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Discussion Paper No. 619

"A Farm in Kumsangir of Tajikistan:
A Perspective of Water/land Use along Pyandzh River"

by

Toderich K., Tsukatani T.,Abbdusamatov M.,Rakhmatullaev R.,
Latipov R.and Khujanazarov T.

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Toderich K.[1], Tsukatani T.[2],Abbdusamatov M.[3],Rakhmatullaev R.[4], Latipov R.[3] and Khujanazarov T.[5]

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We carried out an assessment of natural resources use and management along with the on-farm observations and experience gathered through a fieldwork expedition along the riparian basin of Pyandzh River from Tajik side. It is described the natural vegetation irrigation history, technologies, agriculture, crops diversity and farmer development system through this vast area of Khatlon Province of Southwestern Tajikistan. Target area is Kumsangir District and Mumin Farm in the district along Pyandzh River.

The study was within the framework of a Joint Research Project: «Investigation of natural resources of Central Asia and reconstruction of agriculture in Afghanistan», (Program No. 15252002) that is supported by the Ministry of Education and Culture in Japan and represented by professor Dr. Tsuneo Tsukatani, Department of Natural Resources and the Environment, Institute of Economic Research, Kyoto University, Japan. The field expedition was carried out in September 2005 according to the Joint Project Research Program to study the natural resources and contemporary state of irrigation in Pyandzh River basin.

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1 Department of Desert Ecology and Water Resources Research, Samarkand Division of Academy of Sciences of the Republic of Uzbekistan.
2 Institute of Economic Research, Kyoto University, Japan.
3 Specialized Inspectorate of the State Control on Water Use and Preservation of Water Resources, State Committee for Environmental Protection and Forestry, Republic of Tajikistan.
4 Republican Center for Farm Privatization Support under the Government of the Republic of Tajikistan
5 Technical State University, Tashkent, Uzbekistan.

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Summary

We carried out an assessment of natural resources use and management along with the on-farm observations and experience gathered through a fieldwork expedition along the riparian basin of Pyandzh River from Tajik side. It is described the natural vegetation irrigation history, technologies, agriculture, crops diversity and farmer development system through this vast area of Khatlon Province of Southwestern Tajikistan. Target area is Kumsangir District and Mumin Farm in the district along Pyandzh River.

By performing this survey, we could further examine our preliminary studies on the potentials for agriculture using of Subsurface Drip Irrigation (SDI) technique on the right bank of Pyandzh River. Many of the local farmers, pastoralist communities, and some of the agricultural authorities and governmental leaders were interviewed to help understand the history of their irrigation infrastructures, their concerns on the issue of land use and agricultural activities, and their outlook and desires to implement cost-effective watershed-scale water saving technologies.

Afghanistan mountains in the distance, Parkhar District, Khatlon Province, Tajikistan

Keywords:

natural resources, subsurface drip irrigation (SDI), Pyandzh, Amu Darya, Kumsangir, water quality

1 Department of Desert Ecology and Water Resources Research, Samarkand Division of Academy of Sciences of the Republic of Uzbekistan.
2 Institute of Economic Research, Kyoto University, Japan.
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5 Technical State University, Tashkent, Uzbekistan.

1 Introduction

We are witnessing how the population of the Amu Darya Basin countries is continuously growing and the demand for fresh drinking water, local food production and more employment opportunities is gradually increasing. We are proposing a critical long-term resolution to achieve this aim. Agricultural development using SDI for crops such as rice on the Left Bank, as well as on the Right Bank, of Amu Darya is what we suggest.

The former Soviet Union and Central Asian Republics have irrigated the Right Bank of Amu Darya (Uzbekistan and Tajikistan) since the end of the 19^{th} century. On the contrary, the Left Bank of Amu Darya has been ignored though its soil, climatic and agricultural potentials are almost equal to the Right Bank. Our proposal is to build permanent food production systems on these forgotten dry lands to help feed Afghan people and to provide them with jobs.

For the comparison between right and left banks, we dispatched a fieldwork expedition in September 2005 to the right bank of Pyandzh River, The area was in Khatlon Province among it laid Districts of Kumsangir and Kulyab. Kumsangir represents the southern areas of the Republic of Tajikistan. It adjoins in the south with Islamic Republic of Afghanistan, in the southeast with Pyandzh sub-district, in the north with Kolhozabad, and in the west with Dzhilikul. The general objective of the field expedition was as following:

- assessment of current status of micro-watershed natural resources sectors, including water, rangelands, agriculture, irrigation infrastructures etc. in Pyandzh River Valley (right side near Dusti settlement);
- integrating one-farm participatory research, water management and technology transfer activities towards the practical developments of agribusiness and irrigated farming systems;
- development of rural community-based research and technology transfer programs that recognize the special needs of local farmers, operation and technical design construction of focus areas (in southern Tajikistan) that will be allocated under SDI transfer technology use.

SDI (Subsurface Drip Irrigation) will be potentially applicable for high fertility of soils with a low degree or absence of salinity, and not deep water tables (from 4 – 6 m on the territory of Mumin Farm and 8 – 10 m on the territory of Lenin and Rakhmonov Collective State Farms). In addition, these sites are supplied with a well-developed sprinkling network, electric power and human resources that together can support the promotion of SDI in the upper part of right bank of Pyandzh River.

This article starts in the analysis of agriculture and farming reforms in the southwestern part of Tajikistan, of characteristics of climate, landscape and geomorphology of soils and vegetation. Then it follows an adequacy of SDI. Fig. 1 shows territories of Pyandzh River Valley in the Kurgan-Tyube and Kulyab regions, as well as those of Northeast Afghanistan.

2 Land resources use and farming development in the Pyandzh River Basin

2-1 Contemporary irrigated agriculture and farming reforms in Kumsangir

Following independence, Tajikistan has been in the slow process of agricultural reform. An integral component of this reform was the decentralization of land ownership through privatization. In theory, this should result in every family having the right to claim land on which they can cultivate the crops they choose to grow. In practice, the situation is often very different (Bezrukov, 2005).

It was estimated that all water users, domestic and agricultural alike, suffer from poor management of the water sector. As we have seen during our field mission a key problem in maximizing water benefits for many agricultural users concerns not only the constraints and weakness of the water system, but problems in the structure of the agricultural sector itself. Besides, in whole the region awareness of the farmers about soil and water conservation and management is very poor. The farmers have not enough knowledge about soil erosion, soil salinity and landscape sustainability. Summer-vegetation, silvi-viticulture and all horticulture crops in south Tajikistan require supplemental irrigation to ensure proper cultivation. No measurement of water applied to the crop and irrigation scheduling is still based on conventional approaches. This is further aggravated by the fact that there is absolutely no data available on basic requirements of water management in crops viz., moisture extraction pattern, water requirements of different crops, impact of water deficits (quantitatively) at different crop growth sub-periods on crop performance for efficient management of limited water supplies. In addition surface gravity irrigation is causing soil erosion, salinization and water logging, thus affecting the land productivity and water quality. Lack of knowledge or information about water holding properties of different soils varying in texture and their impact on irrigation practice are also evident in these areas.

But neither extension workers nor farmers are aware of drip irrigation technology and its utility in enhancing crop productivity and water-saving. About 40% of the residents in the Kumsangir region are farmers. Most crops variety currently grown in this region and neighboring territories are local and have been under cultivation for a long time. Currently there are a relatively limited number of highly skilled professionals available in all Central Asian riparian countries, northwestern Afghanistan as particular case.

During our filed work in 2005 we chose Kumsangir District as one of the southern and closest areas, adjoining to the right Pyandzh River Bank of Tajik-Afghan boundary. Kumsangir District as is shown on Fig. 2.1 represents one of southern areas of the Republic of Tajikistan, adjoining in the south with Islamic Republic of Afghanistan, in the southeast – with Pyandzh sub-district, in the north – with Kolhozabad, in west with Dgilikuli.

Kumsangir, as an independent territorial unit, starts his history from 1921 when Soviet Regime anexed it into the Vakhsh region. From the interview with Mr Abdugafor Rakhmonov, the Governor of Kumsangir District we learned that Khatlon Province was mostly impacted during civil war. In result the majority Russian speaking habitants of all Kumsangir District migrated to Russia and neighboring countries. Land degradation of marginal lands of these territories continued for more than 11 years. The total area of Kumsangir is 96,715 hectare with a population of about 90,000. Its administrative centre is Dusti settlement with the population of 9,550. There are five jamoats (lowest official government unit, and usually comprises a number of villages)[6].

6 Pyandzh, Telman, Kumsangir, Yiakkadin, Krupskaya.

Kumsangir District owns 22.3 thousand ha of land from which about 14.0 thousand are irrigated. On farms is secured (discharged) 2,759 ha. River Vakhsh is the basic source of water for irrigated agriculture in Kumsangir District. Only singular farms are using water from Pyandzh River. The worldly known biosphere reserve Tigrovaya Balka is also located here.

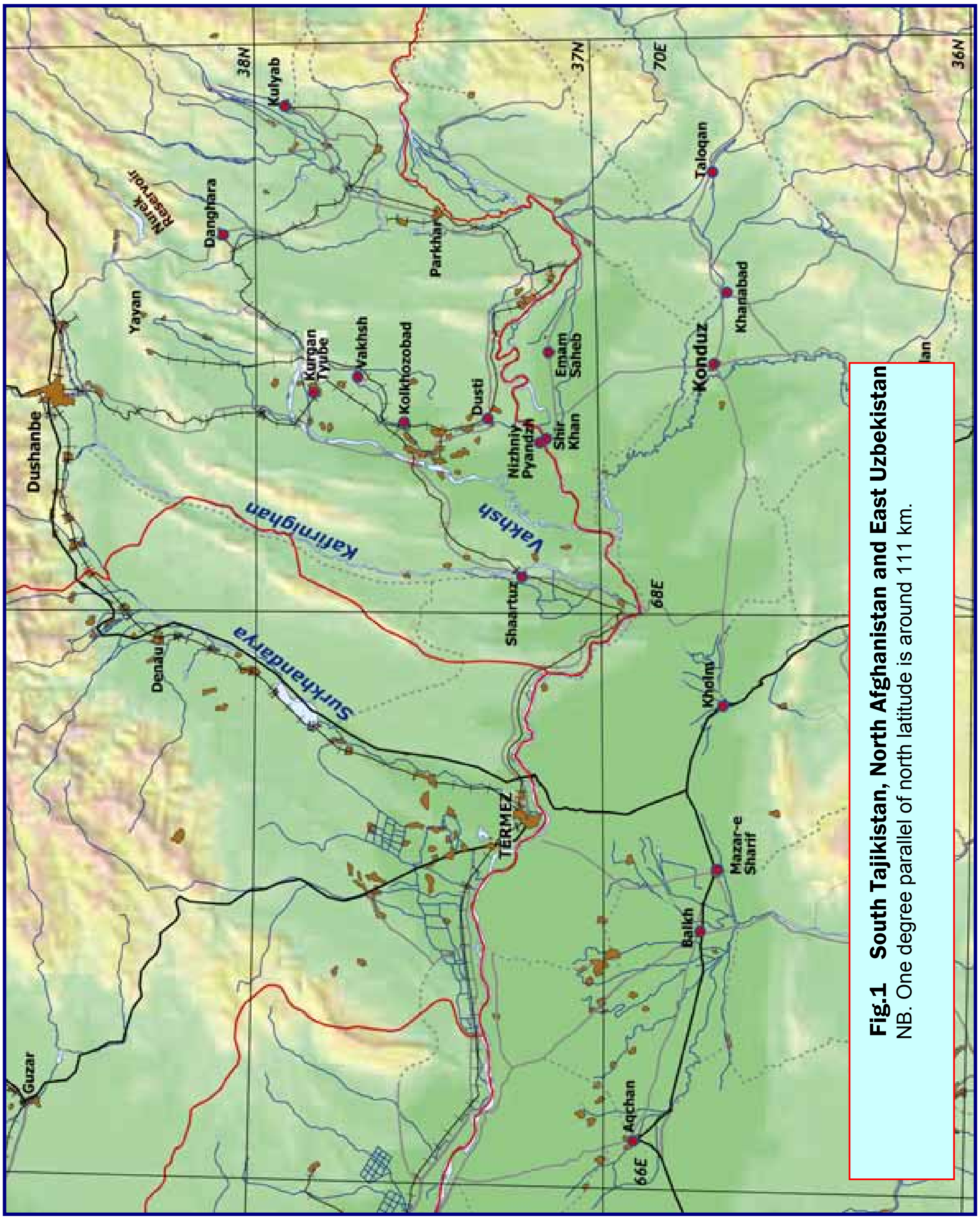


Fig.1 South Tajikistan, North Afghanistan and East Uzbekistan
NB. One degree parallel of north latitude is around 111 km.

Fig. 2.1 Kumsangir District in Khatlon Province

About 50% of lands are irrigated through the pump stations. The lift irrigation in the region is taken from the main canal named Kumsangir, especially from its caudal part. The length of this main canal is more than 65 km from which 25 km flows in the territory of Kumsangir District. The distributive network consists of earthen shaped canals and is supplied with hydraulic engineering structures.

