figure 5.5 shows information on rice protection measures against main pests, with indication of dates and doses of protecting agents.

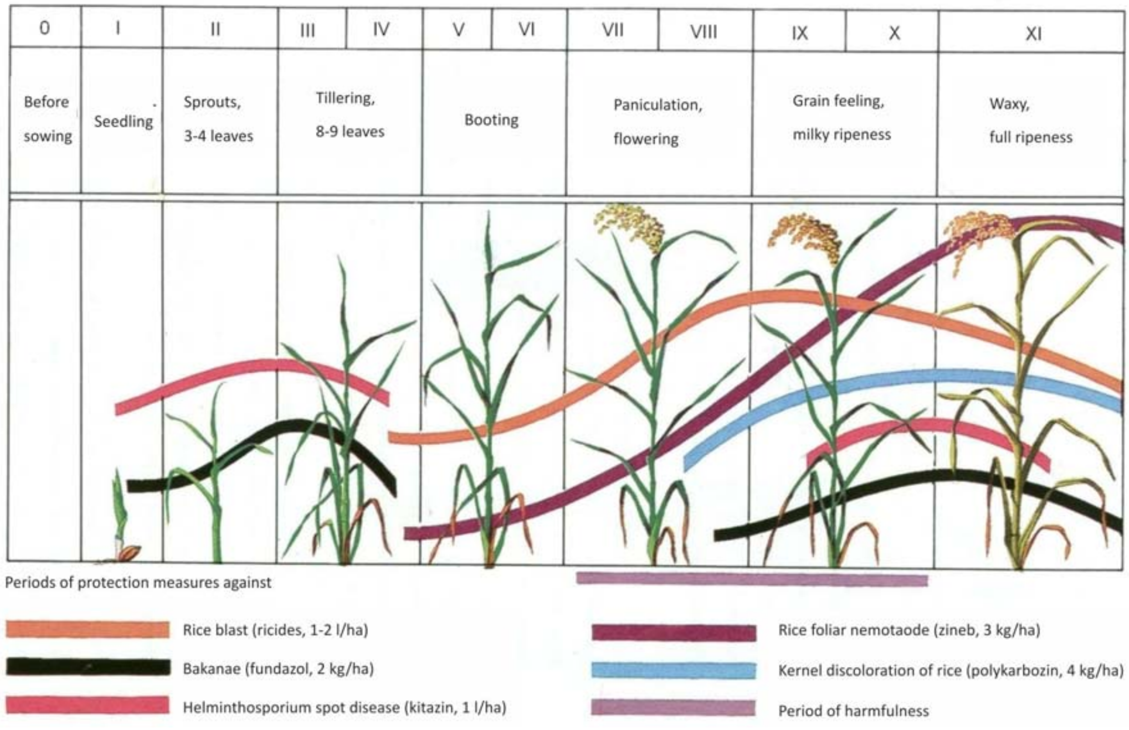


Figure 5.4. Rice protection from diseases by organogenesis stage

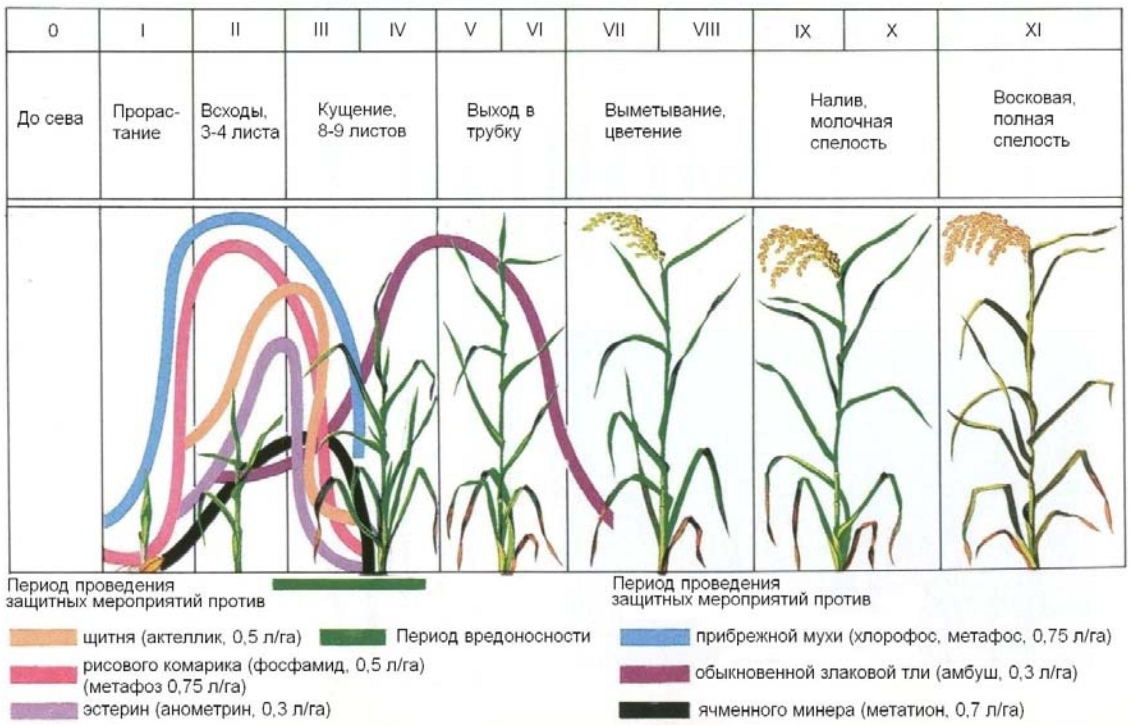


Figure 5.5. Rice protection from pests by organogenesis stage

5.5. Assessment of Actual Rice Yield (YH) in Farm

The actual crop productivity is assessed in particular field depending on performance quality of technological process and provision with resources (fertilizers, chemicals, irrigation water, personnel).

Table 5.12 shows dependence of rice yield on technological factors.

The recommended rates of NPK application by growing stage are given in Figures 5.1 - 5.3.

In addition, the recommended rates of fertilizer application for achievement of high rice yields are as follows: nitrogen - 200-220 kg/ha under 100% of nutrients; phosphorus - 140-145 kg/ha; and, potassium - 150-180 kg/ha.

Table 5.12

Dependence of the actual rice yield (YH) in farm on technological factors

	Factor	**Deviation from the norm, %**			
		low (A) to 15 %	**moderate (B) to 25 %**	**high (C) to 40 %**	**0**
P_1	Provision with labor resources	0.98	0.92	0.85	1.0
P_2	Provision with equipment and transport	0.96	0.90	0.80	1.0
P_3	Quality of technological operations, deviation from the zonal technology recommendations	0.95	0.87	0.75	1.0
P_4	Provision with chemicals, fertilizers (resource provision)	0.92	0.80	0.65	1.0
P_5	Provision with water	0.99	0.95	0.85	1.0

The actual rice yield (YH) in farm is calculated by the following formula:

$$YH = DVY \cdot P_1 \cdot P_2 \cdot K_3 \cdot P_4 \cdot P_5 \qquad (5.3)$$

Example of YH computation for Shortanbai farm located in Karakalpakstan:

$$YH = 44.2 – (0.0+1.1+2.9+0.4+0.0+0.0) = 39.8 \text{ centner/ha}$$

$$YH = 44.2 – 4.4 + 39.8 \text{ centner/ha}$$

where

DVY = 44.2 centner/ha, yield losses = 4.4 centner/ha

5.6. Rice Irrigation Regime

Irrigation regime almost for all rice-production zones in Central Asia is based on permanent or shortened flood irrigation of crops (irrigation schedules are shown in Figures 5.6 - 5.8).

When sowing depth is 1-2 cm, initial flooding of checks is performed no later than in 1-2 days after sowing. The water layer depth is 10-12 cm.

When rice is sown earlier to a depth of 4-5 cm and watered checks are treated, initial flooding is not performed as sprouts emerge under natural soil moisture.

The duration of initial flooding depends on status of sprouting.

Repeated flooding is performed:

1. without application of grass weed killers after emergence of first leaf of rice and no more than 2 leaves of bristle grass. The depth of water layer should be not less than 12-15 cm and overtop weeds by 5-7 cm.

   The duration of flooding depends on time when weeds die off. The depth of water layer after killing of weeds is 5 cm during formation of 5-7 leaves and 10-12 cm since emergence of 8^{th} leaf until waxy ripeness.

2. with application of grass weed killers: propanide and its analogs.

   After sprouting, wetting irrigation is performed before formation of 2-3 leaves of bristle grass. The field is dried a little before treatment with herbicides.

   In two days after treatment of crops with herbicides, water is applied to form a water layer 10-12 cm deep and this layer is maintained until complete killing of weeds. Then similar irrigation regime is kept.

3. When applying grass weed killers during germination, wetting irrigation is performed. The permanent water layer of 5-7 cm is maintained after emergence of 2-3 leaves.

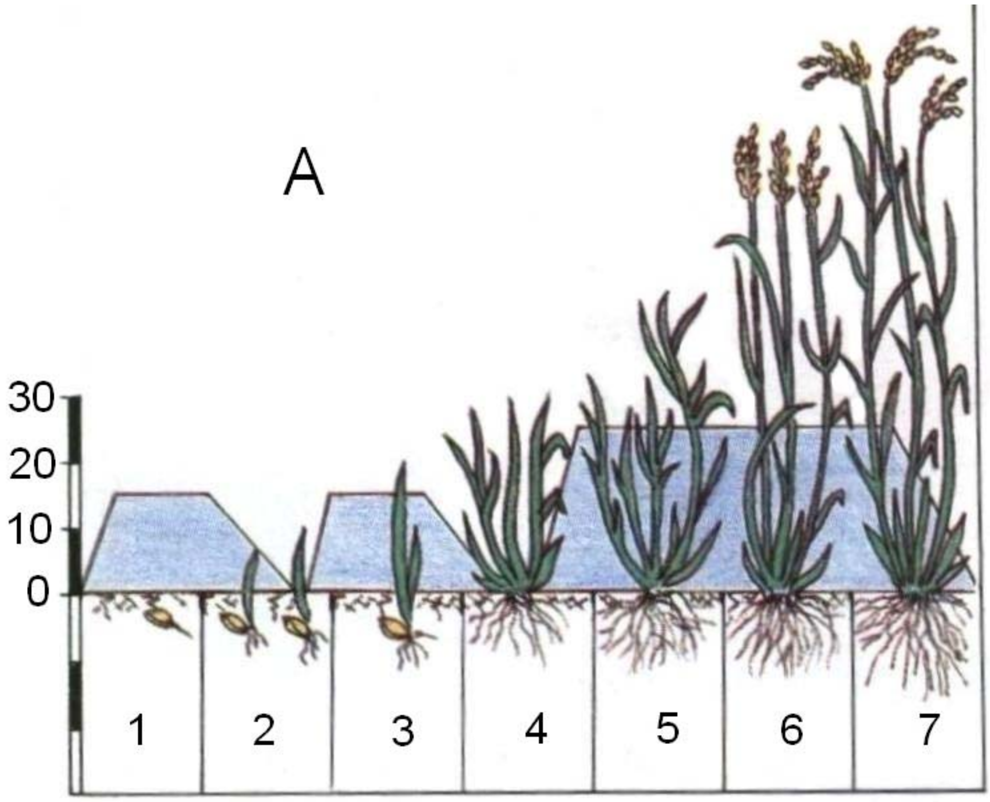


Figure 5.6. Rice irrigation scheduling for non-saline soil

1 – sowing – germination; 2 – germination – first sprouts;

3 – lodged sprouts – beginning of tillering; 4 – tillering;

5 – booting; 6 – paniculation – milky ripeness;

7 – waxy ripeness – full maturity.

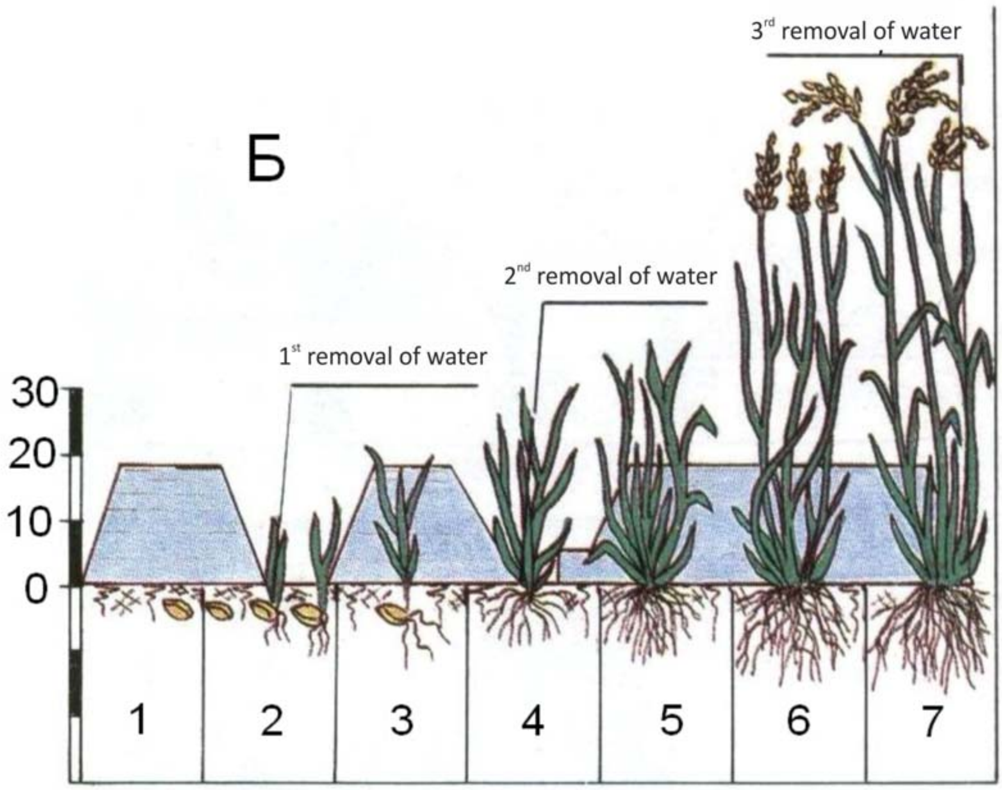


Figure 5.7. Rice irrigation scheduling for saline soil

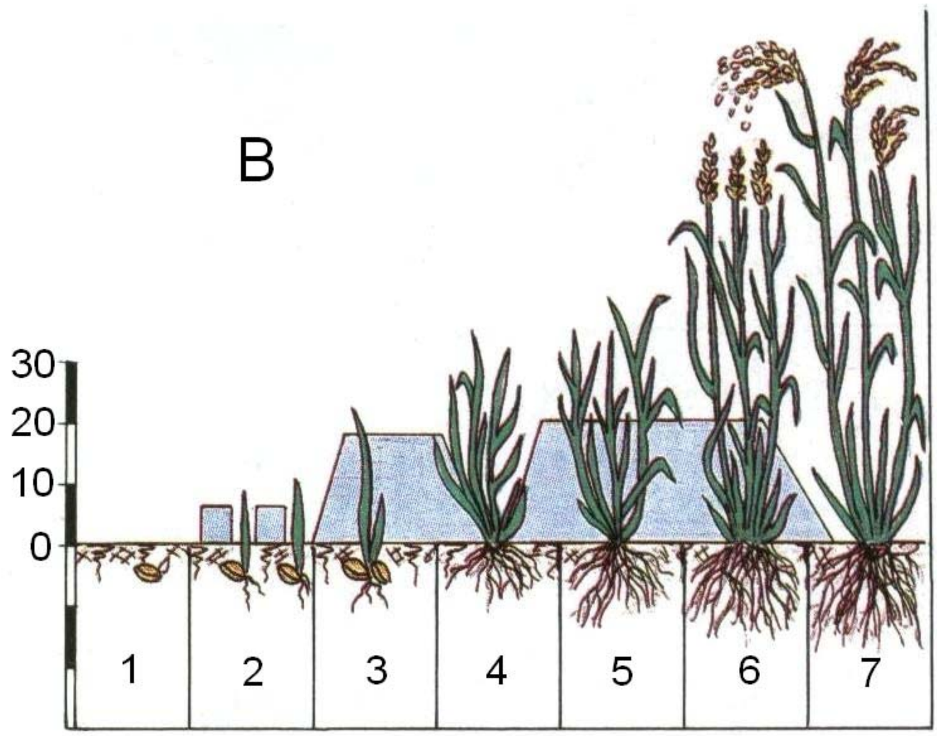


Figure 5.8. Rice irrigation scheduling for early deep sowing

In next growth phases, since tillering, the irrigation schedule is similar to the regime, where grass weed killers are not applied.