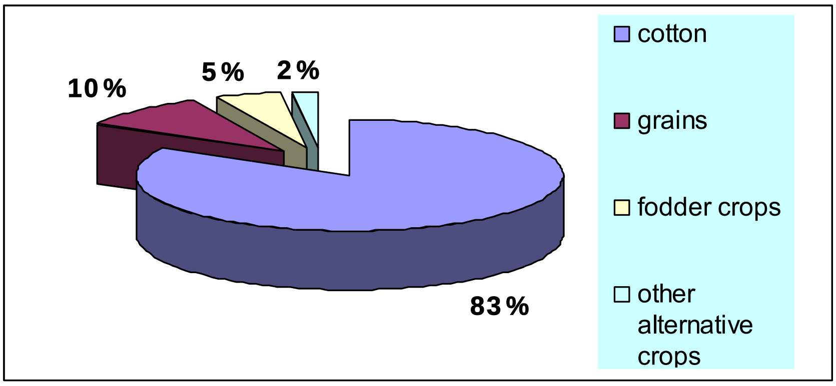


Fig. 2.2 Crops diversity in Kumsangir District (data of 2005)

Due to its arid climate, irrigation is crucial for agricultural sector development and irrigated areas constitute 85% of total agricultural production areas. Land reclamation and most irrigation and drainage schemes were constructed in the 1950s and 1960s during Soviet time. However many have reached the end of their useful lives, and require major rehabilitation. The infrastructure has further deteriorated due to the civil war, lack of capital investment, and inadequate operation and maintenance funds. This is worsened by the fact that the end water users have virtually no participation in operation and maintenance. The poor condition of irrigation and drainage facilities results in excessive water losses, low irrigation efficiencies, water logging, soil salinization, and declining crop yields. The efficiency (the proportion of water diverted from rivers or other sources that actually reaches the fields) averages around 60% for all region. It is estimated that due to the poor condition of irrigation and drainage infrastructure, 16% of formerly irrigated lands, especially towards floodplain of Pyandzh River at Nizhniy-Pyandzh has been out of production since 1991.

Rehabilitation of these systems is therefore a key intervention to boost agriculture sector productivity and farm profitability in Kumsangir District. Inadequate irrigation supplies, insufficient inputs and financing, and lack of agricultural support services have led to a decline in agricultural productivity. Cotton production has significantly fallen during last five years. Current cotton yields average 1.7 t/ha compared with 2.8 t/ha before independence of the Republic of Tajikistan. Wheat yields are also low at an average of 1.3 t/ha. The reduced productivity resulted in declining profitability of farms and increased poverty incidence, especially in rural areas.

Table 2.1 Underground water, mineralization and salinity (data of 2003)

Name of the region	Irrigated area, (th. ha)	Among them the level of underground water (th. Ha)				Level of mineralization and areas of irrigated lands (th. ha)			Degree of salinity and areas of irrigated lands (th. ha)			
		< 1 m	1 – 2 m	2 – 3 m	>3 m	< 1g/l	1 – 3 g/l	> 3g/l	not saline	weakly saline	moderate saline	*
Kulyab	79.7	1.0	21.0	10.2	47.5	49.2	27.3	3.3	76.5	2.3	0.8	0.2
Kurgan-Tyube	241.7	7.1	42.3	25.1	167.2	32.6	178.8	30.3	197.7	26.5	14.9	2.6
Sugda	259.3	1.6	25.4	28.8	203.6	240.0	1.6	17.8	197.3	46.7	10.6	4.8
Gissar	100.1	0.3	2.7	39.2	57.9	99.3	0.7	0.1	99.9	0.1	0.0	0.0
General on Tajikistan	680.9	10.0	91.4	103.3	476.2	421.0	208.3	51.5	571.3	75.6	26.3	7.6

Strongly saline. Solonchaks (see footnote 17)

The basic agricultural crop is cotton (especially fine-fiber sorts) with an area of more than 11.6 thousand ha and a total annual yield in the range of 20.0 – 23.0 thousand tons. According to state plans Kumsangir District is engaged to collect 23,520 tons of cotton 2005 year. The livestock industry in the district is also well developed. There is one collective state farm, 8 large dekhans farms[7], and over 450 small dekhans farms, 13 small industrial enterprises and one cooperative farm that are functioning now within the district. The total areas of irrigated lands comprise 14,063 ha. Among them 11,425 ha (about 83%) is occupied under cultivation of cotton, 1,401 ha – with fodder crops and 754 ha is allocated to the cultivation of other alternative crops, fruit trees and vineyards inclusive (Fig. 2.2.). A little space is left for vegetables, citrus, melon, technical, and volatile oil bearing plants, especially geranium.

7 Dekhan means private. Since June 1999, land reform has accelerated targeting the conversion of a further 160 Kolkhozes into private dekhan farms by March 2000. Dekhan Farms comprise those who engage in private farming as a group independent of their former Sovkhoz/Kolkhoz. They are family-based and organized by the Dekhan Farm Association.

However, long-term intensive irrigation of lands, lack of engineering control on watering process and bad operation of collector-drainage network has lead to the deterioration of soil conditions. Besides, water losses on almost all territories of Pyandzh River Valley are on the increase.

The predominance in this region of earth irrigation channels with a high rate of silt and filtration (seepage into the ground), rather than lined or piped channels, significantly accelerates the degradation of lands. This situation is most aggravated in the lower areas of Kumsangir District, i.e. towards floodplain of Pyandzh River. According to the governor's opinion the marginal lands on the Afghan/Tajik border are enough fertile and productive if the appropriate technologies will be applied.

2-2 Farming System Development based on Mumin Farm management

Mumin Farm within Dusti area serves as one of the best example of agro business and sustainable rural community development. Local administration greatly estimates and supports this farm.

Since 1991, the main pumping station and the irrigation and drainage networks on the right dry bank of Pyandzh River near Dusti have not been properly funded, operated, or maintained. As a consequence, there has been a rapid deterioration of pumping station increased water losses in the main canals, and low field-level water-use efficiency. A significant numbers of irrigation infrastructures, which were constructed during Soviet time (1960 – 70s), had fallen into severe disrepair since independence and due to prolonged civil conflict in the country.

For an agriculture development of marginal lands at the Afghan-Tajik boundary in 1970 – 80s the construction of underground hydraulic extensive network with main waterway, hydrants, and wells etc. was started. However this project was not completed and an urgent rehabilitation are necessary today. Undoubtedly this system could be used for the introduction of SDI here.

In 2003 a “bottom-up” community based approach was established by using micro-watershed as the planning unit through agricultural reclamation and cattle breeding development by Abdulhair Muminov, Engineer on hydrotechique (former army commander). During our fieldwork expedition he expressed a great interest to practical development of agricultural and cattle programs by transferring modern technologies that will lead both to the reduction of water waste and increasing of crops yield. Mumin Farm within Dusti area serves as one of the best example of Agribusiness and sustainable rural community's development in the whole Kumsangir District. Local administration greatly estimated and supports this farm.

As is shown on Figs. 2.3 and 2.4, Mumin Farm includes two demonstration experimental plots: the smaller near settlement Dusti, irrigated by water from Kumsangir magisterial canal (its caudal part) and larger at the right bank of Pyandzh (at the Tajik-Afghan frontier area), irrigated from water of Pyandzh. The latter Mumin Farm, located in the Pyandzh sub-district of about 35 km southwest from Dusti settlement lies around N37°15′ and E68°38′. These territories are characterized by a typical floodplain landscape. Beginning from 2003 farmer Muminov is successfully using more than 230 ha under cultivation of various crops: cotton, wheat, legume, forage, melon, etc.

Fig. 2.3 Location of Mumin Farm

Fig. 2.4 Google Earth of Mumin Farm

Staff (180 people including seasonal workers) of agro pastoral Mumin Farm has renovated the agriculture development of multi-years abandoned lands. It was due to using proper techniques, manual labor and through the reconstruction of water-pumping station that is installed on the frontier area of river banks of Pyandzh. The height of water rise at the location of the former water-pump station does not exceed 4 – 5 m in early spring. Some water could get through the two water pipes of about 1,800 m and main earth canal from the riverbank, where water used to flow (the result of natural sedimentation). Water in the vicinity of Mumin Farm used to flow from the main canal with a length of 7 km. Further irrigation water is distributed through the left and dextral networks of shallow ground canals that can still be differentiated. The irrigation of about 450 ha of virgin marginal drylands was accomplished in this way.

Irrigation water is all supplied from surface water of Pyandzh River. However many irrigated cropping plots are subject to bank erosion, especially along the Mumin channel. Self-flowing irrigated lands of this farm heavily depend on water pumping systems that were recently improved by Muminov Abdulhair. Improvements include the rehabilitation of key pumps (distributed on the neutral Tajik/Afghan frontier), motors, and related irrigation system rehabilitation.

Plain areas are largely maintained by mechanized irrigation systems, and the land is prioritized for cotton growth. Mountain and valley regions are largely rain fed irrigation systems, and require constant maintenance of the hand dug channels leading from the rivers and streams. A significant amount of water is lost through seepage, and in times of low rainfall or snow melt can dry up.

A key feature of existing irrigated agriculture sector in the region is that many systems have been damaged or suffer from lack of maintenance and larger traditional system having salinity and low land productivity. Current irrigation practices are traditional in nature, contributing to water waste and fertilizer. The dominant method of irrigation practiced in all the districts of southern Tajikistan, and by farmer Muminov is through surface furrow or border basins, wherein the water is diverted from a stream located at the head of field plot and allowed to flow down the grade. Distant crop plots as seen from Figs. 2.5 and 2.6 usually does not get enough water during vegetation.

In this context the introduction of new water allocation technologies and farming systems seems to be a good challenge for Mumin Farm. Subsurface drip irrigation (SDI) will be potentially applicable for high fertility of soils with a low degree or absence of salinity, and not deep water tables. SDI could play a crucial role in efforts to redress Tajikistan's food deficit. In addition, this plot demonstration site is well supplied with a well-developed sprinkling network, electric power, small-scale machinery, and human resources that together can support the promotion of SDI in the upper part of Pyandzh River.

Fig. 2.5 Pump station at the border (circled), floodplain of Pyandzh River

Fig. 2.6 Head-water intake infrastructure passing into earth Muminov' chanel

The quality of cotton seeds and other perspective crops available to the farmer, is generally of a low standard with the result that yields are lower than could be achieved if seed of higher performing varieties were more widely available. Increasing the supply of higher quality seed can have significant benefits for farmer.

There is also a need to start an organized seed production program as arrange seed selection from the best available crops. This is why in 2004 staff of Mumin Farm established experimental plots for seed reproduction of highly productive varieties of cotton.

Double cropping is not widespread in Mumin Farm, although there is some scope for it in some places where a short cycle vegetable or fodder crop can follow wheat or an early vegetable crop. According to the opinion of leader agronomist they used the following scheme of crop rotation: cotton: lucerne (alfalfa): corn in proportion 6:9:1. In perspective the potential and practical possibilities for intensifying and diversifying crop production will be demonstrated in the future crop production programs in the core demonstration areas of Mumin Farm. Gradual adoption of these methods, supported by expanding domestic markets as the economy grows, will lead to an increase in cropping intensity.

Fig. 2.7 A part of Muminov's channel (water erosion and Phragmites)

Fig. 2.8 A view of alfalfa and cotton fields at Muminov' s Farm 2

Fig. 2.9 Mumin Farm for seed multiplication of best quality cotton lines (near settlement Dusti, irrigated from Kumsangir magisterial canal)

Soil salinity is a problem in some location of Mumin Farm due to groundwater resulting from excess irrigation during cotton cultivation season, as well as due to high evaporation during hot summer and/or poor drainage. Moreover, rising salinity increases water requirements to flush salt out of the soil by applying large volumes of water, a practice knowing in farming economy as leaching. On the territory of Mumin Farm was established a proper small scale farm machinery units. Building of enclosed pens or fencing of parcels for cattle and storage of forages for winter season are also starting here.

Small-scale processing facilities and developing of a distribution mechanism for products such as meat, milk and milk products are belong to farmer Muminov too. In Dusti there is a small factory for dairy products. Their products are well realized in Dushanbe and other cities.

Fig. 2.10 Cotton collecting in Mumin Farm

Fig. 2.11 Mumin field under water melon cultivation

Fig. 2.12 Non-irrigated fileds, suitable for SDI technology

Fig. 2.13 Technical equipment, water-tank, etc at Mumin Farm

Fig. 2.14 Technical equipment, etc. at Mumin Farm

3 Climatic characteristics

The area of lower floodplain of Pyandzh River Basin is characterized by a dry continental climate with a hot, sunny summer and a mild winter. Temperature ranges from 5 °C in January, to 40 °C – 46 °C (Kolhozabad, Shaartuz) up to 48 °C (Nizhniy-Pyandzh) during the hottest months. The mean annual precipitation averages is 140 mm, most of which (87%) occurs in spring, and only 5% during June – October. Under conditions of arid foothills rainfall varies from 380 to 600 mm. Annual runoff of around 60 – 80% occurs from the end of February to the end of April – May, mostly from snowmelt and rainfall. Mudflows are prevalent in spring. The average wind speed is relatively constant throughout the year, at about 1.0 – 1.7 m/sec, except for the month of summer season, when wind speeds can reach up to 21 m/sec. Strong dust storms can be expected from June through October, lasting up to five or more days, after which it can take another 10 days for the dust to settle.

Southwestern part of Tajikistan is characterized by a dry continental subtropical climatic zone with very warm/hot summer and moderately mild autumn and winter. The greatest lasting period with temperature higher than + 20 °C is marked for foothills zones of the territory of southwest Tajikistan. Up to altitude of 600 – 700 m, where the average temperatures in June, as a rule, are higher + 27 °C and durations of such period exceeds 145 – 150 days, places reaching (Lower Pyandzh, Shaartuz) 158 – 164 days. On plainly and low piedmont the absolute maximum of positive temperatures in many cases are hoisted up to 46 °C (Kolkhozabad, Shaartuz) and even up to 48 °C (Nizhniy-Pyandzh). The lowest temperatures are usually recorded during January and February.