In case of saline soil, during germination and sprouting and then in the beginning of tillering water is drained and again a water layer is formed with a depth of 20-25 cm, which is maintained until waxy ripeness, with the following gradual lowering of this layer so that the field become dry 10-12 days before harvesting.

An optimal irrigation regime in the fields clean from weeds, where application of herbicides is not needed, looks as follows: a water layer is formed after the stage of fully sprouted seed rice and gradually increased so that to overtop bristle grass by 5-7 cm (the total depth of the layer should not exceed 20-25 cm) until emergence of 3-4 leaves; after that application of water is stopped and the layer gradually decreases to 0-5 cm. Additional fertilizing of rice is made during this period of time (tillering phase).

6. Potato Productivity Assessment Algorithm

Potato is one of the most important foodstuffs for people and items for nutrition of animals. It is fifth among energy sources in diet after wheat, maize, rice, and barley. It is popular as "second bread". Besides, potato is an important raw material for a number of industries. 100 g of potato tubers produce 301.5 kJ or 72 kcal of energy.

In many countries, potato is a crop, which generates largest output of dry matter, energy, and protein per unit area. For example, sugar beet has the highest average production of energy per hectare and potato shows slightly lower figures.

As to output of protein per unit area, potato takes second position after legumes. The potato yield of 13.6 t/ha gives the output of protein at 273 kg/ha. Increase of potato production may substantially contribute to food supply, particularly provision with protein.

Potato is of high agronomic importance as well. It is a good plant to sow before other crops. Among all row crops, potato is the best one in cleaning from weeds. It helps to control weeds during preplant treatment and interrow tillage, and, with good density, potato closes up in a relatively short time (in 7-10 days after the last cultivation), thus suppressing weeds. Besides, the remained weeds are rooted out during harvesting of potato.

6.1. Computation of the Highest Possible Potato Yield (MVY)

The main components of the formula for computation of the highest possible yield are the photoactive radiation, photosynthetic efficiency, yield caloricity, and the coefficient of conversion from total plant biomass to yield (Chapter 1, formula 1.2),

where for potato

$\sum Q_{PAR}$– total average long-term influx of PAR during growing season – $52.0 \cdot 10^8$, kcal/cm^2 per hectare;

q – yield caloricity (4300 kcal/kg);

η_f – photosynthetic efficiency = 2-3 %; (6.1)

K – coefficient of conversion from phytomass to yield = 2.5.

Computation of the highest possible yield for potato is shown in Table 6.1. The computation was made for early, mid, and late-season varieties that uptake different quantities of solar radiation - 20, 23 and 27 kcal/cm^2, respectively. The average utilization of solar radiation by potato is 3 % PAR. However, this value is true only for light, well-aerated and fertile soils. In practice, the coefficient of PAR use for potato varies from 0.8 to 2.5 %. Potato yield caloricity is 4,300 kcal/kg. The ratio of tubers to tops is 1 usually, i.e. 100 centners of raw biomass (both tubers and tops) contains on average 20 centners of dry organic matter and 80% of water.

The coefficient of conversion from dry biomass to yield (tubers, standard moisture regain 80%) is equal to 2.5. The computed highest possible yield of potato tubers at 80% of standard moisture is 53 centner/ha to 955 centner/ha, depending on photosynthetic efficiency and climatic zones. Given the photosynthetic efficiency 1-2%, the highest possible yield ranges from 101 centner/ha to 240 centner/ha for transient zone, 126 – 283 centner/ha for thermal zone, and 137 - 307 centner/ha for subtropical zone.

Table 6.1

Computation of MVY for early, mid, and late-season varieties of potato

Class	**Photosynthetic efficiency, %**	**MVY, center/ha**	
		dry mass	**tubers standard moisture (80 %)**
Transient zone. Early-season variety, PAR influx = 20 kcal/cm^2			
I	7.0(6-8)	140	747
II	4.2(3.5-5)	85	454
III	2.2(3-1.5)	45	240
IV	1.0(1.5-0.5)	20	101
Y	< 0.5	10	53
Thermal zone. Mid-season variety, PAR influx = 23 kcal/cm^2			
I	7.0(6-8)	187	879
II	4.2(3.5-5)	114	534
III	2.2(3-1.5)	60	283
IV	1.0(1.5-0.5)	27	126
Y	< 0.5	13	63
Subtropical zone. Late-season variety, PAR influx = 55 kcal/cm^2			
I	7.0(6-8)	802	955
II	4.2(3.5-5)	487	580
III	2.2(3-1.5)	258	307
IV	1.0(1.5-0.5)	115	137
Y	< 0.5	57	68

Based on climatic requirements of potato, it is recommended to grow early-season varieties in the transient zone, mid-season varieties in thermal zone, and late-season potato in subtropical zone.

6.2. Computation of Potential Potato Yield (PY)

Potential level of crop productivity is the yield that can be reached under specific soil-climatic conditions of given year. PY is computed by formula:

$$PY = MVY \cdot K_b \tag{6.2}$$

where

MVY – the highest possible yield;

K_b – coefficient of soil bonitet, which is calculated using the formula:

$$K_b = K_{ocn} \cdot K_{gum} \tag{6.3}$$

where

K_{ocn} – main bonitet score,

K_{gum} – reduction coefficient for humus content in soil.

K_{ocn} is taken according to the irrigated soil bonitet scale, depending on zonal location of given site, granulometric composition, automorphy or hydromorphy of soil, and thickness of fine grained soil (see Chapter 2, Table 2.2).

Table 6.2 shows the values of the reduction coefficient for humus content (K_{gum}), which is computed as the average for soil phase in t/ha (see Chapter 2, formula 2.3).

The highest possible yield (MVY) of late-season potato grown in the Fergana Province, Republic of Uzbekistan is:

MVY = 580 centner/ha (weight of tubers at standard moisture = 80 %)

Example of potential yield (PY) computation for late-season varieties grown in the Fergana Province

$PY = MVY \cdot K_b$, where: $K_b = K_{ocn} \cdot K_{gym}$

The reduction coefficient K_{ocn} is 0.95 (yield reduction by 27.8 centner/ha).

The reduction coefficient K_{gym} is 0.80 (yield reduction by 111.4 centner/ha).

The total yield reduction is 139,2 centner/ha

Computation: PY = 580 centner/ha – 139.2 centner/ha = 440.8 centner/ha

6.3. Potato Development Stages and Temperature Requirements

Roots of potato start to emerge at the temperature not below than 7°C. The tops start to grow at 5-6°C and its most intensive growth starts at 17-22°C. An optimal temperature for assimilation is about 20°C (25°C in the daytime and 12-14°C in the night). The temperature at 29-30°C slows down the growth. Tops stop to grow if the temperature is higher than 40°C. In spring, at -1.5 − -2°C tops die but grow again when positive temperatures are established. However, yields decrease in this case because of delayed development of plants.

An optimal temperature for potato flowering and tuber formation is 18-24°C. When the temperature is higher than 27°C, buds and flowers drop and tuber formation becomes stunted.

The most important period for potato development is tuber formation, which coincides with budding. This period is very critical in terms of temperature. An optimal soil temperature for tuber formation is 16-19°C, and this corresponds to the air temperature at 21-25°C. With the soil temperature at 6°C and higher than 23°C the growth of tubers is retarded and stops completely at the soil temperature of 28-29°C.

6.4. Computation of the Actual-Possible Potato Yield (DVY)

The actual-possible productivity is a yield, which is formed through such field parameters as salinity, nutrient content, diseases, pest infestation, weeding, and uniformity of the field.

It is well-known that salts have a negative effect on plants reflecting in an increase in osmotic pressure of soil water making it less available. Here both type and degree of salinity are of importance. Different soils may have the same amount of salts but, depending on their composition, be characterized by different degrees of salinity since various soluble salts differ in their toxic effect on plants.

As in the saline soil these are toxic salts that suppress growth of crops, it is preferably to classify soil in terms of degree of salinity not only by solid residue but also by the sum of toxic salts.

The relative salt tolerance of crops can be classified as follows: tolerant crops – barley, sugar beet, cotton; moderately tolerant crops – wheat, oats, sorghum, soybean, alfalfa, sweet clover, rice, maize, sunflower; low tolerant crops - vetch, peas, beans, clover.

Table 6.2 gives degrees of salt tolerance of potato according to FAO and yield potential, depending on electric conductivity of soil solution.

Table 6.2

Degrees of salt tolerance of potato (ECe and ECw) and yield potential, %

Yield potential, %								
100 %		**90 %**		**75 %**		**50 %**		**MAX**
ECe	ECw	ECe	ECw	ECe	ECw	ECe	ECw	ECe
1.7	1.1	2.5	1.7	3.8	2.5	3.9	3.9	10.0

ECe – electric conductivity of saturated soil extract, mmol/cm;

ECw - electric conductivity of irrigation water, mmol/cm.

The yield potential describes the degree of lowering of the potato field productivity depending on ECe and ECw.

Table 6.3

Crop requirements for soil (FAO)

Crop	**Rating of crop tolerance**
Potato	Moderately sensitive

The reduction coefficients for salinity are similar to those of cotton (see Chapter 2, Tables 2.6 and 2.7).

According to CINAU's data, 2.5 kg/centner of nitrogen are needed per unit potato production.

The ratio of phosphorus to nitrogen under balanced nutrition should be 0.3-0.5 for potato.

Table 6.4

Soil assessment by degree of availability of nitrogen (N- NH_3) and phosphorus (P_20_5), mg/kg

Availability	**N-NH_3**	**P_20_5**
Very low	< 20	< 30
Low	21-30	< 80
Average	31-50	80-150
High	51-65	> 150

Table 6.5

Soil assessment by degree of availability of potassium (K_2O), mg/kg

Availability	K_2O
Very low	< 100
Low	100-250
Average	250-350
High	> 350

Yield dependence on nitrogen, phosphorus, and potassium contents is considered in computation of the actual-possible yield by adding reduction coefficients for availability of such nutrients.

Reduction coefficients for initial content of nitrogen, phosphorus and potassium in the soil are given in Table 6.6.

Table 6.6

Reduction coefficients for availability of nitrogen (N), phosphorus (P) and potassium (K), %

Availability	Reduction coefficient for N, %	Reduction coefficient for P, %	Reduction coefficient for K, %
Very low	0.80	0.83	0.97
Low	0.90	0.90	0.99
Average	0.94	0.95	1.00
High	1.00	1.00	1.00

Diseases, pests, and weeds may substantially decrease yields and, therefore, these factors are critical in programming rice yield under conditions of current deficit of plant protection agents.

Table 6.7

Reduction coefficients for weeding (K_{sor})
(no weed control), %

Group of weeds	Degree of weeding, %		
	poor	moderate	heavy
Annual and biennial monocotyledonous	0.96	0.92	0.83
Annual dicotyledonous	0.95	0.90	0.80
Perennial rhizome plants	0.92	0.83	0.65

Table 6.8

Reduction coefficients for weeding (K_{sor})
(weed control), %

Group of weeds	Degree of weeding, %		
	poor	moderate	heavy
Annual and biennial monocotyledonous	1.00	0.98	0.96
Annual dicotyledonous	1.00	0.97	0.95
Perennial rhizome plants	0.98	0.96	0.93

Table 6.9

Reduction coefficients for disease (K_{bol}) and pests (K_{vr}), %

Degree of infestation	**low**	**moderate**	**heavy**
Disease	0.92	0.83	0.68
Pests	0.95	0.85	0.75

Reduction coefficients (%) for field uniformity are shown in Chapter 2, Table 2.15.

An important factor of crop yield is the uniformity of land. Detailed research carried out in this area allowed identifying an impact of micro- and mesorelief on yields.

Example of the actual-possible yield (DVY) computation for late-season potato varieties grown in the Fergana province, Republic of Uzbekistan

$$DVY = PY \cdot K_c \cdot K_{sor} \cdot K_N \cdot K_P \cdot K_K \cdot K_{bol} \cdot K_{vr} \cdot K_f \quad (5.2)$$

DVY = 440.8 – (0.0 + 18.3 + 22.0 + 18.3 + 0.0 + 62.3 + 62.3 + 0.0) = 257.6 centner/ha

DVY = 440.8 centner/ha – 183.2 centner/ha = 257.6 centner/ha

where: PY = 440.8 centner/ha, yield losses = 183.2 centner/ha.

6.5. Computation of the Actual Yield (YH) in Farm

The actual crop productivity is assessed in particular field depending on performance quality of technological process and provision with resources (fertilizers, chemicals, irrigation water, personnel).

In order to determine degree of provision with a factor of production, it is necessary to have actual and planned (standard) indicators. Standard indicators of technological process performance are the zonal operations sequence charts for crop production. Deviation from standard technological process is assessed by two indicators: poor quality of technological operations and deviation from zonal technology.