Autumn, which in the southwestern part of Tajikistan usually lasts 63 – 90 days, is characterized by instability of temperature regime. Annual valuable use of thermal resources during crop vegetation cycle under irrigation in a series of cases is aggravated by early spring and autumn frosts. Autumn frosts are especially dangerous to the majority of heat-loving crops with long-lived period of vegetation, particularly for cotton – the main cash crop in this region. Most vegetation growth and fruit maturation of crops is delayed also by extreme high air temperatures in summer and related to them droughts and hot winds with dust and sand storms, which are very common in the Pyandzh River Valley both from right and left banks.

The annual amount of precipitation received as snow and rain on the lowland of south part of Kumsangir and Nizhniy-Pyandzh districts varies within limits of 140 – 205 mm. It increases to 400 – 800 mm between foothills and highlands of southwestern sites of Tajikistan. The high surrounding mountains of the Pamir-Allay system protect the cold influence along Pyandzh River Valley open to the south and to the climatic impact of the Afghan steppe. Annual precipitation is linearly related to elevation. The maximum precipitations are observed in March – April. In the Vakhsh, Kulyab and Nizhniy-Pyandzh Valleys the stable snow cover is absent for almost 90% of winters, and at 3.0 – 15% of winters does absolutely not exist.

The annual curve of relative air humidity for plainly sites of Tajikistan shows typical characteristics for the continental climate. Having a maximum value in winter and minimum within summer months the relative air humidity reflects the annual course of air temperatures. The major annual amplitude makes about 49% as it is the case in Danghara areas of Kulyab region. In cold period of the year the relative humidity of air reaches maximum values in December – January. Kurgan-Tyube and Kulyab regions according to value of humidity index[8] (M_d=0.009 – 0.051) belong to the dry zone. The limited falling

8 The Global Humidity Index is based on a ratio of annual precipitation, P and potential evapotranspiration , PET as P/PET, and largely follows the classification used in a 1984 UNESCO study. The Global Humidity

out of precipitation in the winter – spring time in Kurgan-Tyube region (except for Yavan district[9]) does not provide a sufficient stock of moisture in the ground that is necessary for the getting of seedlings and crop growth at the early stages of their development. Therefore in these conditions supplying with additional water resources, which allows crops to develop, is an obligatory condition.

Table 3.1 Climatic Parameters for Main Cotton Cultivated Regions of Tajikistan

Climatic parameters	Natural-economic region			
	Kurgan-Tyube	Kulyab	Gissar	Sugda
Daily temperature amplitude for August–September (°C)	19 – 27	19 – 20	19 – 20	16 – 17
Average air temperature (°C) per year August–September	 15.7 – 17.2 23.5 – 26.3	 14.2 – 16.3 22.1 – 24.5	 14.1 – 15.1 21.8 – 22.8	 12.4 – 14.0 21.1 – 23.7
Total sum of effective temperature (above 10 °C), °C	2,687 – 3,238	2,663 – 2,910	2,192 – 2,510	2,190 – 2,618
Average relative air humidity (%) per year April to September	43 – 56 31 – 46	47 – 54 36 – 45	46 – 53 39 – 50	49 – 63 38 – 54
Sum of solar radiation hours	2,800 – 3,100	2,700 – 2,900	2,600 – 2,800	2,600 – 2,800
Sum of direct solar radiation	3,896.6 – 4,148.1MJ/m^2 (93 – 99 kcal/cm^2)			
Sum of dispersed solar radiation	2,199.8 – 2,346.4MJ/m^2 (52.5 – 56.0 kcal/cm^2)			
Rainfall, mm Total sum per year Total sum April–Sept.	 150 – 624 41 – 205	 386 – 693 51 – 234	 475 – 705 144 – 248	 123 – 298 54 – 99
Transpiration, mm Sum per year Sum for April–Sept.	 1,469 – 2,101 1,129 – 1,622	 1,501 – 1,843 1,141 – 1,401	 1,252 – 1,597 1,016 – 1,232	 1,188 – 1,573 914 – 1,266
Relation between annual transpiration to the total sum of atmospheric precipitation	10.9 – 13.4	2.3 – 7.8	2.1 – 2.3	4.0 – 10.9

The thermal continentality, rainfall deficit and its seasonal distribution in the southwestern part of Tajikistan significantly influence on the evapotranspiration effect. The value of this parameter calculated by using Ivanov's[10] is equal in magnitude to 0.8. The climatic parameters for southwestern part of Tajikistan were summarized and given in the Table 3.1. Apparently from Table 3.1 in all southwestern zones the farming agriculture is based exclusively on irrigation.

In semi-arid regions with insufficient rainfall but with a viable water source (such as a large river or pumpable wells), growing conditions are better than in rainy regions. Radiation and irrigation quantities result in better agricultural results than in rainy regions, where the soil is usually heavier, e.g.

Index surface shows mean annual potential moisture availability for the period 1951-1980, classified into four aridity zones and one humid zone, defined in this data set as follows. Hyper-Arid Zone: P/PET<0.05, Arid Zone: 0.05≤P/PET<0.20, Semi-Arid Zone: 0.20≤P/PET<0.50, Dry-Subhumid Zone: 0.50≤P/PET<0.65, Humid Zone: 0.65≤P/PET.

9 Yovon; south of Dushanbe near Nurek Reservoir.

10 Ivanov formula which gives potential evapotranspiration ET in mm/month through $ET = 0.0018 \times (25+T)^2 \times (100 - RH)$, where T and RH are average values of temperature and air humidity.

in comparing with agronomic conditions in the regions of Xian ding, China and in other semi-arid regions (Gus Gintzburger et al. 2005).

4 Landscape and geomorphology

The mountain ridges of Southwestern Tajikistan separate from each other by the valleys of right tributaries of Amu Darya and Pyandzh Rivers[11]. The most considerable mountain ridges in this region are relatively short mountainous ridges and are the following: Babatag, Aktau, Karatau, Djilantau, and Sarsaryak, which represent the branches of biggest Karateginsk and Vakhsh ranges. Babatag is low (up to 2,000 m) in the east of Surkhandarya region forming from tertiary-chalk rocks. Karateginsk ridge is a southern spur of Gissar Mountains along the left coast of Kafirnigan. Its length is about 80 km and up to 3,950 meters of height. Between the above-mentioned mountainous ridges, which extend predominantly from northeast to southwest the broad valleys with flat or moderately rolling plains are distributed. Among them the most valuable economically are Gissar, Nizhniy Kafirnigan, Vakhsh and Kulyab steppes/valleys. Gissar lies just north of the capital, Dushanbe, which is situated in west-central Tajikistan.

The irrigated farmlands of cotton cultivated zones of South Tajikistan essentially differ on their geomorphologic constitution. Kurgan-Tyube zone is disposed in limits of absolute altitudes of 306 – 750 m high and includes territories of Beshkent, Nizhniy Kafirnigan, Nizhniy Pyandzh (valleys), Vakhsh, Yavan and Obikiik valleys, as well as areas of Garaut and Tashrabad gorges. Irrigated lands of Kurgan-Tyube and Kulyab cotton zones as is shown on Fig. 3 are mostly dated for alluvial terraces of different level and age country between rivers Vakhsh – Yakhsu – Surkhob – Kyzylsu – Pyandzh.

Five terraces are clearly distinguished here. The maiden terrace (floodplain), tracked along the beds of Vakhsh, Kafirnigan and Pyandzh, occupies the lowlands and floodplains along rivers course. The part of this territory permanently is below than the level of acting waterflows. The terrace is folded by pebbles deposits that one fragmentary are bridged over by sandy-argillaceous alluvium of different capacity. The regime of subterranean on this terrace is determined by water line in the rivers. The greatest propagation it has received in the lowest reaches of Vakhsh and Pyandzh rivers. Along riverside belt the subsoil waters are fresh and/or weakly mineralized (up to 3.0 g/l). Its mineralization is increasing gradually with removing from the riverbed. On the territories with medium or strongly mineralized levels of subsoil waters the saline soils are quickly developed.

The second terrace in Vakhsh and Nizhniy-Pyandzh valleys is hoisted above a level of the first terrace on 0.5 – 4.0 m. Lithologic profile of this terrace consists from two-layers: the alluvial boulder beds are bridged over 1.0 – 1.5 m of small granular alluvium. The large irrigated farmlands under cotton cultivation are prevalent here. For an elevation profile of the second terrace characteristically expressed binomial structure: the upper layer is folded by

11 Amu Darya has an ancient name Oxus and is one of the longest rivers of Central Asia. It is formed by the confluence of Vakhsh and Pyandzh rivers. Amu Darya forms part of Afghanistan's northern border with Tajikistan, Uzbekistan, and Turkmenistan.It springs up in the Pamir Mountains and was once lapis-lazuli mines along its banks famous throughout the ancient world.

small granular alluvial deposits of various granulometric compositions, while lower one consists from homogeneous alluvial-pebbles and sandy-loamy deposits.

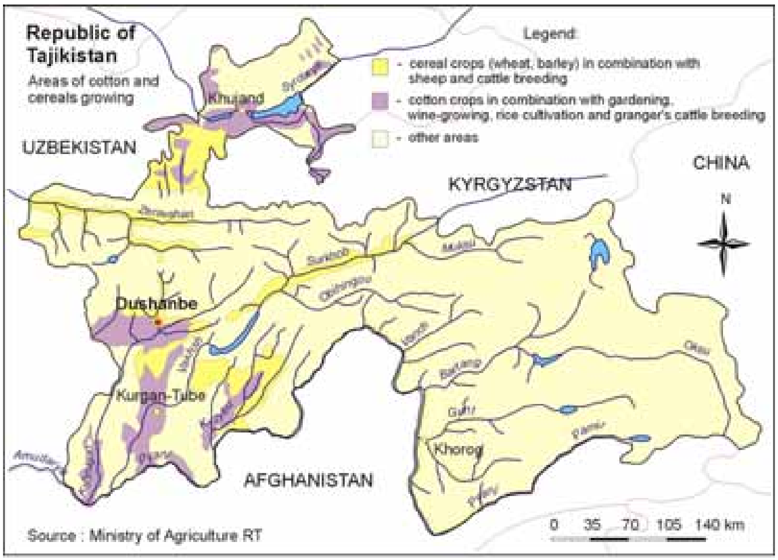


Fig. 4.1 Cotton and Cereals of Tajikistan

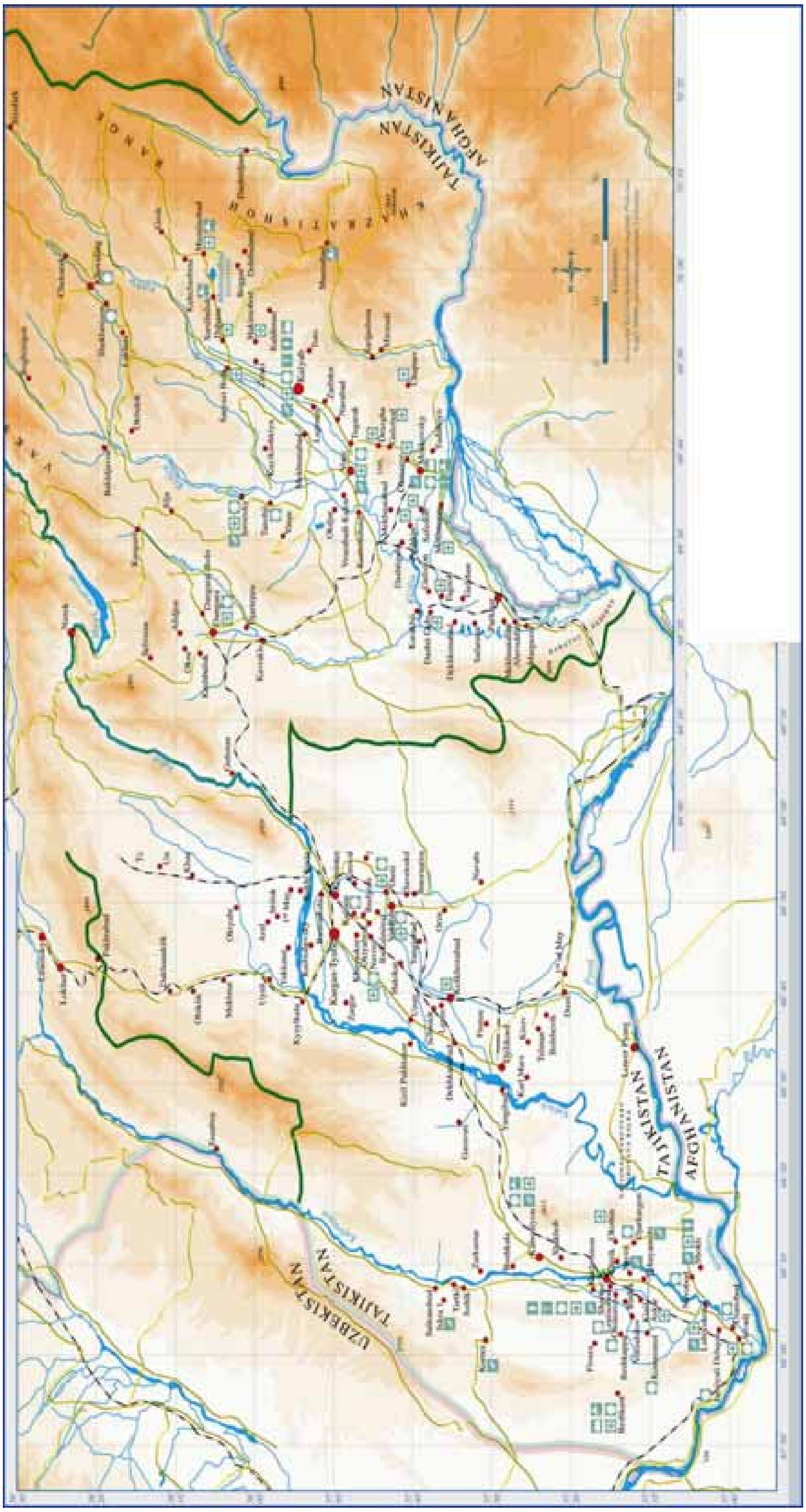
In the northern part of Vakhsh Valley the small granular alluvium deposits are less expressed. Considerable territories in the southern part of the Valley at the place of confluence of Vakhsh and Pyandzh river near Tigrovaya Balka[12] the alluvial deposits are bridged over by fixed and moving sands with aeolian-hilly relief.

The subsoil waters on detritus cones lie deeply, while on the remaining parts of the relief, despite of well developed drain networks the level of water table occurs at 0.5 – 3.0 m depth. Its mineralization varies from 3.0 up to 10.0 g/l. The regime of water table level also varies under influence of irrigation reaching maximal value in July – September.

Superficial bedding of water table promotes propagation of hydromorphic soils and development of processes of salinization of active stratum of irrigated lands.

The third terrace in the Vakhsh and Nizhniy-Pyandzh Valleys by its size is one of the largest from all terraces and from the second terrace separates by a bench at 2 – 4 m height. Its territory is irrigated from ancient time, and today on the third terrace the main massifs of cotton cultivation zone is located. At the results of long-term irrigation of these territories with muddy water from Vakhsh river on the surface of this terrace a cup-shaped relief was formed.

12 A reserve 'Tiger Valley', located in a lower reaches of Vakhsh River, is one of the world centers of preservation of a biological variety and a genofund of flora and fauna.



Lithologic profile of deposits on the third terrace is represented by trizonal layers. On the alluvial pebbles with sandy-loamy basis a powerful small granular alluvial deposits are developed, which in return is covered by irrigational detritus deposits of different grain composition with a capacity of 1.0 – 5.0 m in depth. The terrace is folded by alluvial sandy-argillaceous deposits with a loess appearance. On the depth of 15 – 60 m the gravel-pebbles deposits are spread. The subsoil waters are weakly mineralized with a water table of less than 3.0 m in depth. At the present time the territory of third terrace is well boarded with a drainage network, but the cup-shaped relief caused a considerable dimensional variation in bedding of water table.

The main massif of irrigated farmlands of Pyandzh district is dated to this third terrace. Lithology of deposits on the third terrace of Pyandzh river by its structure is similar to the constitution of deposits of the third terrace of Vakhsh river with an exception that capacity of irrigational deposits are a little less pronounced and do not exceed 2.5 – 3.0 m. Water table level varies spatially from 1 – 2 m at the bottom of the relief up to 3 – 6 m in the upper layers of the relief. On the greater part of the territory of third terrace the salinity of subsoil waters does not exceed 5.0 g/l.

The fourth terrace of Vakhsh and Nizhniy-Pyandzh valleys is represented by a weakly rolled pre-foothills plain of 3 – 10 km width. The strata of the fourth terrace are folded from powerful loess and loess loamy sands of homogeneous granular composition. The water table lies on considerable depth.

The bottomlands of the Pyandzh River Valley are relatively flat, but grade into moderately sloping arable lands with pastures. The prevailing soil types in the valleys and foothill zones are sierozems[13] (light and standard, sometimes with low salinity). The soils in the lower Pyandzh River Basin are dark gray sierozems (desert soils) while meadow-sierozem soils are distributed on the valley's terraces. The most common soil types in river flood plains are alluvial meadow and alluvial tugai.

5 Characteristics of soils and edaphic condition for main cotton cultivation

The soils of southwestern parts of Tajikistan evolved under sharply continental semi-arid/arid and progressively less under subtropical conditions. The distinctive features of soils in vertical belts is the low content of organic matters and nutrients (<1%), a high level of calcium, often associated with gypsum. The low agricultural potential of soils in this region is determined by a very high erodibility, increasing the areas of human-induced saline soils, unfavorable reclamation status of soils that are limited by poor maintenance of drainage system (Sanginov, 2001).

The soils are composed of particles of varying sizes with unfavorable physical and physico-mechanical properties of water, and often a high level of compaction. Most of these soils have evolved from alluvial, colluvial or aeolian loessic deposits with little weathering of the parent rock. They have been intensively studied for their agricultural development potential because of the availability of irrigation water, mainly from Vakhsh and Amu Darya rivers.

Sierozems of different origin and composition are the most distributed types of soils in the region. The sierozem is the grey semi-desert soils typical for

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13 Any of a zonal group of soils found in cool to temperate arid regions that are brownish gray at the surface with a lighter layer below and is based in a carbonate or hardpan layer.

the adyr steppes[14] (foothill plain belt: Lobova, 1960, Le Houerou, 1960). It is the most common soil type in the Iran-Turanian regions. This type of soil is always alkaline, has a poor organic matter content of 0.5 – 2.0%. Humus horizon of them has a capacity of more than of 20 cm. The texture is mostly sandy-loam to loam. These lands are prospectively used under rainfed/non-irrigated arable lands agriculture and/or as winter natural pastures; with irrigation these lands are widely utilized under cotton, fruit-tree, grapes and other crops. N.K.Nurmatov et al.(1991) subdivides soils of the irrigated farming zones of south Tajikistan on degrees of water penetration into three groups. The first group of soils is represented by brown-carbonate, gray-light sierozems, typical and meadow soils, compositing about 70% from the all irrigated lands. These types of soils are characterized by the lowered water penetration.

Light sierozems differ by high content of carbonates. The content of calcium carbonate in the top horizon of soils varies 14.1 – 18.0% and 16.0 – 20.0% in the lowered soil's layers. Reaction of the soil environment, in connection with it high content of carbonates is alkaline. Value of pH changes within the limits of 8.5 – 8.7. Adequate provision of mobile phosphates as a whole soil profile is low, while potassium supply is rather good. The granulometric structure of light sierozems is mainly composed by light and medium sandy loam. The content of uliginous particles (diameter <0.001 – 0.005 mm) at a scale of one meter is insignificant and makes about 12–16%. The total amount of particles with <0.01 mm (physical clay) varies from 33.0 to 36.0%. The volumetric weight of the top layers of light sierozems on loessic loams changes within the limits of 1.22, 1.37 t/m^3; 1.10 – 1.50 t/m^3 on proaluvial-small grained and on proalluvial-dealluvial deposits and of about 1.33 – 1.45 t/m^3 volumetric weight value on old-irrigated light sierozems. The volumetric weight of light sierozems of lower horizons changes within the limits of 1.38 – 1.70 t/m^3. The specific weight of light sierozems varies in narrow limits of 2.65 – 2.79 t/m^3 with a total porosity of soil as 37 – 45% for compact layers to 48 – 54% for arable layer of loessic loams.

The minimum moisture capacity of irrigated light sierozems on it profile structure and stretch changes from 14 up to 20% for sandy-loamy texture; 19 – 24% for medium loams and up to 20 – 26% for heavy loams calculated from weight of absolutely dry ground. The maximal hygroscopic at sandy-loamy and light loamy soils makes 0.4, 1.8% and increases up to 2.2, 6.7% for heavy loamy soils by its granulometric texture. Water penetration of sandy-loamy and light loamy soils at the first hours makes 52 – 96 mm. The second group are represented by dark sierozems soils having average water penetration (V_{in} = 0.6 cm/h) occupy 14.3% of the irrigated lands. The dark sierozem-meadow soils are distributed in more humidified (wet) conditions at water table of 1.0 up to 2.0 m with mineralization 0.5 – 1.5 g/l. The humus content in the top horizon varies 1.5 – 3.0%. The volumetric weight of arable layer of such soils changes within the limits of 1.08 – 1.45 t/m^3. Total porosity of the upper arable layer is within the limits of 39 – 53%. The m minimal moisture capacity of soil on it profile and spreading varies from 19 up to 31% from absolute weight of dry ground. The maximal soil hygroscopicity varies from 0.5 – 0.8 up to 4.0%; water penetration at the first hours is 15 – 94 mm gradually decreases up to 2.8 mm/h.

14 Local physiography calls “chul” as the plain belt, "adyr" for foothills, “tau” for average high mountains and “yaylau” for high mountains.

The third group of soils are gray brown and rocky soils that occupy 14.6% of the irrigated cropping land and have a high water penetration value (more V_{in} = 3 cm/h). At a depth of 55 – 88 cm the content of humus declines up to 0.2 – 0.3%. The proportion of carbon to total content of nitrogen on light sierozems in relation to soil profile decreases from top to bottom within limit of 8.9 up to 7.6. Gray brown or gray soils occur widely in the various geomorphological structure defined as low mountain ranges, inner low mountains, sloping proalluvial piedmont plains, ancient alluvial plains, basins, recent river valleys. They have a heterogeneous texture and physical properties.

When deep enough, both sierozem and grey brown soils, because of their good texture, are increasingly favored by cereal growers cultivating the depressions and dry river beds of the Nizhniy-Pyandzh steppes, where run-off water is available. These soils are rarely affected by salinity or gypsum deposits, especially when they have developed on rich loess or sandy-loam colluviums deposits. Light sierozems and meadow sierozems soils are mainly distributed in the irrigated zone of Vakhsh and Kulyab valleys. According to Table 5.1 these types of soils occupy more that 55% from total numbers of soil types.

Table 5.1 Distribution of irrigated farmlands on the territories of cotton cultivation

Soils	Distribution of area in conformity with natural-economic region, ha				Total	
	Kurgan Tyube	Kulyab	Gissar	Leninabad	ha	%
Light sierozems	112,506	4	0	32,856	145,336	33.88
Meadow sierozems	50,882	35,891	11,336	4,402	102,511	23.89
Gray-brown	115	0	0	59,576	59,691	13.91
Dark sierozems	9,171	0	37,236	0	46,690	10.81
Typical sierozems	23,933	16,600	0	157	40,690	9.48
Brown carbonate	3,694	0	9,618	,0	13,312	3.13
Meadow sierozems	0	0	6,797	2,067	8,864	2.07
Alluvial-meadow	2,842	2,626	1,223	1,679	8,370	1.79
Brown-carbonate-meadow	2,014	0	241	0	2,255	0.52
Meadow-marshy	229	1,043	135	115	1,522	0.35
Total	205,386	56,164	66,586	100,852	428,988	100

Shodiev and Zeman. 1985

The humus content is higher than in the previously described types of soils and usually reaches 3.5% on light sierozems and up to 4.0% on dark sierozems. On the floodplains of Vakhsh and Pyandzh rivers the alluvial-meadow and tugai types of soils are widely distributed. The water table is usually superficially with high level of salinity. Saline soils and solonchaks[15] are patchy located on the plainly and lowlands of Vakhsh and Pyandzh rivers valleys, overlaying the high saline water table. They have usually alkaline (high calcium carbonate content) with a heavy loamy-clay texture; the clay is flocculated giving a course lumpy texture. Under the influence of arid dry climate, which accelerates evaporation in summer and causes salts to concentrates at the ground surface. There is a recent evidence of increasing secondary salinization in many places and the trend is continuing (Sanginov,

15 Soil which has a salic horizon starting within 50 cm from the soil surface, and do not show fluvic properties, having salic properties and having no diagnostic horizons other than an A-horizon, a histic H-horizon, a cambic B-horizon, a calcic or a gypsic horizon.

2001, Toderich et al, 2004, Bezrukov et al, 2005). Most of these soils limits or delay the seed germination and establishment of seedlings at the early stages of plant ontogenesis that finally have a negatively impact on crop yields and its nutritive quality.

6 Natural vegetation, degradation trends and irrigated farming agriculture

Floristic characteristics of the southwestern part of Tajikistan are very variable and depend on landscape, humidity, length of winter, soil texture, wind force and grazing pressure. Natural vegetation on the right riverbed of Pyandzh (on its upper reaches near Parkhar and Nizhniy-Pyandzh settlements) is characterized by riparian forest ecosystem fragments. Dense vegetation is found in regularly flooded areas of Pyandzh River. In places where the water table reaches the soil surface, resistant annual and perennial grasses like species from genera Phragmites, Erianthus, Typha, Arundo, Scirpus. Here depending on the frequency of inundation, tugay vegetation[16] includes tree-like and shrubs of genera Tamarix, Eleagnus, Populus, Salix, Hyppophae, Lonicera, Halimodendron, Clematis, Lycium, Berberis and a plant community with a dominant xero-halophytes, e.g. Karelinia, Limonium, Equisetum, Capparis, Alhagi, Salsola, Glycyrrhiza, Zygophyllum that are associated with halophytes species: Suaeda, Aeluropus, Halostachys, Halocnemum. As seen on Fig. 5 the density of plant populations and botanical diversity of cover vegetation of floodplain lands on the frontier Tajik-Afghan zones are sharply different.

The ecosystems of the valley, plains and low mountain belt are typical of Babatag, Aktau, Karatau, Djilantau, and Sarsarak Ranges of Pamir-Alay mountain system. Wider watershed basin of Pyandzh River at the Tajik-Afghan boundary contains a rich mix of wild species of plants including rare and genetically valuable grasses, herbs, and small bushes. However the flora of left dry river bank of Pyandzh from Afghanistan side displays a poor botanical diversity.