Table 6.10

Computation of the actual potato yield (YH)

Factor		Deviation from the norm, %			
		low (A) to 15 %	moderate (B) to 25 %	high (C) to 40 %	0
P_1	Provision with labor resources	0.98	0.92	0.85	1.0
P_2	Provision with equipment and transport	0.96	0.90	0.80	1.0
P_3	Deviation from the zonal technology	0.95	0.85	0.70	1.0
P_4	Provision with chemicals, fertilizers (resource provision)	0.92	0.80	0.65	1.0
P_5	Provision with water	0.93	0.89	0.76	1.1

Example of computation of the actual yield (RY) for late-season potato grown in the Fergana province, Republic of Uzbekistan

$$YH = DVY - (K_{mech\ labor} \cdot K_{manual\ labor} \cdot K_{technology\ deviation} \cdot K_{resource\ provision})$$

YH = 257.6 centner/ha – (5.1 centner/ha + 0.0 + 12.7 centner/ha + 0.0 +0.0) =

= 239.8 centner/ha

YH = 257.6 centner/ha -17.8 centner/ha = 239.8 centner/ha

where:

DVY = 257.6 centner/ha, yield losses = 17.8 centner/ha.

6.6. Potato Irrigation Regime and Yield Losses Depending on Water Availability During Growing Season

Irrigation is scheduled in such a way so that to make water available for plants during critical periods, when the plants are particularly sensitive to drying of the soil. The following phases are critical for potato in terms of water: budding and intensive root formation.

Potato needs for water are determined by saturation of potato tissues with water (75-85%), emergence of comparatively large evaporating overground part of the plant, degree of development, near-surface location of the rooting system and level of formed tuber yield.

For production of 10 t/ha of dry matter (≈ 50 t/ha of tubers) 3,000 t of water or 300-400 mm of rainfall are needed. Moreover, uniform distribution of water is also important during the growing season.

Water demands of potato vary with growing phases. Water of the maternal tuber is enough during germination. In this period, potato does not depend on soil water and only needs heat and oxygen. This time potato is not so sensitive to drought as in other periods. Therefore, dry spring with quick warming of the soil is good for early spring sowing of potato. If the soil is extremely dry, water of the maternal tuber is not enough for germination and the roots develop poorly, while sprouting is delayed. For summer sowing, when the temperature is very high and the soil become warm and dry quickly, potato should be sown after pre-sowing irrigation or should be watered just right after sowing under conditions of Uzbekistan.

Before tuber formation, water demand of potato is low but then until the end of flowing it needs sufficient quantities of water. With development of overground mass and increase of leaf area, the needs for water increase, with maximum being reached during budding and flowing, when tubers develop. During growing, 80-100 liters of water are used on average for formation of 1 kg of tubers. Maximum growth of the tops is observed when the soil moisture is 70-85% FC, while that of tubers under 85-95% FC. At the end of growth and development, potato needs for water decrease again. High content of water in the soil contributes to growth of tubers but the latter have low content of dry matter, loose skin and poor keeping capacity.

Despite high demands for soil water, potato can stand short droughts. When drought occurs, productivity of potato decreases but the plants do not die and tuber formation starts again if moisture increases. Potato yield abruptly drops if drought is prolonged (soil moisture below 50% FC).

Moisture stress during tuber formation prevents emergence of stolons and, consequently, leads to reduced number of formed tubers. Growth of tubers stops if water is deficient. All this has a negative effect on size of tubers and on yield. The skin of tubers becomes hard.

Potato response negatively to over-moistening. Excess of water in the soil, similar to its deficiency, has a negative effect on potato yield. Contents of dry matter and starch decrease in tubers and the plants are more subjected to diseases. Increased content of water during maturity phase delays maturing of tubers, while lack of air leads to their suppression and the tubers become unfit for consumption.

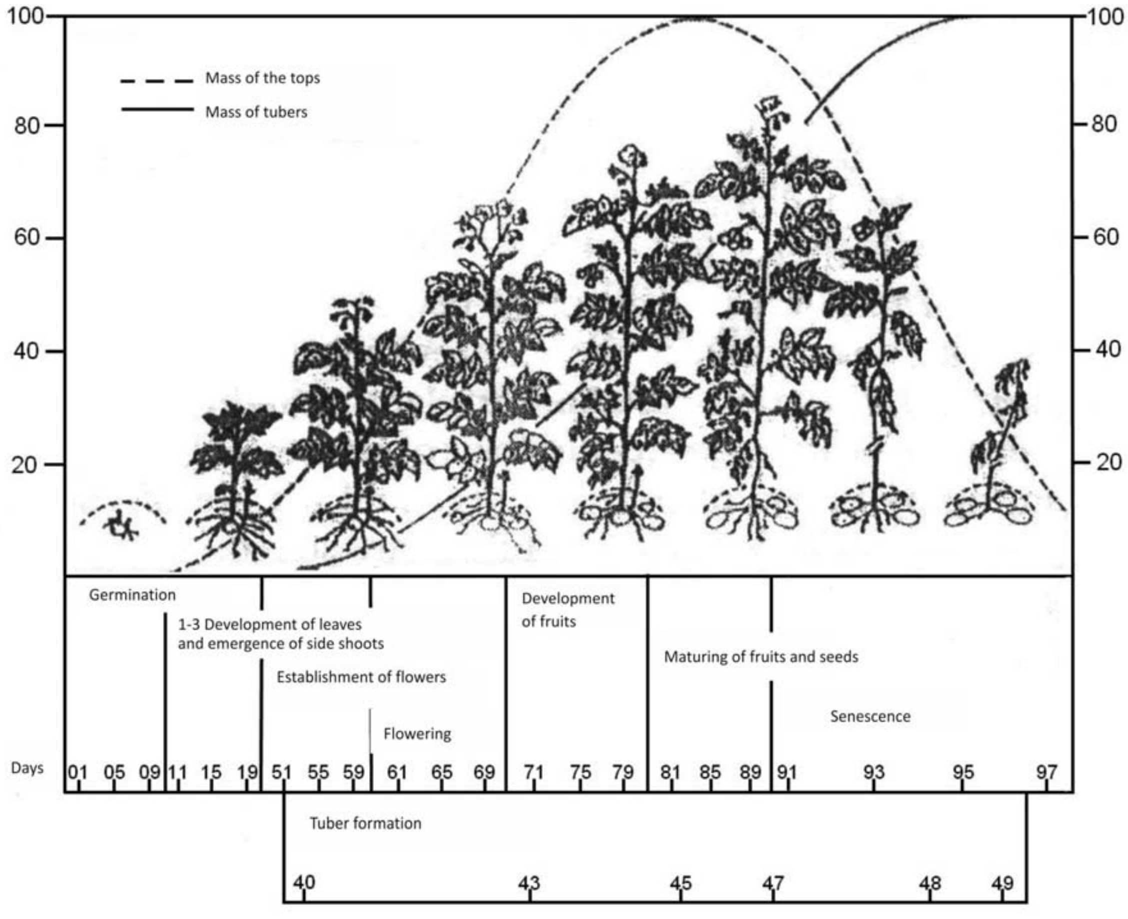


Figure 6.1.Potato development stages

The best conditions for growth and formation of tuber yield are created when the soil moisture is 70-85% FC. Here, yield increase over five days is 20-30 centner/ha on average, whereas in case of moisture stress during flowering, potato yield may decrease by 50% and more. In valleys, 4-5 irrigation events for early-season potato and 8-10 irrigation events for late-season potato are needed in order to maintain optimal moisture in the soil. For mountain areas, potato is watered 4-6 times during growing season. The soil with closely bedded groundwater is irrigated 2-4 times, while stony soil, 8-14 times. First furrow vegetative irrigation of potato should be performed during budding, the second irrigation, in 10-15 days after the first irrigation, and next irrigation events are performed, depending on weather conditions, on average in 7-12 days with a depth of 500-700 m^3/ha. 12-15 days before harvesting in mountain area and 7-10 days in valley area irrigation should be stopped.

Lowering of soil moisture to the optimal for potato level marks the date of next irrigation event.

The irrigation depth is computed by formula:

$$m = (V_1 \cdot P - V_2 \cdot P) \cdot h + K \qquad (6.4)$$

where

m – irrigation depth, m^3/ha;

h – depth of design soil layer, m;

P – bulk soil density, t/m^3;

V_1 – field capacity of the design layer, % of its dry mass;

V_2 – soil moisture before irrigation, % of dry mass,

K – water losses through evaporation during irrigation, equal to 10% of soil water deficit before irrigation.

Example of computation: depth of design soil layer — 0.4 m; bulk density of this layer — 1.25 t/m^3; field capacity in this layer — 28.5%; soil moisture before irrigation — 22.8% FC.

By inserting these values in the formula, we get water quantity, which is required to bring soil moisture to field capacity.

$$m = 100 \cdot 0.4 \text{ m} \cdot 1.25 \text{ t/m3} \cdot (28.5\% - 22.8\%) = 285 \text{ m}^3\text{/ha}$$

In setting irrigation depth, one should take into account water losses through evaporation. For example, about 10-15% of water evaporates in hot weather. Therefore, irrigation depth is increased accordingly to amount to 314-328 m^3/ha.

One should note that up to 10 mm of rainfall are not accounted in scheduling irrigation. Rainfall from 10 to 25 mm allows shifting date of irrigation to 3-6 days. Rainfall in the amount of 30 mm and more replaces next irrigation event.

Critical periods of potato in terms of water, when moisture stress causes significant reduction of yield, are well defined. These are intensive budding and flowering.

It is recommended to maintain the antecedent soil water at a level of 80% FC for potato. Spring sown potato is irrigated 3-4 times (at a depth of m^3/ha) with 9-12 days interval (taking into account rainfall) during growing season.

The best time for irrigation is cool time of day. Summer sown potato is watered every 8-10 days, depending on air temperature. The depth of water is roughly the same as in spring sowing. However, at high air temperature, the depth of irrigation is increased to 500 m^3/ha for account of evaporation. Watering is stopped two weeks before harvesting as high soil moisture during this period lowers quality and storage time of tubers.

An important condition for efficient furrow irrigation is the right choice of irrigating stream and length of furrow that correspond to soil permeability, irrigation furrow slope and established irrigation depth. The higher permeability of the soil, the shorter should be furrow and the larger irrigating stream should be. And vice versa, for low permeable soil furrows should be longer and irrigating streams should be smaller.

Irrigation is scheduled in such a way so that to make water available for plants during critical periods, when the plants are particularly sensitive to drying of the soil. The following phases are critical for potato in terms of water: budding and intensive root formation.

In case of optimal water availability for irrigated crops, the reduction coefficient for water factor is not applied as a priori it equals 1. Water regime should be optimized and controlled based on recommendations of a water duty zoning (the so called “hydromodule zoning”) and crop irrigation schedule (Stulina G.V., 2010).

Example of potato irrigation schedule for VIII hydromodule zone.

Table 6.11

Potato irrigation schedule for VIII hydromodule zone

Crop	Irrigation norm, m^3/ha	No. of irrigation event	Irrigation depth, m^3/ha	Irrigation dates		Irrigation interval, days
				beginning	end	
Potato	10,100	1	600	26.03	10.04	16
		2	600	11.04	25.04	15
		3	600	26.04	10.05	15
		4	600	11.05	25.05	15
		5	600	26.05	10.06	16
		6	600	11.06	20.06	10
		7	700	21.06	30.06	10
		8	700	1.07	10.07	10
		9	700	11.07	20.07	10
		10	700	21.07	31.07	11
		11	700	1.08	10.08	10
		12	600	11.08	20.08	10
		13	600	21.08	31.08	11
		14	600	1.09	15.09	15
		15	600	16.09	30.09	15
		16	600	1.10	15.10	15

Table 6.12

Approximate depths and dates for potato irrigation by development stage

Parameters	Irrigation event						Number of irrigat events	Irrigat norm, m^3/ha
	0	1st	2nd	3rd	4th	5th		
Development phase		beginning of tillering	Budding				6	4,400
Dates	Before sowing	In 20-25 days after sowing	In 55-60 days after sowing	In 10- days after 2nd irrigation event	In 7-12 days after 3rd irrigation event	In 7-15 days after 4th irrigation event		
Irrigation depth, m^3/ha	700	700	700	700	800	800		

Table 6.13

Average yield losses depending on water supply to potato (with orientation to optimal supply) during growing season [22]

Water supply, %	
90	0.04
80	0.14
70	0.24
60	0.34
50	0.44

7. Algorithm of Alfalfa Productivity Assessment

7.1. Biological Characteristics of the Crop

Under conditions of Central Asia, alfalfa is sole among food crops in terms of green biomass and hay yield. This crop contributes to improvement of soil conditions and is good as first crop in crop rotation.

With intensive technology, 250-300 centners of dry hay (1 kg of which equates 0.5 of fodder units or 0.5 kg of barley or oats) or 125-150 centners of grain can be produced per hectare. Green mass, hay, silage, haylage, grass meal and cakes are excellent forage rich of proteins, mineral elements and vitamins for livestock and poultry.

Alfalfa can develop extensive root system and after 2-3 years standing in the 50 cm soil layer accumulates up to 15-20 tons and more of root and crop residues that substantially improve physical-mechanical, chemical and water-air properties of the soil. As leguminous plant, it has nodule bacteria on the roots that enrich soil with biological nitrogen. Up to 700-750 kg of biological nitrogen is accumulated in the soil over 2-3 years standing of crop. Thanks to its phytosanitary properties, alfalfa disinfects the soil from a number of malignant bacteria and viruses. Thus, alfalfa is also an essential forecrop in crop rotation and the soil improver, which increases its fertility.

Alfalfa prefers soil with neutral or mildly alkaline reaction (pH = 7.5-8.0). In the acid soil, development of nodule bacteria is delayed and capacity to fix free nitrogen decreases. This leads to abrupt fall of alfalfa yield.

The recommended seed application rate is 15-20 kg/ha; the row spacing of approximately 15 cm provides density of crops as 600-700 culms per 1 m^2 or 6-9 million per hectare.

For production of 130-150 centners/ha of hay, 40-50 kg of active ingredient of nitrogen, 90-120 kg of phosphorus, and 80-100 kg of potassium are applied before sowing of first year alfalfa.

As alfalfa belongs to leguminous crops, nitrogen is not applied anymore after the first year. For each 100 centner/ha of hay, alfalfa removes 240 kg/ha of nitrogen, 72 kg/ha of phosphorus, 220 kg/ha of potassium, and 290 kg/ha of calcium from the soil.

7.2. Methodology for Computation of Potential Yield (PY) for Alfalfa

For programming of alfalfa yield, 5 categories of yield are distinguished (Tooming H.G.) [19], (Yuldashev Kh.) [24]:

1. Potential yield (PY) is a theoretically possible yield that can be achieved under ideal conditions (i.e. water, heat, and light are sufficient). This yield depends on PAR and crop (variety) potential.

2. Climate-supported yield (KOY) is the level of crop productivity that can be achieved under ideal weather conditions. It depends on heat and water availability.

3. Actual-possible yield (DVY) is the level of crop productivity that depends on soil fertility and observance of crop growing technology.

4. Programmed yield (PrY) is an economic category. It is dependent on production and technological capacities.

5. Actual yield (RY) is the actually achieved yield in particular field. The categories of yield are shown schematically in Table 7.1.

Table 7.1

Categories of alfalfa yield

Factors affecting yield	PAR, variety	PY
	Weather conditions (heat, water)	KOY
	Soil fertility	DVY
	Economic resources	PrY
	Technological capabilities	RY

Programming of yield implies improvement of coefficient of PAR efficiency, use of high-productive crop varieties, uninterrupted supply of water, heat and nutrients, and application of intensive technology.