According on interviews of local agronomists and farmers, huge areas of natural pastures of Artemisia ephemeral-ephemeroids plant formations on gently rolling plains of Pyandzh River Valley tends to disappear. This is because of the excessive and permanent grazing and also because currently heavily uprooted for fuel wood and additionally destroyed by civil war that was severe expressed in the Kumsangir District than in other part of Khatlon Province. The natural vegetation at Tajik-Afghan boundary is replaced by poor and degraded steppe of Peganum harmala, Cousinia resinosa, Aegilops squarrosa, Psoralea drupaceae, Girgensohnia spp., Ceratocarous and some annual species of Salsola, which are poorly palatable and acceptable only when feed is in short supply. Conservation measures for the Artemisia steppe are urgently needed and should be developed and implemented in some places.

The foothills and highlands areas between Kurgan-Tyube and Danghara towards Parkhar have an extremely diverse and rich woody species vegetation (Rodin, 1961), e.g. species of genera Pistacia, Amygdalus, Punica, Ephedra, Ulmus, Crateagus, Rubus, Malus, Junglans, Rosa etc. The northern slopes of

16 The typical tugay vegetation is flood-lands and salt steady, where trees and shrubs with dense stands of tall reeds and grasses. Salix spp. and Tamarix spp. are typical.

these ranges receive more precipitation and develop carpet of large grasses, Carex and graminaceous steppe vegetation with Festuca, Eremopyrum, Hordeum, Bromus, Stipa, Aegilops, Poa and others. The ecosystem of the low mountain comprises savanna-like communities with the dominant vegetation including Elytrigia, Agropyron, Prangos, Artemisia, Phlomis, Eremostachys, Ferula, Convolvulus, Cousinia, salvia, Melandrium, Scutellaria, Eremurus, Allium, etc.

Landscape with natural vegetation near Mumin Farm

Near Gulshan of Parkhar District, showing Afghanistan mountains far in the distance

Fig. 6.1 Cover vegetation of natural ecosystem at the Afghan-Tajik frontier zones

The intensive development of cropping agriculture started here in 1970s – 90s with extensive construction of irrigation system has superseded natural vegetation. This ecosystem, in addition, has been drastically altered by overgrazing, deforestation, farming, and livestock industries that still remain to be the principal economic human activities in the vicinity of the Afghan-Tajik boundary.

However, huge territories of virgin open plains in the Pyandzh River Valley are completely converted into farming irrigated lands. As seen on Figs. 6.1 and 6.2 near Parkhar at the upper floodplain and lowlands of Pyandzh River Basin with its loessic soils is now rapidly becoming a prime target for farmers, because of its relatively good soils, water supply, and favorable climate.

Farmers in this region are mostly specialized in the cultivation of cotton, tobacco, cereals, potatoes, vegetables, fruits, grapes, and silkworm cocoons. Large territories of the lands are occupied by gardens, vineyards, melons, and gourds-growing fields. Due to a hot subtropical climate in this zone it is possible to receive the highest yields of heat-loving crops, e.g. fine-fiber sorts of cotton, sugar beet, citrus. The plain valley of Kulyab, a right tributary of Pyandzh (Fig. 4), is considered one of the most advantageous regions by progressing of grain growing, in combination with tobacco-cultivation, food-processing industry, and horticulture and silkworm production.

Arid foothills – include lands within 300 – 660 m elevation, which are used for gardening and vineyards. Double cropping was in general in those semi-arid regions. Farmers usually cultivated wheat and barley in winter-spring and cotton, beet, melon and others crops in summer by lift irrigation. And only in the second half of 19 – 20th in the south part of Tajikistan the grain crops were dominated: wheat, barley, rice, djugara, despite of rapid progressing interest to cultivation of cotton (Maksumov, 1965). Especially major value (96%) the grain husbandry had in Kulyab district. In that time the rice took about 85% of arable irrigated lands. Kurgan-Tyube region in past decades was widely specialized in silkworm production. Special mulberry nurseries were a long time functioned there. The artificial plantations of mulberry trees are usually distributed along the sprinkling channel and roads.

Fig. 6.2 A settlement of Parkhar

Fig. 6.3 View of Pyandzh far from the border

The geranium (volatile oil bearing plant) in Tajikistan was introduced into the culture from Georgia in 1931. The following long-fibred sorts of cotton: 108-Ф, and domestic sorts 406-B, 5230-B, 504 have a long history of cultivation in the southwestern part of Tajikistan. Great interests have also oil-yielding crops, e.g. sesame, sunflower, saffron, flax etc. Occasionally a little diversity of fruit trees is seen on the right banks of small and dry beds of canals in the Pyandzh River Valley. The most distributed among them are persimmon, pomegranate, fig tree, walnut, pistachio, citrus species, unabi and various fruit trees.

7 Water resources use and management in the right bank of Pyandzh River

7-1 Irrigation infrastructure development in the Southwestern Tajikistan

Learning former agriculture in southwestern Tajikistan gives us a better understanding of local farming system and help us to develop a more elaborate agricultural reconstruction plan in the right bank of Amu Darya Basin.

In some regions of Tajikistan the irrigation systems has a long history. The archaeological excavations on settlements farm in the foothills of Mug Mountains near Pendzhikent (northwestern part of Tajikistan) showed that premises of transition to regular irrigation had been arisen at two thousand years BC. Preserved seeds of cotton, grains of barley, millet, beans, clingstone of apricot and almond, which have been found out during archaeological survey near Pendzhikent indirectly testifies that irrigated agriculture occurred in the region from ancient time (Asimov, 1974, Andrianov, 1969). Archaeological remains of old irrigated constructions has been well preserved and found out near Shaartuz and Khoshad (Vakhsh Valley), Zulumaryk, Khukumat (Kulyab region) and Kalanchi (in the Pyandzh district).

According to different sources one of the most important achievements of medieval irrigation technique on the right bank of Amu Darya River was the invention of water mills, water pumping constructions system and water lifting wheels. These types were widely used beginning from the 7 – 9th centuries BC, especially in the floodplain areas of Amu Darya.

Later from 12th until 18th centuries the installation of an irrigating mainline (water quantity intake) system was one of the basic constructions associated with the cropping development in the delta of Amu Darya, Zerafshan River Basin and in Fergana Valley. Double cropping was in general in those semi-arid regions. Farmers usually cultivated wheat and barley in winter – spring and cotton, beet, melon and others crops in summer by lift irrigation.

In 1886 during tsarist Russia about 86% of lands were allocated under cultivation of cotton. A highly advanced irrigation system has been developed following the addition of Turkestan to Russia. In the upper part of Amu Darya Basin, B.N.Kastal'skii (1885 cited by Asimov, 1974 and Bosworth, 1998) first proposed a new design of irrigated system (Fuchinoue et al., 2002). This project had envisaged the reclamation and farming land improvement with using artificial irrigations on the arid/semiarid lands at Bukhara-Afghan border near Kerki-Iola. In 1886, the principles of water use and development of irrigation techniques were applied mostly in the Syr Darya River Basin, including the northern part of Tajikistan. From the Soviet era on the territory of southwestern Tajikistan the most important and large hydro technical and irrigation constructions was started in 1933 with building of Vakhsh canal. The capacity of this water-intake construction at that time included 13 thousand kilometers of channels and irrigated more than 92 thousand ha of lands. Today the existing irrigation system in Vakhsh Valley is considered one of the largest and advantaging hydro technical constructions in the whole Republic. Contemporary water supply system in the Vakhsh River Basin has under its responsibility more than 3,813 engineering hydro technical installations. The largest among them are completely electrified.

The registration of water use was carried out through 392 hydrometeorological stations. However, the number of meteorological stations has been reduced during the period of 1991 – 1998 by 23% on average (Agaltseva, 2002). Besides that, the collapse of the Soviet Union induces the fragmentation of water resources research and the irrigation construction system that partially is reflected on agricultural and farming development in the south part of Tajikistan.

Since the collapse of the USSR, irrigation systems have become increasingly dysfunctional, as they have been poorly maintained and the capital is not available to purchase spare parts for repairs. The new stage of irrigated agriculture was developed during Soviet Period with the introduction of irrigation by sprinkling machine and through system of tunnels. Taking into account the predominance of mountain-hilly landscape of the Republic of Tajikistan in Soviet period were initiated the construction of many staged consecutive (cascade) irrigation pump stations with lifting water on altitude up to 250 m.

To facilitate the water-supply of irrigated lands in lower part of Pyandzh River Valley large-scale hydraulic engineering water-intake constructions were completed in 1970 – 1980. Chubeksk and Kholkoyarsk head water intake undamp constructions with a capacity of 54 m^3/sec were the most important in the south Tajikistan. In 1961 – 1980 in Kholhozabod and Pyandzh districts the construction of irrigated and collector-drainage network of new lands has been built. In Kurgan-Tyube during the same period were functioned more than 100 pump stations and 300 km of irrigated channels were concreted to prevent water infiltration. The construction of Nurek complex[17] (with a capacity of 10.5 km^3) was one of the biggest water construction projects in the southwestern part of Tajikistan.

This and chronic mismanagement has resulted in water logging, salinization and desertification of some lowland plains. The impact of this is massive, as without irrigation many areas cannot harvest a second crop, significantly reducing household food security. Plain areas are largely maintained by mechanized irrigation systems, and the land is prioritized for cotton growth. Mountain and valley regions are largely rain fed irrigation systems, and require constant maintenance of the hand dug channels leading from the rivers and streams. A significant amount of water is lost through seepage, and in times of low rainfall /snow melt, these systems can dry up[18].

Today, the dominant method of irrigation practiced in all the districts of southern Tajikistan by almost all of the farmers is through surface furrow or borders/basins, wherein the water is diverted from a stream located at the head of the field plot and allowed to flow down the grade. No measurement of water applied to the crop and irrigation scheduling is still based on conventional approaches. This is further aggravated by the fact that there is absolutely no data available on basic requirements of water management in crops viz., moisture extraction pattern, water requirements of different crops, impact of quantitative water deficits at different crop growth sub-periods on crop performance for efficient management of limited water supplies. In addition surface gravity irrigation is causing soil erosion, salinization and water logging, thus affecting the land productivity and water quality. Lack of knowledge or information is also evident in these areas about water holding properties of different soils varying in texture and their impact on irrigation practice.

The basic obsolete equipments that generate loss of water have applied to the majority of old irrigated lands of the Tajikistan at the present stage due to difficulties of transition period. This region suffered greatly in the 1990s during civil war. As results the various hydraulic engineering systems, hydro technical constructions, and about 40% of collectors and drain networks on all their extent require technical reconstruction. Most major canals need urgent silt removal and reshaping to improve their hydraulic properties. Many canal banks are in poor condition and numerous water control structures do not work properly and need to be replaced. The areas dependent on pumped irrigation are most at risk where pumps and motors have reached the end of their working

17 Nurek (Norak) Dam is a large earthfill dam located at 38.37 N, 69.35 E on the Vakhsh River. It is the tallest dam in the world at 300 m as of 2005. Construction began in 1961 and was completed in 1980.

18 Tajikistan Humanitarian Assessment, Visit Report, 2001

lives and pipelines have been badly damaged by corrosion. Unless effective rehabilitation measures are carried out soon, Tajikistan's Ministry of Land Reclamation and Water Resources estimates that over the next 10 – 15 years the country could lose a substantial portion of the land currently under cultivation[19].

Nowadays, almost half of irrigated lands and irrigation systems require improvement, physical repairs of the canal system, restoration of many pump stations, collector drainage systems, and introduction of new cost-effective water saving technologies.

It should be noted that the surface gravity irrigation is causing soil salinization and water logging, thus affecting the land productivity and water quality. Poor management of collector-drainage networks and limited drainage infrastructures, as well as the lack of well-timed clearing (from thickets of Phragmites and different plants) or de-silting work could be one of the main reasons for a rapid decrease of sown irrigated lands in the region. Improving the institutional environment for canal operations, controlling outputs and computerizing the process of water use, distribution and management are urgently needed.

The Ministry of Land Reclamation and Water Resources of Tajikistan with the assistance of USAID drew up a priority list of pumping schemes that needed urgent attention[20]. The ideal tool for urgent rehabilitation and further agricultural reclamation of dry lands in south part of Kumsangir appears to be the introduction of new water allocation technologies and farming systems. Subsurface drip irrigation (SDI) will be potentially applicable for high fertility of soils with a low degree or absence of salinity, and not deep water tables (from 0.5 – 2.5 m).

7-2 Hydrological characteristics and water quality

Southwestern territories of Tajikistan are transverse by several multi-aqueous rivers, e.g. Vakhsh, Kafirnigan, Pyandzh, Kyzylsu, as well as a great numbers of small-sized rivers that all of which are tributaries of Amu Darya Basin. Gunt, Shahdara, and Bartang are the most important right tributaries[21] of Pyandzh that is fed by snow and glacial melts from the Pamir Mountains. This feature determines the favor for irrigation within annual flow distribution where 80 – 90% of the annual flow is generated from April to October; the maximum flood falls from June to August.

It was also found that flow rate is controlled at various canal inlet, collectors, reservoirs, etc., according to the timing of sowing and harvest. The flow rate of the water (Fig. 7.1) of the middle and lower reaches therefore has a different feature from that of the upper part of the river (Tsukatani et al., 2001, Khujanazarov et al., 2005).

The water resources generated in the Basin of Pyandzh River makes up 36 km^3/year that it is four times highest than the water volume in the basins of Kafirnigan, Surkhandarya and Sherabad[22] taken together. In the process of

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19 http://www.usaid.gov/regions/europe_eurasia/car/index.html, Report USAID, 2005.
20 USAID: Irrigation Improvements in Tajikistan, 2002.
21 Gunt with the affluent Shahdara, Bartang (Murgab) with the affluent Gudara, Yazgulem, Vanch, Kyzylsu (southern) with the affluent Yakhsu, Vakhsh with the affluent Obikhingou.
22 Surkhandarya and Sherabad rivers lost connection with Amudarya in recent years.

development of Pyandzh river floodplains, its constantly migrated by following the accumulation of alluvial depositions and changes in the direction of principal riverbed. Up to the present, the main role in the formation of relief of the floodplains belonged to the hydrological regime in particular to the peculiarities of deposition and re-deposition of river drifts, as well as to the granulometric compositions of the rock.