7.3. Methodology for Potential Yield Assessment

Given the irrigation conditions in Central Asia, alfalfa is among the crops that more efficiently use necessary elements during the growing season to form huge biomass. During this period (March-September) up to 4 billion kcal of PAR fall on 1 ha of crops. The coefficient of PAR efficiency in high-yield fields reaches 2.5 % and more. The yield of alfalfa hay is estimated by formula:

$$PY = 10^4 \cdot K \cdot K_{hoz} \frac{\sum Q}{q} \qquad (7.1)$$

where

PY – potential biological yield, centner/ha;

K – coefficient of PAR efficiency, %;

K_{hoz} – coefficient of yield efficiency;

q – caloricity of absolutely dry biomass, kcal/kg;

∑Q – total PAR over growing season, kcal/cm^2.

It should be taken into account that caloricity of 1 kg of dry alfalfa hay is 4800 kcal; K_{hoz} = 1, if the absolutely dry biomass is computed and K_{hoz} = 1.19, if the potential yield of 16%-moisture hay is estimated (100 : 84 = 1.19).

For example, influx of PAR to irrigated land in Uzbekistan is 40 kcal/cm^2 from 1st of March till 1st of October. In addition, over 240 days of growing, alfalfa produces five to six hay harvests and if it uptakes 2.5% of PAR, produces 208.3 centners of hay per hectare

$$\left(PY = 10^4 \cdot 2.5 \cdot \frac{40}{4800} = 208.3 \right)$$

The yield of 16%-moisture hay is:

$$PY = 10^4 \cdot 2.5 \cdot 1.19 \frac{40\, kcal / cm^2}{4800} - 248 \text{ centner/ha}$$

For conversion of hey yield into green biomass, it is necessary to compute the mass of absolutely dry hay. According to National State Standard, hay contains 16% of moisture and 84% of dry matter. In our example, 248 centner/ha of hay correspond to 208.3 (248 : 84 · 100) of dry biomass. Alfalfa for green fodder is harvested at 75% moisture. To convert the mass of absolutely dry hay into the green mass, PY is multiplied by 4:

PYgreen mass = 4 · 208.3 = 833.2 centner/ha

PYgreen mass = 3.36 · 248 = 833.2 centner/ha

If green mass of alfalfa is used for making of haylage (Ysn), which contains 56% of moisture, the absolutely dry biomass should be converted into haylage by formula:

$$Y_{sn} = 2.27 \cdot Y_{bio} = 2.27 \cdot 248 = 563 \text{ centner/ha.}$$

7.4. Methodology for Assessment of Climate-Supported Yield

The climate-supported yield is determined by formula:

$$KOY = K_m \cdot PY, \tag{7.2}$$

where

K_m is coefficient of favorable meteorological conditions which is typically less than 1 (KOY = 0.8 · 208.3 = 166.6 centner/ha).

The highest alfalfa yield is achievable under optimal combination of moisture availability with other factors (nutrients, etc.). In order to determine irrigation water needs, the possible yield is computed based on natural water availability, and the missing quantity of water needed to achieve the programmed yield is provided through irrigation. The level of possible alfalfa yield based on available water is determined by formula:

$$KOY = (E/Eo) \cdot PY, \tag{7.3}$$

where

PY – biological yield of absolutely dry biomass, centner/ha;

E – reserve of moisture productivity, mm;

Eo – water use factor, mm/ha.

Research showed that 700 centners of water were used on average for formation of 1 centner of alfalfa hay under Central Asian conditions. For accumulation of 2.5% of PAR (208 centner/ha of dry biomass), 14,560 m^3/ha (208 centner/ha· 700 centners) are needed. If in autumn-winter-spring period 400mm of effective water (4000 m^3/ha) fall under conditions of Tashkent province, then 57.1 centner/ha of absolutely dry biomass can be programmed through natural rainfall:

$$KOY\ hay = (100 \cdot E) / Eo, \quad (7.4)$$

KYO bio = 100 · 400 : 700 mm/ha/centner = 57.1 of absolutely dry alfalfa mass.

If the biological dry mass is converted into 16%-moisture hay, then:

$$RY\ hay = (57.1 : 84) \cdot 100 = 68\ centner/ha.$$

For yield growth by 151 (208-57), 10 570 m^3/ha of irrigation water (151 centner/ha 700 centner/ha) will be needed.

Necessary quantity of water to be delivered during growing season is distributed depending on rainfall pattern. Thus, in Tashkent province, the first alfalfa hay harvest can be produced without irrigation, whereas for next harvests one-two irrigation events are needed.

In case of sierozem soil with deeply bedded groundwater, preirrigation moisture in 1-m soil layer should not be lower than 70-75% FC in alfalfa fields. To this end, usually recharge irrigation with a depth of 1,200-1,300 m^3/ha is performed in autumn. Good moistening of the rooting layer allows efficient utilization of nutrients from the soil and application of fertilizers.

The efficient usage of mineral and organic fertilizers is an important element of alfalfa yield programming.

Nutrient norms are computed by balance method using the following formula (suggested by I.S.Shatilov and M.K.Kayumov) [16]:

$$N = (100V - Pv \cdot Kn) / Ku \cdot Su \quad (7.5)$$

where

N – norm of mineral fertilizers, kh/ha;

V – removal of nutrients (NPK) with PrY, kh/ha;

Pv – content of available form of nutrients in the soil, kg/ha;

Kn – coefficient of nutrient use from the soil, %;

Ku – coefficient of nutrient use from mineral fertilizers, %;

Su – content of nutrients in given fertilizer, %.

When both mineral and organic fertilizers are applied, the below equation is used:

$$N = (100V - Pv \cdot Kn - Ho \cdot Co \cdot Ko) / Ku \cdot Su \quad (7.6)$$

where

N – quantity of applied organic fertilizers, t/ha;

So – content of nutrients in organic fertilizer, kg/t;

Ko – coefficient of nutrient use from organic fertilizers;

Other variables are the same as in previous formula.

In the balance method, the difficult point is to determine correctly the coefficients of nutrient use by alfalfa from the soil (Kn), mineral fertilizers (Ku), and organic fertilizers (Ko).

Alfalfa producing 1 centner of hay removes from the soil 2.4 kg of nitrogen, 0.72 kg of phosphorus, and 2.2 kg of potassium. The ratio of the main nutrients in yield is roughly 54 % of nitrogen, 14 % of phosphorus, and 32 % of potassium.

Producing hay yield of 248 centner/ha, alfalfa removes 620 kg/ha of nitrogen (248 centner/ha · 2.5 kg/centner), 148.8 kg/ha of phosphorus (248 · 0.6), 372 kg/ha of potassium (248 · 1.5), or in total 1140.8 kg/ha (620+148.8+372) of nutrients. The nutrient use per 1 centner of hay is 4.6 kg (1140.8 kg/ha : 248 centner/ha).

It should be noted that alfalfa uptakes a share of nutrients from the soil and biological nitrogen. Nodules emerge on its roots continuously, live and die and thus the plant is fed permanently with nitrogen. This is demonstrated by good growth and development of alfalfa even without application of nitrogen fertilizers. Alfalfa needs a small amount of nitrogen only at the beginning of growth of its first year life. During growing, alfalfa uses not less than 60-90% of biological nitrogen out of the total amount of removal (more in normal soil and less in acid soil).

Computation of NPK norm for given yield of alfalfa hay (248 centner/ha) is shown in Table 7.1.

If the content of easy hydrolysable nitrogen in the soil is 20 mg/100 g and it is 35% used and Km = 34 kg/ha, the possible yield of alfalfa hay is 95.2 centner/ha (20 mg/100 g · 34 kg/ha · 0.35 : 2.5 kg/centner; 20 · 34 = 680; 680 · 0.35 = 238.0; 238 : 2.5 = 95.2, with which the plant removes 238 kg/ha of nitrogen (95.2 · 2.5) from the soil. If one assumes that biological nitrogen accounts for 60% of the total nitrogen removal (620 · 0.6 = 372 kg/ha) with the yield, it is necessary to apply 11.8 kg/ha of nitrogen fertilizers:

$$\text{Vtotal} - (\text{Vpv} + \text{Vbio}) : \text{Ku} \qquad (7.7)$$

$$20\ \text{kg/ha} - (238\ \text{kg/ha} + 372\ \text{kg/ha}) : 0.85 = 11.8\ \text{kg}$$

Table 7.2

Computation of NPK norms for given yield of alfalfa hay (248 centner/ha)

Indicator	N	P	K	Total
Removal of nutrients for given yield (Vtotal), kg/ha	620	148.8	372.0	1140.8
Yield achievable through nutrients in the soil (Yef)*	95.2	138.4	170	403.6
Removal of nutrients from the soil (Vpv = Yef · B_1), kg/ha	238	83.1	255	576.1
Biological nitrogen uptake by alfalfa (60 of total removal with yield Vbio = 0.6 · Vtotal)	372	-	-	310
NPK required with mineral fertilizers (Vpr = Vtotal – Vpv, for nitrogen + Vbio), kg/ha	10	65.7	117	154.7
Coefficient of nutrient use from fertilizers in the year of application (Ku)	0.85	0.35	0.95	2.75
NPK norm for given yield of hay (Active ingredient = Vpr : Ku), kg/ha	11.8	230.0	123.3	437.7

* - In this case, 100 g of soil contains 20 mg of nitrogen, 20 mg of phosphorus, and 30 mg of potassium.

If the content of phosphorus in the soil is up to 20 mg/100 g, the plants uptake 15 %, and the possible yield is 138.4 centner/ha. The plants remove from the soil 83.1 kg of phosphorus (138.4 · 0.6); therefore 230 kg/ha need to be applied with phosphates:

$$(\text{Vtotal} - \text{Vpv}) : \text{Ku} \qquad (7.8)$$

$$(148.8 - 83.1) : 0.35 = 229.95\ \text{kg}$$

The rooting layer of the soil contains up to 30 mg/100 g of potassium (Km = 34 kg/ha). The possible yield under 25% uptake of potassium by plants is 170 centner/ha:

$$(30\ \text{mg}/100\ \text{g} \cdot 34\ \text{kg/ha} \cdot 0.25 : 1.5\ \text{kg/centner},$$

$$(30 \cdot 34 = 1020), (1020 \cdot 0.25 = 255), (255 : 1.5 = 170).$$

Such yield removes 255 kg/ha of potassium (170 · 1.5) from the soil. With the coefficient of the nutrient use (of applied potassium fertilizers) as 0.95, 123.3 kg/ha of potassium need to be applied:

$$(Vtotal - Vpv) : Ku \text{ or } (372 - 255) : 0.95 \quad (7.9)$$

Thus, 437.7 kg/ha (84.4+230+123.3) of nitrogen, phosphorus, and potassium need to be applied for given yield. For 1 kg of NPK, 25.9 kg of hay is produced (403.6 : 3 = 134.5 centner/ha; 248 – 134.5 = 113.5 centner/ha; 11350 kg : 437.7 kg = 25.9 kg).

Based on average figures of PAR efficiency (by A.A.Nichiporovich), crops are divided into: usually observed – 0.5-1.5 %, good – 1.5-3.0 %, record-breaking – 3.5-5.0 %, and theoretically possible – 6.0-8.0 %.

In our example, given that 2.5 % of PAR is utilized and during growing season alfalfa of past years receives 40 kcal/cm^2 or 4 billion kcal/ha, the yield of hay from one hectare amounted to: PY – 208.3; KOY – 166.6; DVY – 150; PrY – 140 centner/ha.

The actual hay yield of farm (RY) is 112 centner/ha or, if converted into absolutely dry biomass, 94 centner/ha (112 · 0.84).

Thus, the degree of yield reduction as compared to potential level was: PY (208.3 centner/ha) – 100 %, KOY (166.6 centner/ha) – 80 %, DVY (150 centner/ha) – 72 %, PrY (140 centner/ha) – 69 %, RY (94 centner/ha) – 46 % (in form of percentage, KOY = 20 %, DVY – 28 %, PrY – 31% and RY – 54 %).

Table 7.3

Alfalfa yield category and impact of climatic and production factors on reduction of crop productivity

Yield reduction factors	Yield category	Yield, centner/ha	Total reduction of yield, %	Reduction of yield through particular factors, %
PAR, variety	PY	208.3	100	100
Heat, water	KOY	166.6	80	20.0
Soil fertility	DVY	150.0	72	8.0
Economic resources	PrY	140.0	69	3.0
Technological losses	RY	94.0	46	23.0

7.5. Alfalfa Irrigation

The most efficient irrigation method of alfalfa is furrow irrigation. Before sowing or at time of sowing, tractor hoes cut irrigation furrow, taking into account field relief. The depth of furrows should be 12–14 cm, the furrow space, depending on soil texture and field slope, is 60-90 cm. Irrigation is made by furrow through infiltration until the soil surface is fully wet. Next water applications are also made by these irrigation furrows.

After sowing before first cut, alfalfa is irrigated 2-4 times with a depth of 600-700 m^3/ha, depending on soil-climatic conditions. Application of water to alfalfa of the first year and next years between crop cuts is determined by groundwater depth, soil texture, and air temperature.

When groundwater is bedded deeper than 2-2.5 m, alfalfa is irrigated twice between cuts (2-2-2-2-2), whereas in the soil with shallow water table (1-1.5 m), it is irrigated once (1-1-1-1-1). In case of one-time irrigation, water is applied when the height of culms reaches 12–15 cm, and, for twice irrigation events, after growing up of the plant and during budding, with the irrigation depth varying within 700–1,200 m^3/ha. Irrigation dates are determined by soil moisture. The best moisture for normal growth of alfalfa vegetation is 70–80% FC. Decrease of FC to 60–65% (groundwater bedding deeper than 2 m) appreciably keeps down the rates of alfalfa growth.

For estimation of soil moisture, the soil samples are taken from the 0-50 cm layer before first cut and from the 0-100 cm layer after the first cut. Amount of soil water is determined by formula:

$$M = h \cdot d\,(FC\text{-}W) + 10\% \qquad (7.10)$$

where

M – irrigation depth, m^3/ha,

h – depth of wetted layer, cm;

d – bulk density of the soil, cm^3;

FC – maximum field capacity determined empirically;

W – actual soil water before irrigation, % of dry soil mass.

Example: it is determined that FC is 22 % of dry soil mass. Estimation of moisture before irrigation showed that 15.4 % of water was contained in the soil or 70% of FC.

$$W = \frac{22 \cdot 70}{100} = 15.4$$

$$M = 100 \cdot 1.3 \cdot (22 - 15.4) + 10\ \% = 943.8\ m^3/ha$$

Hence, for wetting of 1 m soil layer in alfalfa field, it is necessary to apply 943.8 m^3/ha of water per 1 ha, and, given 5 cuts during growing season, the irrigation norm will be 4719 m^3/ha (943.8 · 5 = 4719.0 m^3) in case of one-time irrigation between the cuts and 9438 m^3/ha (943.8 · 10 = 9438) in case of twice irrigation events.