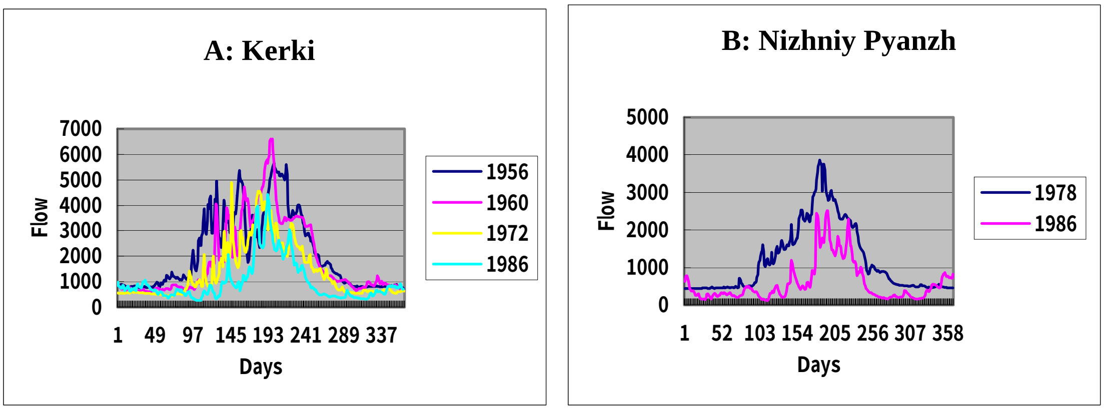

Fig. 7.1 Daily Flow Rate at Kerki (A) and Nizhniy-Pyandzh (B) from 1956 to 1986
(Tsuneo Tsukatani, et al. 2001. Unit of flow rate is x 10^5 m^3/day)

According to our observations at the present time there is no water-intake infrastructure from the Pyandzh River in Tajikistan and Afghanistan, despite of its highest long term flow in compared to all others that have rivers.

Physical-chemical parameters of water from various sources of Kumsangir District, including Mumin Farm were analyzed during our fieldwork expedition and were taken by workers of the State Committee of Environmental Protection and Forestry of the Republic of Uzbekistan.

Table 7.1 Fraction of Alluvial soil of Amu Darya River at Termez (%)

1990

Month	Size of Alluvial Soil Particles (mm)										
	Over 10	10–5	5–2	2–1	1 –0.5	0.5 –0.2	0.2 –0.1	0.1 –0.05	0.05 –0.01	0.01 –0.00 5	0.005 –0.00 1	Unde r 0.001
April		62.0	6.0	2.9	5.2	1.0	11.1	9.8	0.5	0.2	0.2	1.1
May		77.0	3.3	0.6	1.0	7.0	8.5	1.7	0.6	0.1	0.1	0.1
June		98.7	0.3	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
July				0.4	64.1	23.8	0.7	0.2	8.8	0.4	0.9	0.7

1995

Month	Size of Alluvial Soil Particles (mm)										
	Over 10	10–5	5–2	2–1	1 –0.5	0.5 –0.2	0.2 –0.1	0.1 –0.05	0.05 –0.01	0.01 –0.00 5	0.005 –0.00 1	Under 0.001
March	50.4	20.8	12.5	10.0	1.4	3.1	1.1	0.7				
April	62.6	19.1	7.8	6.7	0.6	3.0	0.2					
May	56.3	15.3	12.2	10.3	2.1	3.3	0.5					
June	62.2	17.9	8.8	7.4	1.2	2.2	0.3					
July	62.2	14.1	8.7	8.2	1.1	4.6	1.1					

2000

Month	Size of Alluvial Soil Particles (mm)											
	Over 10	10–5	5–2	2–1	1–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	Under 0.001
March	32.4	20.4	24.2	20.7	0.8	0.9	0.3	0	0.3			
April	27.5	25.0	24.0	21.0	0.6	1.2	0.3	0.2	0.2			
May	35.1	21.2	24.7	16.2	1.3	1.1	0.3	0.1	0			
June	30.4	19.8	24.8	22.1	0.9	1.2	0.4	0.2	0.2			
July	26.5	22.9	27.3	21.4	1.2	0.4	0.1	0.2	0			

2001

Month	Size of Alluvial Soil Particles (mm)											
	Over 10	10–5	5–2	2–1	1–0.5	0.5–0.2	0.2–0.1	0.1–0.05	0.05–0.01	0.01–0.005	0.005–0.001	Under 0.001
March	24.4	21.6	21.9	28.9	1.2	0.9	0.7	0.4				
April	31.0	18.7	19.1	28.6	1.2	1.0	0.3	0.1				
May	27.2	24.3	20.0	26.2	1.1	1.0	0.1	0.1				
June	29.6	24.4	20.9	22.1	0.8	1.8	0.3	0.1				
July	24.6	24.4	24.5	23.3	1.3	1.6	0.2	0.1				

7-3 Water analysis and taking of samples from the Mumin channel near frontier border

Chemical water quality analyzed from different source on the territory of Mumin Farm is generally good. We found that the pH, salinity, Total Dissolved Solids (TDS), specific conductivity of water samples collected from this site is significantly different from similar parameters taken from Pyandzh, Vakhsh, Kafirnigan (Tajikistan), Baghlan and Khnobad (North Afghanistan) rivers from one side and irrigated and collector-drainage channels from other (Table 7.2).

at a Tajik-Afghan frontier zone — from Kumsangir canal, near Dusti settlement

Fig. 7.2 Surface water sampling from Mumin Canal

Table 7.2 Chemical composition of water from Amu Darya Basin

Water parameters	Mumin earth irrigated canal	Irrigated canal from Kumsangir (magistral channel)	Mumin Canal (Tajik-Afghan boundary)	Pyandzh (Nizhniy-Pyandzh)	Kafirnigan (Tartki settlement)	Amu Darya (Tuya-Muyun*)
Suspended particles, mg/l	25	8	12	440	–	174
DO, mg/l	9.2	5.82–5.75	–	–	–	–
Sp.Cond., µS/cm	318–362	470.2	438.1	–	–	–
pH	7.39–8.30	8.5–8.74	7.5–8.47	–	–	–
Chlorites, mg/l	350	180.4	10.1	9.5	23.5	225.8
Ammonium, mg/l	2.4	0.37	0.31	1.27	no data	no data
Nitrates, mg/l	–	0.50–2.01	–	–	1.50–2.01	1.72–3.00
Nitrites, mg/l	–	0.002–0.003	–	0.001	0.013–0.020	0.004
Mineralization, mg/l	1,000	290	150	350	–	2,500
Water hardness, g/l	6.92	20.4	4.87	8.06	11.,5	16.9
Sulfates, mg/l	500	241.3	375	256	21.2–65.8	204.2
Ca 2+	–	84.3	–	37.5	54.8	101.2
Mg2+	–	20.3	–	9.8	14.2	25.9
Carbonates, mg/l	–	112.3	–	–	108.6–162.3	154.9
total iron, mg Fe/l	–	0.68	–	–	0.16–0.90	0.05
total ions, mg/l	–	673.2	–	–	190.8–339.4	869.7

* – some chemical data was taken from Hydrological Year-book, 1981

7-4 Farming system and background for subsurface drip irrigation use

Only a few farmers, however, can afford the increasing taxes and other aspects created by current social-economical situation in Tajikistan. The state is directly and still heavily involved in this lucrative sector. In this sense many farmers lack the opportunity or the skills to diversify into other crops. Private farmers are not free in their choice of crops. They must plant up to 98 percent of their land with state –ordered cotton or wheat. Failure to follow the orders of the local administration can lead to it cutting off water or even taking the land back.

All traditional crops in the Pyandzh river valley require supplemental irrigation to ensure proper cultivation. But neither extension workers nor farmers are aware of drip irrigation technology and its utility in enhancing crop productivity and water-saving. In addition most vegetable varieties currently grown in Kunduz province are local and have been under cultivation for a long time. Most of them lack resistance against viral, fungal and bacterial diseases, are not suitable for market demand (apart from local consumption), have a short shelf life, and lack shipment quality, appearance and size. The widespread use of self-produced seeds of open pollinated vegetable varieties remains a barrier to uniformity and reduces overall crop productivity. Post harvest technologies are poor developed or non-existent in the region. Products are transported in bamboo baskets and gunny bags on bumpy roads in the hot, humid climate, so that the products reaching market are of inferior quality.

Currently there are a relatively limited number of highly skilled professionals available in all Central Asian riparian countries. The critical need for all riparian countries is to develop a longer-term strategy to manage water resources, increase the agricultural byproducts and reduce vulnerability to drought. This strategy must be built within the context of the community development approach and sustainable natural resources management.

In the present paragraph we are going to give an overview of scientific work that has been done for cotton industry development for last decades in Tajikistan (Rakhmatullaev, 2004). It was found that the intensive development of irrigated agriculture and increasing of cotton farming system in the southwestern part of Tajikistan resulted in misbalance between water resources and land use. The average value of irrigative norm for last 20 years compiled 17.7 thous.m^3/sec. Water charges for 1 kg of raw cotton varies from 2.86 up to 4.04 m^3. These data testify about waste of huge quantity of water throughout the entire units of irrigated system. It was also determined that for last 30–35 years the yield of cotton ranges within limits 2.77–3.28 t/ha, despite the fact that factual crop capacity of cotton could be at 3–4 time higher, when soil/water condition and thermal resources are favorable (Akhrorov, 1971). Fig. 6.2. shows that the sharply decreasing was observed from 1992 to 2003, when the average yield of raw cotton was reduced up to 1.5–2 times.

The main reason of such decreasing might be related with poor provision and maintenance of technical basis of cotton industry, bad functioning of irrigation infrastructure (pumping stations and drainage systems) and deterioration of soil fertility. Additionally, the following problems are still present: lack of water controlling instruments for flow rate; accumulation of erosion sediments in the drainage systems; inadequate water consumption according to the yield of crops; loss of surface water (Dzhumankulov et al., 2001). The lack of competition in cotton financing and processing, and the absence of freedom of choice for farmers has resulted in steady decline of cotton farm productivity and profitability.

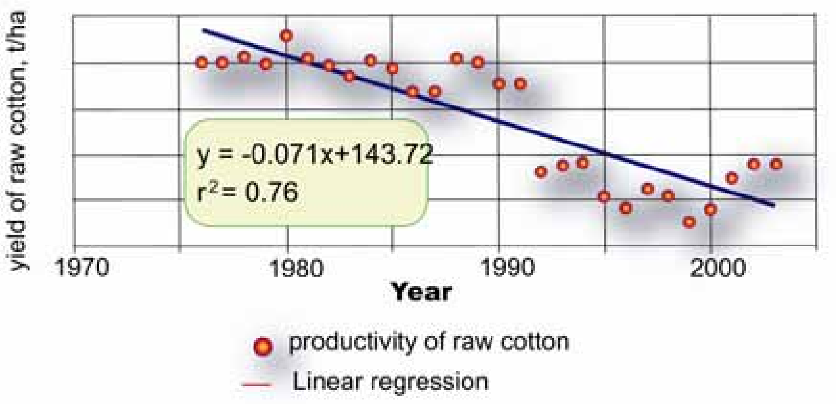

Fig. 7.3 Dynamics of raw-cotton yield in Tajikistan for the period 1976 – 2003

Following independence, Tajikistan has been in the slow process of agricultural reform. An integral component of this reform was the decentralization of land ownership through privatization[23].

In 1996, the introduction of private dekhans farms, instead of collective admitted relocation of land previously controlled by kolhoz. Despite that farmers do not own the land, they have hereditary rights, pay land taxes and in theory are allowed to choose their crops. As far as the sizes of separate dekhans farms, especially in the main cotton-producing zones do not exceed 10 ha the water supply and management, provision with techniques within them are extreme difficult. Farmers recently joint into Water Use Associations, which are considered not only the overall planning of water/land resources use and management, but also taking into account and are learn about the possibilities of implementation of new water-saving technologies for crops cultivation and programming of crop yields in relation to it biologically potential capacity (Rakhmatullaev et al, 2001, 2002, 2003).

Our collaboration with Ministry of Environment Protection and Forestry[24] and Ministry of Melioration and Water Resources of the Republic of Tajikistan will enable to implement cost-effective watershed-scale water harvesting systems that will permit not only to improve the crop farming production, but also to protect the wild riparian biodiversity in the both sides of Pyandz River Basin.

Tajik team has substantial experience in adaptive SDI and DI technologies development in the region. For last years in the northern region of Tajikistan within framework of Chinese-Tajik Project and technology transfer.

The immediate action plan has 4 main purposes:

- Wide demonstration of drip irrigation technology
- Demonstration of modern crop production in several possible locations
- Supplying information on the results attributed to the new technology
- Training and experience of local people in installation, operation, and maintenance of the system

The second most important constraint on development is the lack of farm education and training. If farmers need to operate modern equipment and advanced technology, they must have basic practical agricultural education and training.

8 Programming system of crops by using SDI and DI technologies

8-1 Background for SDI and DI

This section deals with the results of SDI study in Tajikistan, where review of many-years investigation and experiments are to promote the cultivation of cotton and other traditional crops. They are under arid/semiarid climatic conditions of Tajikistan to formulate the basic principles and perspectives of use of these water-saving modern technologies for Central Asian region.