Table 7.4

Yield losses depending on water supply to alfalfa (with orientation to optimal supply) during growing season [22]

Water supply, %	Fractional yield losses
90	0.07
80	0.18
70	0.33
60	0.39
50	0.49

Conclusion

Review of statistics for main provinces located in the Fergana Valley, as well as pilot studies carried out by SIC ICWC as part of the projects WUFMAS and IWRM-Fergana for assessment of water and land productivity in farms indicate to reserve and a real opportunity for improvement of farming effectiveness and land and water productivity. The main factors constraining achievement of potential yield at field level in given provinces were low rates of applied organic and mineral fertilizers, ineffective measures for weed, disease, and pest control, deviation from the schedule of agronomic operations and their poor performance. In the course of monitoring, it was found that irrigation was organized inefficiently, inflow to the field exceeded water requirements, irrigation schedule and technology parameters were incorrect, and significant water losses for surface outflow and percolation took place.

Assessment of field productivity levels allows identifying scarcest resources (limiting factors), estimating actual losses of crop yield under current natural, soil, and organizational conditions, and recommending farm operations aimed to improve land productivity. Here, capacities of a farmer to implement the suggested measures should be assessed and, on this basis, levels of planned crop yield are determined.

By using some elements from the yield programming theory, intensive technologies, and integrated farming management methods, we suggest the following approach to land and water productivity control:

- collecting information about specific features of project site or a particular field;
- preparing a field's agro-reclamation passport;
- computing levels of crop productivity (MVY-PY-DVY-RY-YH);
- assessing crop yield losses through various factors;
- assessing farmer's (financial, technical, technological) capacities to control factors that cause yield losses;
- selecting measures that help to mitigate a negative impact of a limiting factor;
- preparing an individual operations sequence chart for growing season, which takes into account all farming conditions and field specifics;
- implementing measures aiming to increase crop yields and save irrigation water.

Adoption of this approach in demonstration plots located in Uzbekistan, Tajikistan, and Kyrgyzstan allowed increasing yields of cotton by 10-22 % and that of wheat by 18-30 % on average and reducing unit water supply to the field, as well as improving water productivity by 16-88 % and reducing water losses through surface outflow and percolation. It is suggested to implement the proposed approach with the help of extension services.

8. Agro-Reclamation Passport of Farm

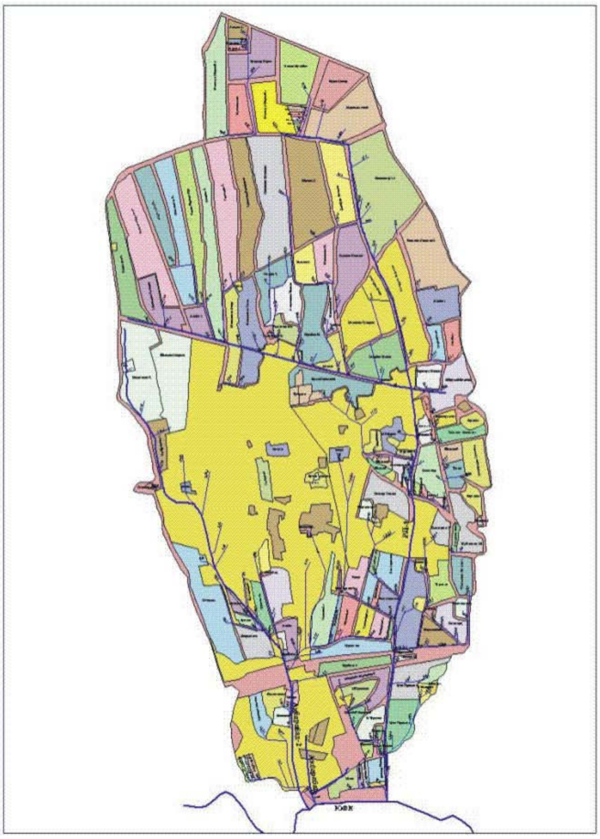
Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

IWMI
International Water Management Institute

Проект «Интегрированное управление водными ресурсами Ферганской долины»

Агромелиоративный паспорт фермерского хозяйства «Одил Мардона Турсун»



Ташкент - 2010 г.

Farm “Odil Mardona Tursun”

Improvement of land productivity through agro-reclamation passportization of farms

The agrarian reforms in Central Asia favored the development of cooperative ownership and establishment of multiple individual farms. Representatives of different professions became new masters of land and often did not have necessary and sufficient knowledge for efficient farming. In the past, information and advisory services provided for large collective and state farms were centralized. However, at present, most produces have no access to information about the current agricultural situation and farming methods under particular natural-climatic, soil and economic conditions. For that very reason farmers make numerous faults and mistakes in farming operations that eventually lead to lower crop yields.

One of the ways contributing to better knowledge of agricultural producers about their lands is the development of the farm's agro-reclamation passport. By present, 23 000 ha of agricultural land in Tashkent, Djizak, and Syrdarya provinces of Uzbekistan have underwent such process of the so called passportization. In the eyes of experts 'field passport' turned to be a reliable and scientifically grounded guide for crop farming operations. An economic effect from usage of this passport reaches 200-300 $/ha in some farms.

Agronomical Passport (AP) is intended for a farmer or technicians of collective dehkan farms and contains the basic agronomical documentation for particular plots, as well as specific reference data, norms and recommendations, which are necessary for arranging scientifically sound measures to develop crop production, raise land productivity, program crop yields, draw up current and long-term plans.

The agronomical passport of farm can be used during a 10 years period provided that it is annually updated. It is an agronomic data pool helping farmers to make proper farming decisions, get unbiased analysis of agricultural production dynamics and improve farming cultivation. If necessary, the passport may be supplemented with new schemes and recommendations in order to improve land and water productivity.

Basic characteristics of farm

Year	Gross area (ha)	Inarable land (ha)	Irrigation network, roads (ha)	Buildings, brigade camps (ha)	Irrigated area (ha)	Crop area (га)	Perennial crops (ha)
2007	42	0.58	0.50	0.42	40.5	37.0	3.5
2008	42	0.58	0.50	0.42	40.5	37.0	3.5
2009	42	0.58	0.50	0.42	40.5	37.0	3.5
2010	42	0.58	0.50	0.42	40.5	37.0	3.5
2011							
2012							
2013							
2014							
2015							
2016							
2017							
2018							
2019							
2020							

Cropping pattern of farm

Year	Main crops (ha)			Second crops (ha)			Total (ha)
	cotton	wheat	other crops	vegetable	maize	other crops	
2007	14.0	23.0	3.5	10.0	2.0	-	40.5
2008	20.0	17.0	3.5	12.5	4.0	-	40.5
2009	13.0	24.0	3.5	10.0	5.0	-	40.5
2010	20.0	17.0	3.5	14.0	3.0	-	40.5
2011							
2012							
2013							
2014							
2015							
2016							
2017							
2018							
2019							
2020							

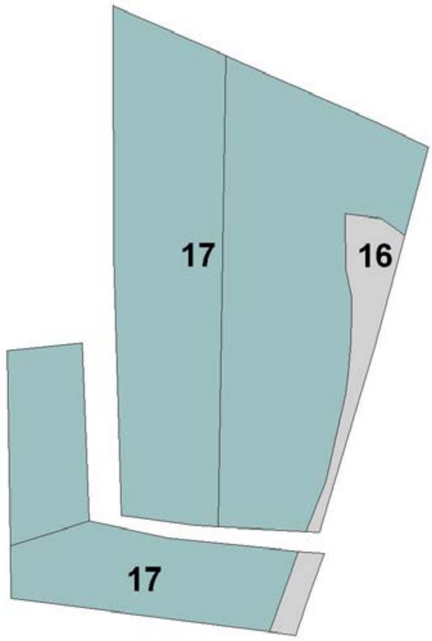
Climatic Characteristics
(average long-term meteorological data)

Weather station: Fedchenko Alt: 466 m Weather vane height: 11 m (K=0.76)													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Aver**
Average temp (°C)	-2.4	1.1	8.0	16.0	21.3	25.1	26.6	24.6	19.6	13.0	5.5	0.2	13.2
Min temperature (°C)	-6.0	-3.0	2.9	9.7	14.1	17.2	18.6	16.7	11.5	5.8	0.3	-3.5	7.0
Max temperature (°C)	2.5	6.4	14.3	22.9	28.6	33.1	34.6	32.7	28.4	21.7	12.5	5.1	20.2
Relative humidity (%)	84	82	73	61	54	47	52	59	61	68	77	84	67
Av. wind speed (m/s)	0.8	0.9	1.2	13	1.6	1.5	1.1	1.0	1.1	1.0	0.9	0.8	1.1
Sunshine hours (h/day)	3.6	4.1	4.9	6.8	9.0	11.2	11.6	11.2	9.8	7.3	4.9	3.1	7.3
Radiation (m1/m2/day)	6.5	8.9	12.6	17.7	22.5	26.2	26.3	24.0	19.2	12.8	7.9	5.5	15.8
Rainfall (mm/month)	22.0	28.0	31.0	22.0	20.0	7.0	6.0	3.0	4.0	16.0	20.0	18.0	197.
Evapotranspiration (mm/month)	12	21	50	96	145	174	174	146	97	51	21	11	998

Soil map of farm

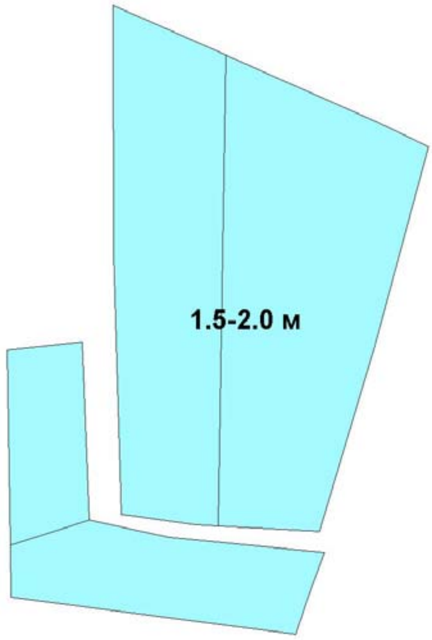
16 – New developed, sasa soil, heavy loam

17 – New irrigated meadow soil, heavy loam



Water table map for farm

GWL – 1.5-2.0 m

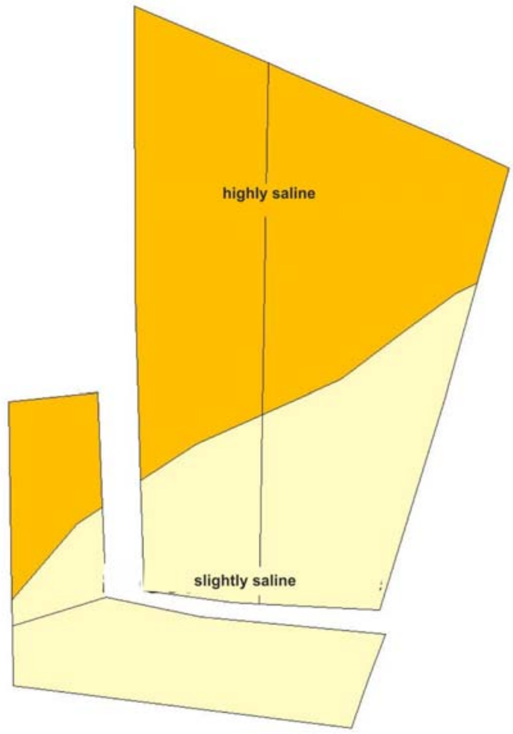


Soil salinity in farm

45 % of the farm's soil is slightly saline

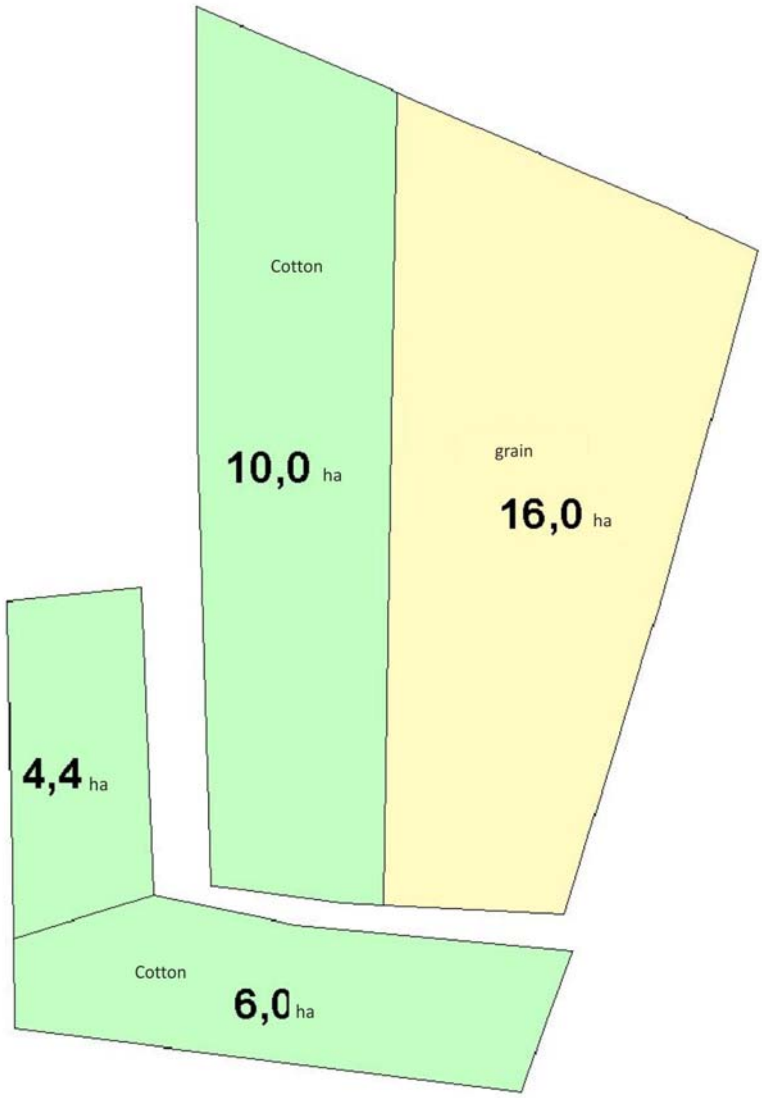
55% - highly saline
(sulphate salinity)

Water table 1.5-2.0 m

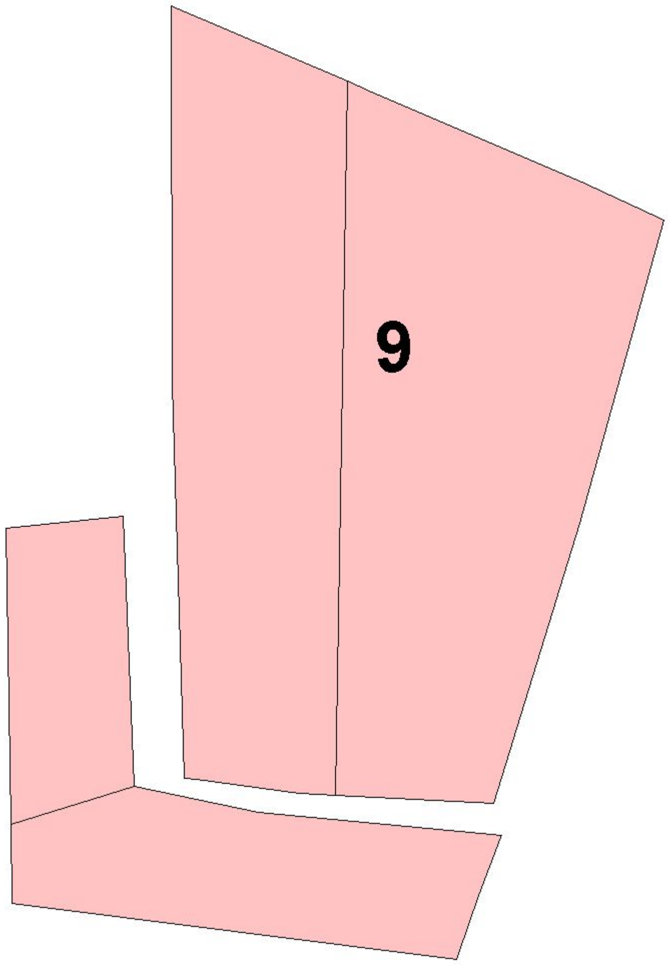


Cropping pattern

Farm "Odil Mardona Tursun" (2010)



Hydromodule zone



9th hydromodule zone

Main farm characteristics

Soil type – light sierozem

Soil texture – heavy loam

Field slope – 0.003

Water table – 1.5 – 2.0 m

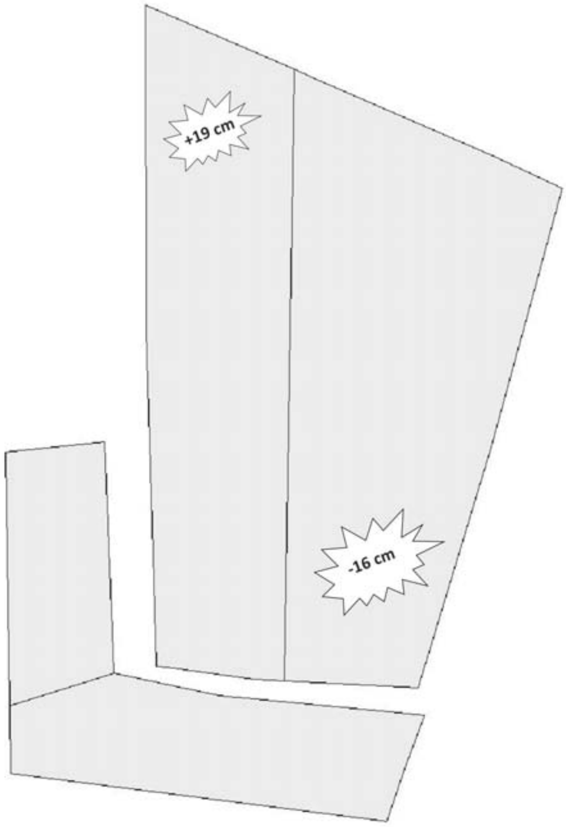
Irrigation began since 1997

Recommendation on irrigation regime for 9th hydromodule zone (HM)

HM	Crop	Irrigation norm	Q-ty of irrigation events	Irrig. depth m3/ha	Irrig. dates		Irrig. interval	HM ordinate
					start	end		
9	Cotton	3800	1	900	16.6.09	5.7.09	20	0.52
9	Cotton	3800	2	1100	6.7.09	25.7.09	20	0.64
9	Cotton	3800	3	1100	26.7.09	15.8.09	21	0.61
9	Cotton	3800	4	700	16.8.09	2.9.09	18	0.45
9	Winter wheat	3200	1	600	11.10.09	25.10.09	15	0.46
9	Winter wheat	3200	2	600	26.10.09	10.11.09	16	0.43
9	Winter wheat	3200	3	700	31.3.09	17.4.09	18	0.45
9	Winter wheat	3200	4	700	18.4.09	1.5.09	14	0.58
9	Winter wheat	3200	5	700	2.5.09	13.5.09	12	0.68
9	Winter wheat	3200	6	700	14.5.09	28.5.09	15	0.54

Map of farm's land uniformity

2011

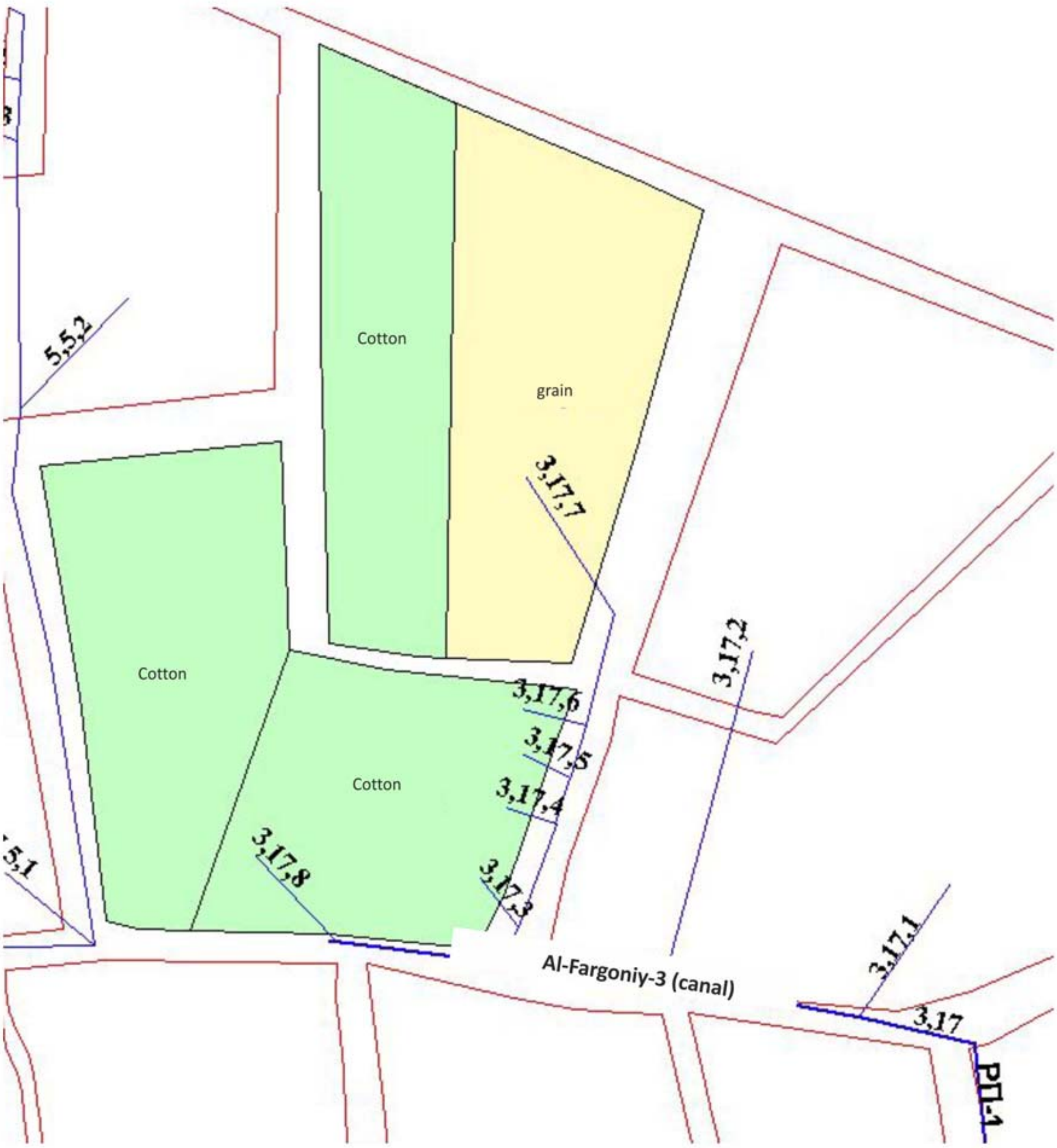


Legend	Causes of non-uniformity	Area	Spareness	Suppression
(orange)	Micro-rise of plot	m^2	%	%
(turquoise)	Close gravel layer	m^2	%	%
(brown)	Poor leveling and soil treatment	m^2	%	%
(grey)	Disease and pest infestation	m^2	%	%

Plant density – thousand plants/ha (deviation ~ % of the norm)

Average plant height - cm (lagging ~ cm)

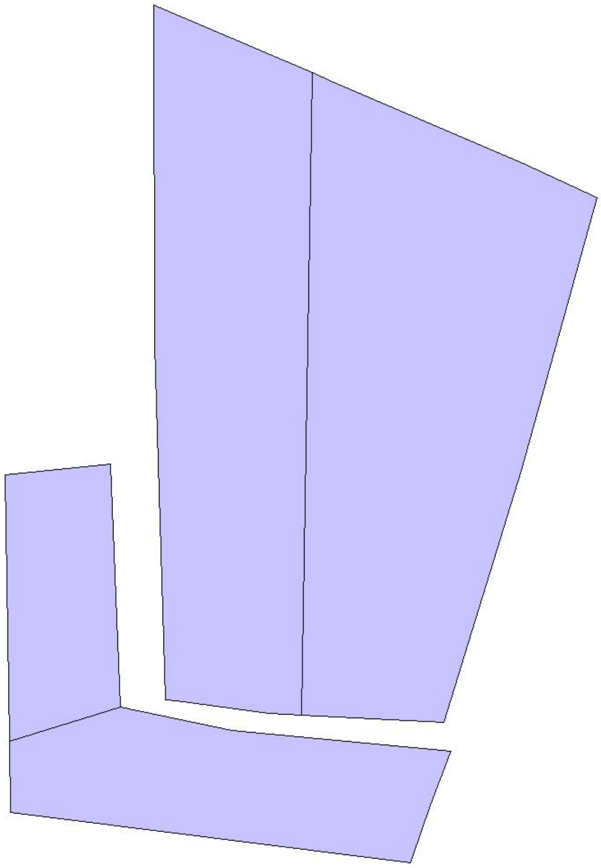
Farm's irrigation network



Main soil characteristics in the farm (horizon 0-70 cm)

Year	Electric conductivity EC 1:1x3.5 dS/m	Bulk density, g/cm3	Humus content, %	K2O content mg/kg	P2O5 content mg/kg	N-NH4 content mg/kg	Physical clay content, %
2008	2.5-3.0	1.36	1.09	159	16.3	31.7	82-84

N-NH4 content in the soil, horizon 0-70 cm

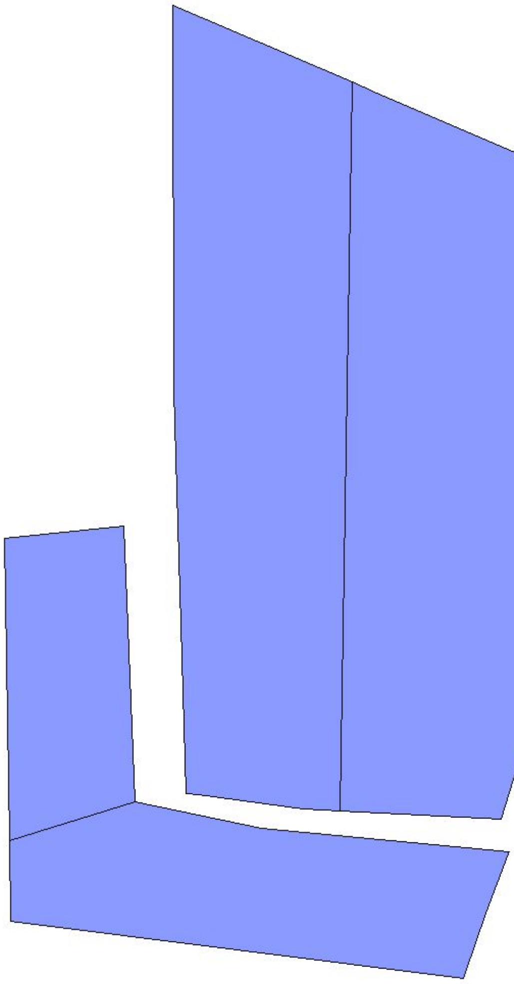


Normal availability of nitrogen

Norm of nitrogen fertilizer application

Color	Availability	Content, mg/kg	Norm of nitrogen application
	Very low	< 20	270 kg/ha (active ingrid)
	Low	20 - 30	230 kg/ha (active ingrid)
	Normal	30 - 50	200 kg/ha (active ingrid)
	Increased	50 - 60	160 kg/ha (active ingrid)
	High	> 60	130 kg/ha (active ingrid)

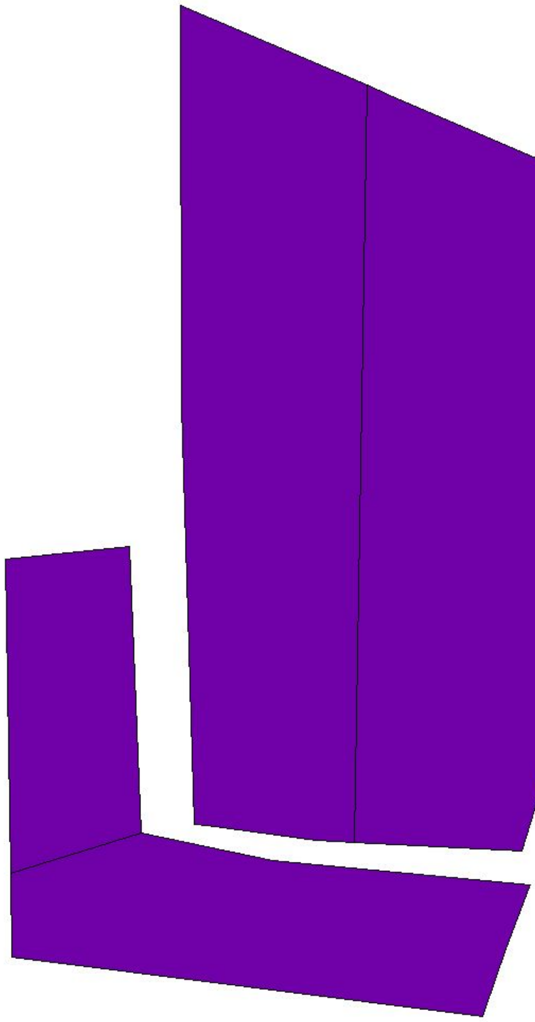
K2O content in the soil, horizon 0-70 cm



Low availability of potassium

Colo	Availability	K2O content (mg/kg)	Rate of potassium fertilizer application
	Very low	< 100	100 kg/ha (act.ing)
	Low	101 - 200	70 kg/ha (act.ing)
	Average	201 - 300	50 kg/ha (act.ing)
	Good	301 - 400	25 kg/ha (act.ing)
	Very good	> 400	15 kg/ha (act.ing)

P_2O_5 content in the soil, horizon 0-70 cm



Low availability of phosphorus

Color	Availability	Content, mg/kg	Rate of phosphorus fert application
	Very low	< 15	210 kg/ha (act.ing)
	Low	15 - 30	180 kg/ha (act.ing)
	Average	31 - 45	150 kg/ha (act.ing)
	Good	46 - 60	120 kg/ha (act.ing)
	Very good	> 60	90 kg/ha (a.i.)