23 Tajikistan Humanitarian Assessment, Visit Report, 2001

24 The state committee for environmental protection and forestry was set up in January 2004 instead of the abolished Ministry of Environmental Protection and Forestry.

It begins with a proper design to satisfy the condition restricted by crop, soil type, soil characteristics, field size, shape, topography, and water source and supply.

SDI involves the supply of water to crops through special moistened pipes (dripperline) laid in rows in arable lands, especially in the region where the deficit of water, land, and labor resources are evidently seen. Water flows in dripperline due to a low pressure head, and water moves vertically in the immediate region of plant root system due to a soaking up force of the soil (capillary pressure). In this way it is possible to adjust the subsurface irrigation system precisely to allow air-moisture soil conditions as well.

Good development and high yield of crops (cotton, grapes, fruit trees, citrus and non traditional plants) are anticipated when sierozems, slightly clayey loam, and rare non-saline gray brown sandy soils, are used under subsurface irrigation system. For instance, the annual yield capacity of cotton would be more than 0.60 t/ha that is 20% higher than traditional types of irrigation such as furrow irrigation. Additionally the decreasing of water intake up to 1.3 – 1.5 times less than that of furrow irrigation. Advantages of SDI as was noted in the literature (Fuchinoue et al. 2002, Erez, 2005 unpublished data) includes decreasing of evaporation that disturbs the treatment of soils under irrigation area;

- it can simplify the treatment of plants; it increases the efficiency of water-soluble fertilizer and oversimplifies its drilled fertilizing;
- the seasonal watering is automatically and easily managed that allows for control of the soil aerial-moisture regimes;
- SDI can be also applied for farming crop cultivation of steep slopes to prevent soils and water erosions.

SDI systems that have been used for cotton production can be established on carefully planned areas with tilt up to 0.02, while DI on less carefully planned areas with the tilt up to 0.05. The configuration of areas must be rectangular. Besides long-term use of polyethylene pipes would save maintenance costs.

The treasure of whole territories of Pyandzh River Basin is the availability of water. There are three basic water sources:

- surface water available directly from the Pyandzh, Kafirnigan, Vakhsh, Kyzylsu[25] (southern) with the affluent Yakhsu and other small rivers;
- water from the diversion canals and ground water (have great underground reservoirs of water, some accessible at 12 to 18 or more meter in depth below ground surface);
- In some distant remote areas the water is also accessible by tube wells, bore hole wells, and horizontally inclined wells that are largely distributed in the both river banks of Amu Darya River (Toderich et al. 2004).

Wdely used of SDI and DI technologies in all riparian countries would be still high cost for construction, installation, and maintenance. It is therefore planned to develop a design of new systems to make these technologies more attractive and acceptable for farmers. The dripperline spacing is obviously important in the system, and wider the spacing, more economic the system

25 Yakhsu, Tairsu, and Kyzylsu river basins in Khatlon province are the high-risk zones of mudflow and flood formation, where suspended solids are basic pollutants. Natural water mineralization in these rivers is 200-1,500 mg/l. Tairsu is even more mineralized more than 6 g/l, while Kyzylsu tends to brackish.

costs. However, wide spacing will not uniformly supply crop water needs and will likely result in excess deep percolation on each soil type.

Maximal content of submerged particles in water should be such that it doesn't block the micropores of pipelines. Otherwise special filters must be used to clean the water. Settling-tanks should be constructed before pipe installation of SDI system. Their working mechanism is mostly connected with the sedimentation of mechanical silt/dust particles, as well as precipitation of many heavy cations (Al, Mg, Ca, etc.) that easily lead to the up silting and/or corking of tubular pipes. The use of clean/pure and non-saline water is more efficient particularly for the development and implementation of SDI in the lower stream of Amu Darya Valley, where the contents of some cations and fraction of alluvial particles are evidently seen.

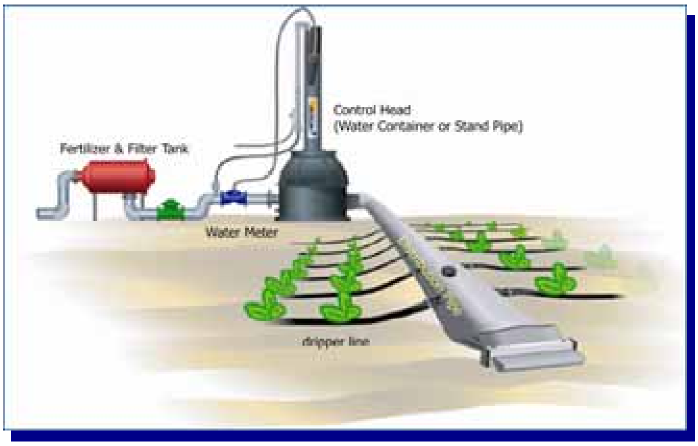

Fig. 8.1 Low Pressure System components of Netafim™
The economic new solution for flood and furrow irrigation of field crops

Using of flexible micro-porous dripperline of small diameter during frequent watering with small doses, change of distribution pipes annually or every 2 – 3 years allows avoiding self-hardening of the soil, which usually occurs during applying of subsoil irrigation with permanent dripperline for cotton. During using of DI technology such event will never happen. Irrigational system of SDI and DI can be conditionally divided into two parts:

1. stationary part, consisting of pump, water filter (if water filtering is required), mixing reservoir and fertilizer batcher, transporting and distributing pipes and equipment for control of water flow (water meter, manometer, tabs, etc);
2. semi-stationary network, consisting of watering network, which is changed annually or every 2 – 3 years when SDI is used.

Watering network, however, should be annually removed from the fields at the end of irrigational season for storage or to be changed with new pipes with water emissions at the case when DI is applied. Thus, the difference between DI and SDI systems is that instead of watering pipes along the cotton fields, on the surface of them watering pipes with sprinklers are placed.

Stationary part of the irrigation network can be built in a form of closed network with sub-surface pipes. When micropore watering is placed once every 2 – 3 years, the distribution network, in a form of irrigation pipes, can be made closed too, and when changed annually, the distribution network can be placed on the surface of the field. Pipes have to be made from a flexible material, for instance from meliorative tissue.

Stationary irrigational network are made of polyethylene pipes. For SDI funnel-shaped opening connection can be used for montage, which allows the tubular sockets (muff) to take the linear deformations as compensators, and during drip irrigation the pipes must be welded together, so that they withstand the water pressure up to 40 – 50 m. Use of SDI and DI allows the multi-profile usage of irrigation network on such operations as fertilizer supply with water, irrigation with warm water to heat the soil, regulation of air regime of soil and the field via supply of various gases through the pipes and the sprinklers.

Experiments on SDI of cotton in Gissar Valley show that when the fertilizers in the form of nutritional solution are supplied directly to the root, with the usual doses of nitrate and potassium fertilizers, a high coefficient of consumption of not only supplied fertilizers, but also the nutritional elements of the soil itself is provided (Dzhumankulov, 1977, Dzhumankulov & Rahmatilloyev, 2001a). A. Bogushevskiy (1955) and G.Y. Sheynkin et al. (1980) studied the possibilities of use of SDI network, to fertilize the fields and to heat the soil when warm water is supplied.

Supplying fertilizer with the help of injector pumps is appropriate for SDI and DI technology. The pump to dose fertilizer can be selected depending on maximal usage of the mother solution in the system. The mother solution after lightening is supplied directly into the transporting pipe with the beginning of irrigation. Warming water, enriching it with some gas or magnetizing it can be carried out in the same reservoir, and it is supplied to the system via pump for dosing the fertilizers.

Thus, the use of SDI and DI is dictated by the universality of the system itself, and with negligible exploiting expenses maximal effectiveness can be reached. One of the main operations in the building technology of SDI and DI systems is lying down and montage of watering network. Currently, the technology of mechanized trenchless lying of perforated polyethylene pipes of various diameters at the depth of 40 – 60 cm or more, for irrigation and drainage has been developed (Bezuyevskiy et al, 1977, Shevtsov, 1979).

For this reason arises necessity in constructing equipment for trenchless lying of drippers aiming to mechanize the process of building the irrigation network. Equipment installation should correspond to the following requirements:

- Be light, attachable to plowing tractor;
- Have the capacity to simultaneously lay down several rows of drippers,
- To regulate their depth and the distance between them or irrigation pipes with sprinklers.
- Be simple to use and provide a good quality of laying of drippers at the required depth.

8-2 Defining optimal elements of SDI and DI techniques

8-2-1 Selecting micropore dripper type for SDI system

The main part of the equipment for trenchless lying of dripperline could be passive operational organs with suckers through which pass the drippers and lie down in the soil. It requires the establishment of consistent row spacing for all crops. Research of Kazakov V.S. (1968) demonstrates that the operational organ should have flat frontal cutting part (sharpness angle of 180°) with the tilt of the cutting part 32 – 36° (cutting angle). Such parameters of operation organ when cutting the soil provide the formation of only loosen zone and will require less pulling power.

The width of the operational organ depending of the critical depth and can be defined according to Dinglingers formula:

$$h_{\alpha} = AB^{0.5} \quad (8.1)$$

where: h_a – critical depth, equal to the depth of laying the drippers;

A – coefficient, according to V. S. Kazakov, 1968 for moderate loamy soil A= 74;

B – width of the operational organ (in mm).

The power for cutting P for flatly sharpened knife in friable (loose soils) zone can be calculated with following formula:

$$P = K_0 Bh(1 + f_2 \times ctg\alpha) \quad (8.2)$$

where K_0 – resistance of the soil, kg/cm^2;

B – width of the knife, cm;

h – the depth of cutting, cm;

f_2 – coefficient of soil-soil friction;

a – cutting angle.

To calculate the required power according to formula (8.2) the coefficient K_0 must be known and it can be defined through the formula of Goryachkin:

$$K / K_0 = (1 + f_2 ctg\alpha) \quad (8.3)$$

or through experimental data.

After defining the optimal depth of laying the dripperline with formulae (8.1) and (8.2) we can calculate the parameters of operational organ and select the tractor class based on the required power (P).Equipment for trenchless lying of drippers also can be used to lay irrigation pipes with sprinklers. In this case, passive operational organs will serve as directing pipes, through which the irrigation pipes will pass during laying them on the surface. The irrigation pipes with sprinklers can be gathered by winding then on bobbin (resistor), which is attached to the tractor.

The basic operation element of SDI system is the drippers, via which water, nutritional solution, and warmth are distributed on the irrigation surface. The cost of SDI system largely depends on the structure of drippers and the material they are made of. Experiments on studying drippers of various structures were recently started (Sheynkin, et al., 1977). Analysis of the test results showed that loss characteristics of the drippers for leaking water into the atmosphere can be divided into two groups, the first – Viaflow-I, Viaflow-III, IV and open-pore pipes, and the second – Viaflow-II, Chapin and newway (Fig. 8.2).

As it is seen on Fig. 8.2 the loss of drippers of the first group depends in greater extent on the pressure, than the loss of drippers of the second group. Thus, the conclusion is that the drippers of the second group during their work on the surface provide more even distribution of water along their length.

During the tests of dripper of Viaflow[26]-I, II, III and Chapin[27] drippers, depending on weather conditions of the year, 12 – 14 watering sessions were conducted. Watering norms varied 369.3 – 413.3 m³/ha (Table 8.1). Research showed that the water expenditures of new drippers Viaflow-I, laid into the soil, is 0.0013 *l*/cm, and water consumption of drippers Viaflow-II and III and Chapin dripper a little less, i.e. 0.0009; 0.0007 and 0.00043 *l*/cm, respectively (Fig. 8.3).

With the increase of irrigation norm from watering to watering, from the beginning of vegetation to its end, there was a decrease in water expenditures of drippers, but depending on their modification, in various degrees. At the end of vegetation the decrease in water expenditures in average constituted: Viaflow-I – 3.3 times, Viaflow-II and III – 2.3 and 3.5 times, i.e. all Viaflow drippers are clogged to the same extent. On the field with Chapin drippers, there was uneven irrigation, excessive moisture near the pore, frequent pools of water, water leakage into the neighboring rows and soil displacement in upper 0 – 50 cm layer. Moisture in the upper layer of the soil caused intensive growth of weeds, which required extra work clearing them away.

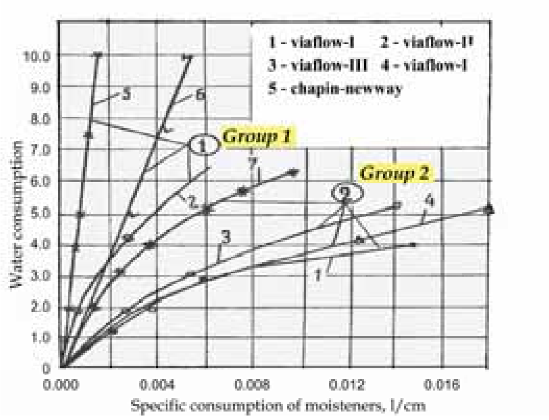

Fig. 8.2 Water consumption characteristics of drippers of various constructions

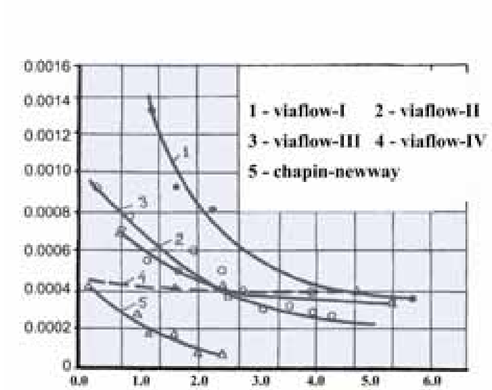

Fig. 8.3 The change in water expenditures of Viaflow and Chapin drippers depending on the irrigational norm

Table 8.1 Watering and water irrigated norms, row-yield of cotton and charges of water per one ton of cotton depending on construction of moisturizer

Dripper type	Period of use, year	Average watering norm, m³/ha	Irrigatio nal norm, m³/ha	Cotton yield, t/ha	Irrigational water expenditure, m³/ha
Viaflow I	First	413.3	5,289	5.78 ± 0.35	915
Viaflow I	Second	384.6	5,000	5.77 ± 0.75	866
Viaflow II	First	413.0	5,363	4.74 ± 0.35	1,132
Viaflow III	First	369.4	4,802	5.58 ± 0.22	860
Viaflow III	Second	410.3	5,744	5.23 ± 0.10	1,099
Chapin	First	396.3	4,756	4.11 + 0.76	1,158

26 DuPont old product. Viaflow was discontinued in the early 1980's.
27 In the United States, in the early 1960s, the first dripperline, called *Dew Hose*, was developed by Richard Chapin.