Information on weeding in farm

Year	Crop	Weed	Q-ty of weeds per run.meter)	Yield losses (%)	Control methods
2008-2009	Cotton	Prickly grass	2 3	5%	Pulling
2010					
2011					
2012					
2013					
2014					
2015					
2016					
2017					
2018					

Information on herbicide application

Year	Name	Date of treatment	Application doze (kg/ha)
2008-2009	Not applied		
2010			
2011			
2012			
2013			
2014			
2015			
2016			
2017			
2018			

Information on diseases and pest infestation

Year	Disease, pest	Control method	Application rate (kg/ha)	Yield losses
2008-2009	Aphid, spider mite	Not applied	-	7
2010				
2011				
2012				
2013				
2014				
2015				
2016				
2017				
2018				

Information on crop yields (cotton)

Basic data	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Average yield on plots for last 3 years (t/ha)	3.48									
Planned yield (t/ha)	3.50									
Actual yield (t/ha)	3.65									
Sowing date	12.04									
Plant density - 50 days after sprouting (thousand/ha)	93.0									
Plant density - 100 days after sprouting (thousand/ha)	91.0									
Harvesting (centner/ha) 1Harvest	26.0									
2 Harvest	5.4									
3 Harvest	3.9									
4 Harvest	1.2									
Total harvest (centner/ha)	36.5									

Indicators of cost-effectiveness of agricultural production (national currency), cotton

Indicator	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Yield (t/ha)	3.65									
Product price (thous soums/t)	480.0									
Total production cost (thous soums/ha)	1752.0									
Mechanized labor (thous soums/ha)	380.9									
Manual labor (thous soums/ha)	501.4									
Variable costs (thous soums/ha)	1132.0									
Gross margin (thous soums/ha)	620.0									
Fixed costs (thous soums/ha)	170.0									
Net profit (thous soums/ha)	450.0									

Information on crop yields (grain)

Basic data	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Average yield on plots for last 3 years (t/ha)										
Planned yield (t/ha)										
Actual yield (t/ha)										
Sowing date										
Plant density - 50 days after sprouting										
Plant density - 100 days after sprouting (thousand/ha)										
Harvesting (centner/ha) 1Harvest										
2 Harvest										
3 Harvest										
4 Harvest										
Total harvest (centner/ha)										

Indicators of cost-effectiveness of agricultural production (national currency), grain

Indicator	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Yield (t/ha)										
Product price (thous soums/t)										
Total production cost (thous soums/ha)										
Mechanized labor (thous soums/ha)										
Manual labor (thous soums/ha)										
Variable costs (thous soums/ha)										
Gross margin (thous soums/ha)										
Fixed costs (thous soums/ha)										
Net profit (thous soums/ha)										

9. Specialized Computing System for Extension Services

One of the problems that emerged in the post-Soviet space in context of development of new market relations in agriculture was the massive flow of new workers to this sector who often lacked necessary knowledge for farming. In addition, agricultural business entities have increased manifold as compared to the Soviet period. The problem was aggravated by the lack of trained professionals, such as agronomists, economists, lawyers, entomologists. Moreover, land allocated to farms often needed reclamation. In this context, farms in those Central Asian countries that increasingly advanced market reforms virtually were left face-to-face with yet wild market, without having enough knowledge on agricultural technologies and prices of both agricultural inputs and outputs. Against this background, a need for well-organized and equipped extension services for farmers became especially topical.

Let us note specifically a need for information support of farmers (particularly, considering the situation with cotton in South Kazakhstan). Bad harvest of cotton in Asian countries in the last years and, consequently, high purchasing prices of raw cotton at the leading world markets (and in the republic) urged farmers on growing cotton practically in all available land (including subsidiary plots) in 2004. However, cotton production restored in the world in 2004, and, as a result, purchasing prices in Kazakhstan decreased almost threefold. At the same time, fuel and food prices jumped up. As a result, unskilled farmers ruined. Such sad end could be avoided if price dynamics had been analyzed by the results of market trading and appropriate crop changes had been recommended to farmers.

Profit management by farmers, farm budgeting is also important. Many farmers did not establish stabilization funds and allocated minimum funds for production, also based on last years' prices. This also contributed to ruin of farms.

It would be advisable to link extension services (ES) to larger groups of farms united on the basis of certain criterion, e.g. administrative boundaries or water sharing (water user associations – WUA). This question of ES linkage is important for definition of volume and content of tasks to be solved by such services.

The computing system of ES should include a package of services, the quantity and quality of which would increase as far as serviced crop areas are studied. Usage of modern irrigation and land use methods and a great number of economic entities translate into a substantial volume of information (e.g. in Kyrgyzstan more than thousand small farms are united in WUA), which would be advisable to store in databases. On the other part, optimization methods of water distribution and the algorithms for searching optimal yield conditions also need high-performance computers. Thus, this calls for equipping of extension services with up-to-date computers.

9.1. Available Cases

Research institutes in the countries of the Aral Sea basin have developed a lot of methodologies for water and land use. However, Soviet-time developments were oriented to large irrigation schemes with single-crop (cotton) and did not consider market economy requirements. Present-day developments under the projects financed by foreign sponsors also addressed large areas and delivered recommendations for governmental level rather than for farmers, except for WUFMAS sub-project of the WARMIS project, monitoring of which covered about 330 fields throughout the Aral Sea basin. However, for a number of administrative and financing reasons, the project failed to develop a component related to technology of crop growing for profitable agricultural production. The little that could be used for direct help to farmers is scattered all over projects and cannot be integrated in terms of farming technology. Of course, the author is not aware about all on-going projects in this area but if such work is undertaken, all stakeholders will know this. The consulting work delivered by IWMI in the Fergana province implied mainly advices on water use and embryo elements of land use. The crop growing process-oriented part of the consulting is yet not pronounced and calls many questions. Thus, one may say that by present no special toolkit has been developed for farmer.

9.2. Main Points

The two levels of users of this computing system are suggested: 1) farm; and, 2) group of farms united through water sharing, i.e. Water User Association.

The objective of the computing system is ensuring information support for profitable agricultural production at farm level. For Water User Association, it is added by a water use plan and computing water discharge at offtakes of irrigation system to WUA on ten-day basis.

The infrastructure of an economic entity for which advisory services are provided is the key for developing the software package. This includes communication, conditions of internal irrigation system, and access to fertilizers and irrigation water. The degree of economic self-reliance of entities, access to sales markets (commodity exchange), opportunities for future transactions, etc. are of equal importance.

The main aim of the extension service is the introduction of economically sound farming methods in farm practices. In doing so, more high technologies will be adopted in production with the development of the computing system. At the same time, farmers need to be trained in the use of efficient farming methods.

The system's backbone will be the database to store information on served farms (from surveying and monitoring of farms, field passports) and, for WUA, information on irrigation system and offtakes of the system, which delivers water to WUA. Thus, the DB should store data on the irrigation network of WUA/farm. Information about geometry of irrigation system, WUA, farm, and fields is GIS-based (MapInfo or ArcInfo).

Monitoring is to be carried out for the following groups of information:

- meteorological and agrometeorological information;
- farm fields (geometry, location on irrigation system, topography);
- soils of farm fields (texture, nutrient contents);
- irrigation water (quantity, quality);
- groundwater (depth, salinity);
- crops (water requirements, desired sum of effective temperatures, nutrient demand);
- agro-economics (cost-effectiveness of crop production, variable and constant costs of production, market cost of produced agricultural products).

After collection and input of relevant data into the DB, the system will help the farmer to select a crop, based on farmer's seed money, which would generate maximal income at minimum costs. Then, the system computes:

- irrigation water demand and water cost and ten-day water discharge at inlet to farms;
- if crop land is salinized, leaching requirements for non-growing season, schedule of leaching water delivery and cost of such water;
- required amount and cost of mineral and organic fertilizers to produce planned yield;
- required quantity and cost of plant protection agents;
- amount and cost of machine hours and manual labor for crop production;
- amount and cost of transportation;
- expected profit from the sale of agricultural products.

Besides, the system should offer an operations sequence chart for production of the selected crop, adjusted to climate, sowing date and soil conditions.

In the process of monitoring of target fields, the set of agronomic operations from the operations sequence chart may change or their scheduled time can be modified. This can be caused by natural-climatic conditions, e.g. abrupt warming or fall of temperature, changes in water regime, heavy infestation of weeds, or socio-economic factors, such as unexpected growth of inputs prices, drop of purchasing prices, new laws and tax policies that complicate old farming practices. The extension service is to develop the algorithms that help to overcome such crises with minimum losses, for example through harvest insurance or future transactions.

9.3. Structure of the Computing System

The proposed model of the computing system of extension services is shown in Figure 1.

- **Irrigation** component computes irrigation water requirements on the basis of crop distribution map. It is necessary to draw a layout of WUA irrigation network and compute discharge in canals of this network and in offtakes of irrigation system, which delivers water to WUA. At the first stage, at least, the desired dynamics of water discharge in canals should be determined. Then, optimization can be made to have appropriate water use plan at WUA level. If the required water discharge cannot be guaranteed in offtakes, the water use plan should be corrected and damage is assessed in order to recommend changes in crops or areas if the damage is not acceptable.

Depending on soil texture and slopes, irrigation schedules that minimize losses and prevent the soil from erosion are to be recommended.

If irrigation water quotas are applied, crop areas will be optimized to generate maximum yield or profit (at farmer's request).

On-line monitoring of soil moisture should be carried out in order to determine more exact irrigation dates. It can be done by the weight method (drying oven) or by meters (neutron moisture meter).

- **Land reclamation** component monitors drainage and soil salinity in order to recommend measures for reclamation and leaching of irrigated land;

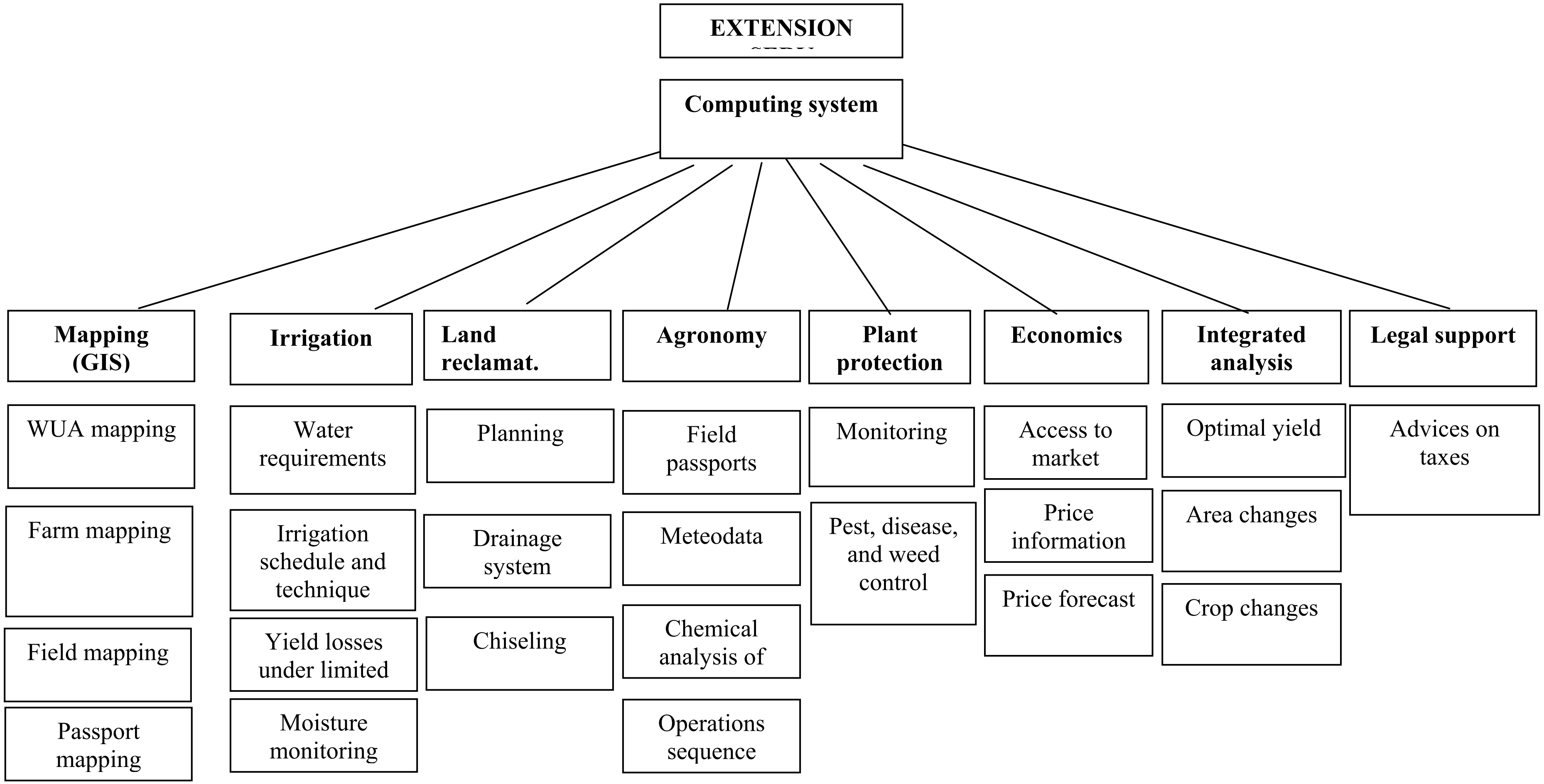
- **Agronomy** component prepares passports for all irrigated contours in service area. The soil bonitet should be also estimated in the service area in order to determine maximal yield of different crops. Existing bonitet rating often is overestimated.

The optimal yield for selected crops is computed by searching maximum profit against costs and gross margin.

At first, it is necessary to prepare operations sequence charts for crops, depending on zonal conditions. With development of the system, the charts will be prepared for all crop varieties that can be produced in given zone.

Over time, the dates of farming operations should be determined by weather conditions of given year rather than by average statistical data. For monitoring of climatic situation, it is desirable to equip extension service with a portable weather station and ground thermometers placed in special site. In addition, the extension service should make active use of the forecasts of Hydrometeorological Service.

Preparation of passports involves laboratory analysis of a lot of soil samples. Such operation needs to be done every year. First, this work can be done at expense of outside sources, and in the future ES can be equipped with portable instruments that allow for enough accurate passportization; however, these instruments should be calibrated periodically in laboratories.


EXTENSION
Computing system
Mapping (GIS)
Irrigation
Land reclamat.
Agronomy
Plant protection
Economics
Integrated analysis
Legal support
WUA mapping
Farm mapping
Field mapping
Passport mapping
Water requirements
Irrigation schedule and technique
Yield losses under limited
Moisture monitoring
Planning
Drainage system
Chiseling
Field passports
Meteodata
Chemical analysis of
Operations sequence
Monitoring
Pest, disease, and weed control
Access to market
Price information
Price forecast
Optimal yield
Area changes
Crop changes
Advices on taxes

- **Plant protection** component monitors pests and weeds and, if requested by farmers, gives recommendations for their control. Based on pest and disease infestation, type, amount and cost of protection agents is determined. In doing so, it is necessary to optimize the costs of chemicals based on the following principle: chemical costs must not be higher than the cost of expected yield losses.

- **Economics** component is closely linked with information from the markets on prices of agrochemicals, fertilizers, seeds, irrigation water, fuel, vehicle service and agricultural output prices. In addition, based on the analysis of market information, the component will make forecast on these prices for a year ahead. Analysis of price dynamics can be made by data from the Internet. This component provides the client with the current information on prices of all agricultural inputs and outputs.

- **Integrated analysis** component, by comparing costs and benefits, helps to find an optimal solution by playing with crop areas or crops. The integrated analysis uses all information from other components. As part of this computing system, it is proposed to develop an interactive GIS interface, which computes maximal profit based on cropping patterns of farm or field irrigation contour (inputted directly to irrigation contour map by GIS-tools).

- **Legal support** component provides the farmer with information on effective laws that are of relevance for agricultural producers, including information on how to minimize taxes. Every state has legal software with updated database; thus, it would be necessary only to incorporate this software into the computing system.

The above mentioned list of services to be offered by the computing system is not exhaustive and can be changed substantially, depending on national legislation. For example, a package of services can be supplemented by analysis of aerial and satellite images, mapping and forecasting of groundwater depths, development of irrigation and drainage designs.

The authors have a number of preliminary studies carried out within international projects that can serve as a basis of the software. Since each project solved its specific tasks, those studies were not linked technologically with each other.

The software developed for the computing system should have an intuitive interface and be oriented to users with low level of knowledge. Such software largely should be as flexible handbook for actions in any given farming situation. At the same time, more advanced user should be provided with additional information, including description of algorithms and ability to add updates to individual reference books of this software. This can be done through the well-built help system.

9.4. Development of the Computing System

Design of the software toolkit should be built on 'simple to complex' basis and be divided into several stages. At the first stage, the software is filled with data on the main six crops, such as cotton, winter wheat, maize, potato, rice, and alfalfa (sequence operations chart, prices of variable inputs and outputs), the average long-term data from the closest weather station are inputted, and prevailing crop diseases and pests and methods of their control are determined. Generally, all solution options are examined on the basis of minimal data. Using this minimal data, the interface and consulting methodology are fine-tuned and, as result, the base software is created for the computing system. During the second stage, two parallel activities are undertaken:

– filling of reference books/ with new crops and their varieties (operations sequence charts), fertilizers, diseases, pests and control methods,

- improvement of decision making algorithms by development and incorporation of optimization methods for management of WUA's irrigation system and agricultural production in farms.

For first version of the software, information for reference books on variable inputs can be taken from the databases of the past projects, such as WUFMAS[2], Best Practices in Water Conservation[3], Climate Change[4], IWRM-Fergana[5], etc. All these projects, among other activities, conducted monitoring of agricultural production in a number of farms in the Republics located in the Aral Sea basin.

a) Getting off the ground

In order to create high-quality software toolkit for extension services, it should be developed on the basis of actually functioning WUA or large farm. In this case, problems occurring during WUA operations will be reflected in the software, and developed programs will be tested against actual data. At the same time, monitoring of production activities of farms should be conducted on the basis of dedicated data collection forms for more accurate definition of information from the past projects. Regular monitoring is a part of market-oriented farming; therefore, it should be carried out by farmers themselves as a kind of training.

Depending on financing, either the whole WUA or some farms from the WUA taking water from several offtakes can be selected as a study object. Work should be started from GIS-based mapping of WUA. As a rule, official land use data almost always give

[2] The Water Use and Farm Management Survey (EU, 2002)

[3] "Water Resources and Environmental Management in the Aral Sea Basin". Component A-2 "Participation in Water Conservation", (GEF, the World Bank, 1999-2000)

[4] Addressing Water Scarcity and Drought in Central Asia Due to Climate Change (CIDA)

[5] "Integrated Water Resources Management in Fergana Valley" (SDC, 2000-2012)

error and inconsistent information. Whereas usage of a high-resolution image of WUA territory and high-performance GPS allow generating an acceptably accurate WUA map.

Then, soil sampling sites should be determined in WUA area (or its part under agricultural production) and points for drilling pressure observation wells should be located. Soils samples are taken from the topsoil (0-30 cm) and subsoil (30-70 cm). These samples are analyzed for contents of humus, phosphorus, nitrogen, potassium, salinity (electric conductivity EC), and texture (if solid plow pan is present, chiseling can be recommended).

For judging on leveling needs and preparing irrigation design for each field, topographical survey of WUA area can be made or relief map (30-m resolution) of a site where WUA is located can be downloaded from the Internet. Such information is downloadable for certain fee on the NASA website.

As the above mentioned parameters change in the course of agricultural production, the surveys are advisable to make every year during non-growing season.

Based on the analysis, maps for WUA, farm, and field passports are generated.

In addition, for monitoring of climate, a small observation site should be arranged in any farm to install there a weather station and soil thermometers.

Another method for acquisition of data for given year is to get them from the closest weather station. If there is access to climatic data from surrounding weather stations, it makes sense to develop (using GIS-tools) three-dimensional interpolation maps of climatic parameters by which climate for virtually any point of the area covered by weather stations could be derived.

The irrigation network of WUA needs to be equipped with weirs for each farm. Weirs at offtakes from the main canal are not under the responsibility of WUA and they are installed and maintained by the organization of the upper-level irrigation system. Measurement of water discharge at outlets to farms allows estimating performance efficiency in reaches of the WUA's irrigation network and, if bottlenecks are identified, minimize losses.

The maps of groundwater levels generated on the basis of piesometric observations help to determine drainage needs (for very shallow water table < 0.5 – 0.75 m or saline groundwater), the cost of drainage installation and payback period.

In case of surface drainage, it is necessary to map it and make measurements of drainage flow in drains during irrigation events (to determine irrigation efficiency) and periodically measure drainage water salinity as an indicator of general salinity of arable land in WUA. If the data on irrigation water inputs, evapotranspiration, and surface drainage outflow are available, one may estimate deep percolation and efficiency of irrigation. Consequently, this would help to adjust irrigation design (surge irrigation, alternate furrow irrigation) and parameters (furrow length, flow rate at furrow head).

The described measurement equipment base has not been arranged yet in any WUA, partially, because of lack of funds, partially due to lack of knowledge on what such information could serve for.

b) Work done by present

By present, the authors have at their disposal:

- FAO publications on crop water requirements (NN 24, 33, 56);
- the CROPWAT model offered by FAO for the countries practicing irrigated agriculture to compute norms and dates of irrigation on the basis of crop evapotranspiration;
- the program for computation of irrigation water requirements (LandWat) on the basis of hydromodule zoning and computation of water discharge in all offtakes from the upper irrigation system;
- databases of the projects WUFMAS, Best Practices, Climate Change, IWRM-Fergana;
- technology of field passportization and usage of information from the passports for computation of fertilizer application rates for a planned level of crop yield;
- two-dimensional model of climate data interpolation;
- unlicensed geoinformation system MapInfo 7.5[6];
- SURFER program;
- GAMS optimization package;
- GIS-unlicensed system for satellite information processing Idrisi32[*];
- technology for computation of potential and actual-possible yield of crops;
- operations sequence charts for main crops (15);
- sums of effective temperatures needed for adequate development of main crops;
- technology and experience of agricultural production monitoring;
- work started on development of the database for the software;
- algorithms and programs solving the following tasks: selection of sowing dates, rates and dates of fertilizer application, resource limit card for agricultural production, computation of profits from agricultural production.

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[6] The software can be developed with the use of MapInfo и Idrisi32 but for certification of the developed product we need to purchase licensed versions of MapInfo and Idrisi32.

c) Work to be done

Preparation of documentation

- *first stage of software development* – prepare monitoring forms for farms and WUA;
- prepare output forms for farm and WUA level.

Mapping component:

- *first stage of software* – on the basis of high-resolution image of WUA area and measurements by highly accurate GPS in representative points, generate a map of WUA, including roads, irrigation ditches, drainage network, farms, and fields. Ability to provide maps on any farm and any particular field of a farm. Irrigation and drainage networks should be represented on the map with installed weirs on them and flow capacities of canals and drains;
- create software for automatized generation of thematic maps from field and farm passports;
- by using GIS, develop interactive interface for ability to choose objects for processing.
- *second stage of software* - process the DEM files of WUA area and, using GIS adds-in, generate relief map of WUA and on its base estimate average slopes and exposure of fields in all farms of WUA. This information is needed to build an optimal field irrigation design;
- by using GIS, develop a three-dimensional model for computation of climatic parameters for any point in the command area of hydrometeorological stations.
- *third stage of software* – develop interactive interface for ability to distribute crops among farm's fields;
- develop GIS-based output of optimized cropping patterns.

Irrigation component:

- *first stage of software* – create a block for processing of current information on groundwater depths (data from pressure observation wells);
- create a block for computation of ten-day water discharge in canals of the WUA's irrigation systems and water discharge in offtakes from the main canals, based on water duties of crops.
- *second stage of software* - develop alternative approach to determination of agricultural land demand for irrigation water: water duty (hydromodule) zoning, crop requirements modeling for particular field (CROPWAT);

- develop a block for estimation of yield damage from water stress (based on available algorithms).
- *third stage of software* – implement algorithm of water delivery, which takes into account irrigation technique elements and, finally, computes operation regime of main canal on five-day basis;
- develop a block for optimization of water discharge in irrigation canals of WUA by using flow capacity, canal performance efficiency, quoting and schedule of water delivery from the main canal.

Land reclamation component:

- *first stage of software* – determine criteria for construction of surface or subsurface drainage and install vertical drainage wells;
- determine criteria of leveling and chiseling.
- *second stage of software* – develop a block for design and cost estimation of subsurface and surface drainage and vertical drainage well installation;
- develop a block for design and cost estimation of leveling and chiseling.

Agronomy component:

- *first stage of software* – prepare standard operations sequence charts for main crops with account of zonal conditions;
- collect and input into DB for selected main crops the recommended sowing temperature (threshold temperature) and sums of effective temperatures. For winter crops, determine the sum of effective temperatures for the time point when the plants enter into winter dormancy;
- describe methodology for estimation of yield losses through various factors, such as diseases, pests, weeds, provision with agricultural machines and equipment, labor resources, soil treatment, availability of gypsum parting, etc.
- *second stage of software* - prepare standard operations sequence charts for main crops with account of soil types and climatic data;
- implement algorithm for computation of the actual possible yield depending on humus, phosphorus, nitrogen, and potassium contents in the soil and water availability;
- create a program block for computation of required amounts of fertilizer application for planned yield level, based on maps of humus, phosphorus, nitrogen and potassium availability in the soil.
- *third stage of software* – input into reference books the methodology for selection of an optimal cropping pattern for farms, taking into account correct crop rotation and growing of second crops in order to use the land fund efficiently.

Plant protection component:

- *first stage of software* – develop methodology for monitoring and assessment of potential yield damage from diseases and pests (similar work was done within the WUFMAS Project).
- *second stage of software* – create a block for optimized selection of plant protection strategy, with indication of chemicals, their doses and dates of application, as well as the cost of work.

Economics component:

- *first stage of software* – develop a block for SW-based connection to stock market web-sites and, based on information from the Internet, project prices of agricultural production inputs and outputs;
- create price reference tables depending on WUA locations;
- prepare (or acquire outside) a handbook for preparation of farm budget.
- *second stage of software* – develop a block for prediction of regional and local prices. This item is very complex even for firmly-established market relations and this complexity of prediction rises ever more for transition economies. Therefore, in the first software version we should implement algorithm to trace price change trends.
- *third stage of software* – finish the block for prediction of prices of agricultural inputs and outputs.

Integrated analysis component:

- *first stage of software* – create an optimization block for selection of such elements of agricultural production that would contribute to maximum yield at minimum costs under fixed cropped area and crops chosen for production. Seed money, soil conditions, cropping pattern, crop areas, water regime, and price forecast serve as entry point. Fertilizers and chemicals vary.
- *second stage of software* – create an optimization block for selection of such elements of agricultural production that would contribute to maximum yield at minimum costs under fixed crops chosen for production. Seed money, soil conditions, cropping pattern, crop areas, water regime, and price forecast serve as entry point. Fertilizers, chemicals, and cropped areas vary.
- *third stage of software* – create an optimization block for selection of such elements of agricultural production that would contribute to maximum yield at minimum costs under fixed cropped area. Seed money, soil conditions, cropping pattern, crop areas, water regime, and price forecast serve as entry point. Fertilizers, chemicals, and crops vary;

- create an optimization block for selection of such elements of agricultural production that would contribute to maximum yield at minimum costs. Seed money, soil conditions, cropping pattern, crop areas, water regime, and price forecast serve as entry point. Fertilizers, chemicals, crops, and cropped areas vary.

Legal support component:

- *first stage of software* – either choose software containing laws regulating the actions of agricultural producers or create such database within the project.
- *second stage of software* – pool the experience of lawyers on cases in their practices related to agricultural production and input it into relevant reference book. Develop the interface for handling such reference book;
- elaborate methods to minimize taxes in a legal way.

Conclusion

The author understands that the computing system will not address all problems in farming practices. However, it is clear that the gap between developments of the research institutes and farmers should be filled. This should be done in a consistent manner by using state-of-the-art technologies. Today things have changed little in research institutes. On the other hand, the economic model of human environment has changed radically. Thus, the farmer should be provided with an easy and simple tool.

Given project should be purely technological. The computing system must have open architecture, user-friendly interface and well-developed help system.

It is necessary to elaborate data and interface standard for incorporation of new algorithms into the system. This will allow integrating developments from the third parties in the system.

Upon finishing the software, it would be advisable to organize an entity on the base of available technical infrastructure to:

- maintain the computing system,

- develop and incorporate new algorithms into the system,

- implement the system in interested WUA or farm.

The developed Computing system is linked with certain technologies of land- and water use and therefore should be viewed as a single whole with the suggested by it agricultural production technology. With some modifications (reworking of legal block and translation of interface into the language of the country where the system is adapted), the system can be used in any country practicing irrigated agriculture (Afghanistan, Pakistan, Africa region) so that the project may become commercial.

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