Comparative laboratory tests of dripper Viaflow-IV and newway showed that they are superior to the previously tested drippers both hydraulic and constructive. The study of the dynamics of change of water expenditures showed, that in required pressure at the beginning of vegetation, they constituted: Viaflow-IV drippers – 0.0012 *l*/cm; newway drippers – 0.0014 *l*/cm. These readings decrease from the beginning to the end of vegetation cycle. If average lines of water expenditures of the drippers are examined, it is clear that the level of decrease in this parameter of the newway drippers is twice as much.

To find out if it was possible to clear the newway drippers, the water pressure was increased to 23.5 m for 15 minutes. Water expenditures before clearing were 0.00025 *l*/cm. As the result of the clearing, the water expenses increased in 2.0 – 2.5 times. However, during watering for 6 hours, the expenses decreased to its original level before the clearing. The same process was observed when newway drippers were repeatedly cleared, i.e. clearing of newway drippers doesn’t provide the desired result.

To find out the reason for ineffective clearing, the newway drippers were excavated. It was discovered that around the drippers a zone of dense dispersed soil with the thickness of up to 2 mm formed that in some way prevents the increase of water absorption. Moreover, newway drippers were discovered to change their physic-mechanical qualities, i.e. the material (PVC) from which the dripper is made starts to wear out.

To define the reason for uneven distribution of moisture, water losses from newway and Viaflow drippers, during leakage of water into the atmosphere on 1 meter distance at the end of vegetation, were measured. The results showed that water expenses of newway drippers largely depend on the thickness of walls and the degree of pore clogging. In the process of use, initial thickness of newway pipe walls, equal to 1 mm, decreased. With this, decrease of thickness for 0.11 mm caused decrease in water expenses in 5.5 times, and the decrease for 0.22 mm for 14,3 times. The decrease in water expenses of Viaflow drippers along their length goes more evenly. The coefficient of variation of change of water expenses along the length of the drippers constituted 7.7% for Viaflow-IV, and 92% for newway. According to visual observation, it should be noted that, the parts of newway drippers with lesser permeability have lost their elasticity, became hard and fragile compared to new drippers, and they have a certain degree of deformation of wall thickness.

Rapid changes in temperature and soil moisture strongly affect the physic-mechanic properties of newway dripper. It is obvious from the fact that newway drippers left in the soil over the winter stopped permitting water through their pores altogether, even at the increased water pressure, when used again next season. On the contrary to this, Viaflow drippers have been successfully used in our tests during three years without any changes of their physic-mechanic properties.

8-2-2 Studies of the depth of laying the drippers

The experiments were conducted on studying the optimal depth of lying of drippers in order to level out the background and to obtain uniform seedlings in all variation an induced sprinkling/watering with the norm of 1,077 m^3/ha.

The results showed that during watering through drippers laid at the depth of 0.15 m, with average norm of 303 – 304 m^3/ha (option 1) mainly only the first half meter is moistened. The moisture distributes itself below the axis of the pipe up to 25 – 30 cm. During the same watering norm and the depth of 0 – 30 cm, with the increase of the depth of laying the drippers from 0.30 to 0.45 m (options 4 and 8), the upper layer of 10 – 20 cm of soil stays dry, but deeper soil horizons are moistened. For this reason in these options to maintain the pre-watering moisture at the level of 70% RH[28] we had to increase the number of watering compared to the drippers laid at the depth of 0.15 m as in options 1 and 6 (Table 8.2).

During maintenance of pre-watering moisture of the soil at the level of 70% RH in the layer 15 cm above and below the micropore pipes (options 1, 5 and 9) 50 – 60 cm, zone was moistened, above the drippers; 15 – 20 cm and below; 25 – 40 cm. In this case the number of watering has decreased for 1 and 2 watering with the increase of the depth of drippers from 0.15 to 0.3 and 0.45 m.

During watering through drippers laid at the depth of 0.15 m in the layers 0 – 60 and 0 – 90 cm (options 2 and 3), the entire zone is completely moistened. At the same norms, but with drippers laid at the depth of 0.3 m (options 6 and 7), the upper 5 – 10 cm of soil stays dry, the depth of moistening reaches up to 0.8 – 1.1 m. In the option when drippers were laid at the depth of 0.45 m (options 10 and 11) with the increase of watering norm from 590 to 850 m^3/ha, the thickness of dry upper layer decreased from 20 to 10 cm, and the depth of watering, in this case, constitutes 1.1 – 1.3 m.

Table 8.2 Depth of laying the drippers and calculated soil horizon on the terms and number of watering

Options	Depth of laying the drippers, m	Depth of the horizon, cm	Watering period		Duration of watering period, days	Number of watering
			beginning	end		
1	0.15	0 – 30	8. VII	26. IX	81	15
2	0.15	0 – 60	11. VII	28. IX	80	7
3	0.15	0 – 90	15. VII	26. IX	74	5
4	0.30	0 – 30	8. VII	28. XI	83	16
5	0.30	15 – 45	13. VII	29. IX	80	15
6	0.30	0 – 60	11. VII	1. X	83	7
7	0.30	0 – 90	15. VII	29. IX	77	5
8	0.45	0 – 30	8. VII	29. IX	83	21
9	0.45	30 – 60	14. VII	30. IX	79	14
10	0.45	0 – 60	11. VII	30. IX	83	8
11	0.45	0 – 90	15. VII	30. IX	78	5

The experiment showed that in all options with the increase of the depth of control land zone, the time for the beginning of watering postpones for 2 – 6 days, and their number decreases to 5 – 7, at the expense of increased inter-watering intervals.

It should be noted that when drippers are laid at the depth of 0.15 m and the norm is 303 – 304 m^3/ha (option 1), 2 – 3 cm wide slight darkening of the soil along the line of sowing was observed. When the watering norm was

28 RH: Relative humidity

increased up to 604 m3/ha, the surface of the field is darkened for 10 – 15 cm at both sides of the axis of the pipes. Further increase of watering norm to 850 m3/ha leads to complete darkening of the space between the rows. In the last two cases, weeds appeared early in the space between the rows of cotton, and intensive physical evaporation started. At the same time, during watering through pipes, laid at the depth of 0.3 and 0.45 m, the surface of the soil between the rows of cotton stayed dry and loose ploughing at the end of vegetation. Here only few cases of weeds along the dripperline were observed.

Different character of moistening of soil during different depth, at which the pipes are laid, had a significant affect on the development of underground and aboveground biomass of the cotton bush. The results of uncovering trench conducted in the background of watering norm of 304 – 307 m3/ha, showed that with the increase of the depth, at which the drippers are laid, the roots penetrate deeper into the soil (Fig. 8.4). This phenomenon is explained with the presence of positive hydro-and hemotropism of cotton root system, i.e. its tendency to develop in the place, where there is sufficient moisture and nutrition.

The same tendencies were noted with the background of watering norm on 827 – 887 m3/ha, but here the root penetrated deeper into the soil (Fig. 8.5). The differences in maximal depth of root penetration between these two watering norms in the experiment options constituted 26 – 30 cm, and maximal measurement was 105 cm, measured in the case of drippers laid at the depth of 0.45 m and watering norm of 850 m3/ha.

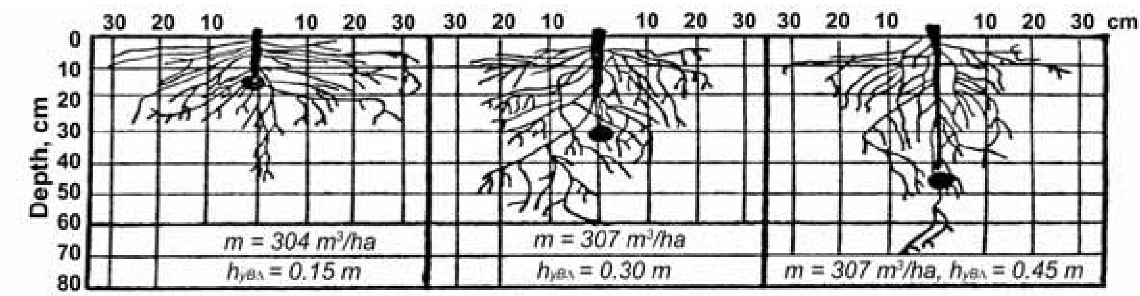

Fig. 8.4 Development of cotton root system depending on the depth, at which drippers are laid, in the control layer of 0 – 30 cm.

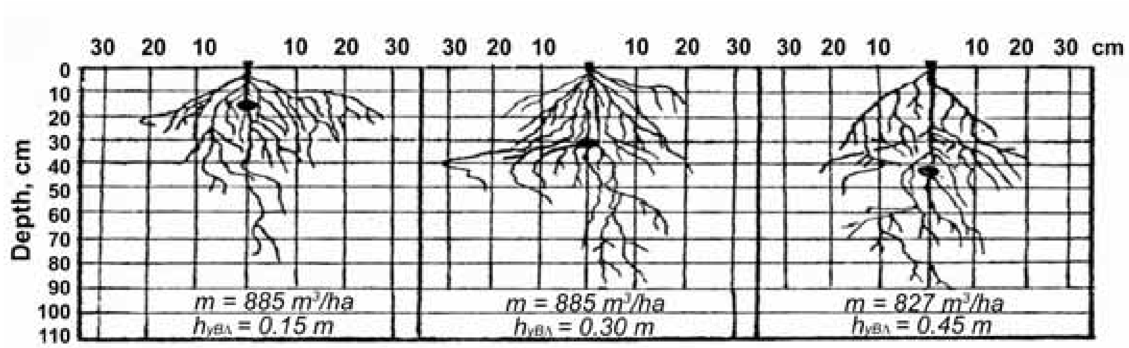

Fig. 8.5 Peculiarities of cotton root system in the variant: depth of soil 30 – 105cm and watering norm 827 – 887 m3/ha

The results of weight calculations confirmed the data of uncovering trench of root system and showed that with the increase of the depth at which the drippers are laid, the general mass of air-dry biomass of the roots in the root-nutrition layer of soil increases, but the mass of operating roots decreases (Table 8.3).

Depending on the depth, at which the moistening pipes are laid, and watering norms, from 13.09 to 20.27 g/plant of dry mass of operating roots forms.

Description of above-the-ground control plants showed that the increase of root penetration causes cotton to waste significant amount of its energy, followed by decrease of formation of absorbing roots (operational), decrease of linear growth of the main stem for 2.0 – 7.8 cm that lead to decrease of air-dry biomass and reduction of raw-cotton yield (Table 8.4).

Table 8.3 Affect of the depth, at which the moistening pipes are laid, on the character of per-layer distribution of cotton root system (gram per plant)

Depth, cm	Watering norm, m3/ha	General mass of dry roots at the depth of dripperline, m			Mass of operating roots at the depth of dripperlines, m		
		0.15	0.3	0.45	0.15	0.3	0.45
0 – 10	305	4.88	5.32	6.73	0.99	0.32	0.12
	857	4.41	5	4.47	0.78	0.46	0.29
10 – 20	305	9.71	4.23	4.78	2.37	0.57	0.31
	857	3.84	4.27	3.38	1.84	0.53	0.4
20 – 30	305	1.66	4.01	3.90	0.85	1.74	0.52
	857	2.16	2.30	2.76	0.94	0.82	0.53
30 – 40	305	0.63	2.73	2.27	0.52	1.01	1
	857	0.97	2.02	2.61	0.52	0.97	1.13
40 – 50	305	0.35	0.94	1.84	0.24	0.54	1.38
	857	0.72	0.96	2.32	0.23	0.59	1.05
50 – 60	305	0.35	0.49	0.53	00.	0.06	0.53
	857	0.5	0.78	1.08	0.13	0.32	0.35
60 – 70	305	0	0.19	0.15	0	0.03	0.09
	857	0.31	0.62	0.92	0.04	0.22	0.06
70 – 80	305	0	0	0.07	0	0	0.04
	857	0.18	0.44	0.74	0.02	0.13	0.04
80–90	305	0	0	0	0	0	0
	857	0	0.23	0.65	0	0.09	0.03
90–100	305	0	0	0	0	0	0
	857	0	0.10	0.41	0	0.05	0.01
0 – 100	305	17.23	17.81	20.27	4.97	4.26	3.99
	857	13.09	16.72	19.34	4.51	4.17	3.89

Table 8.4 Air-dry biomass and yield of cotton at control plants at different depth, where drippers are laid with different watering norms

Depth, at which the drippers are laid, m	Air-dry mass of above-ground, g/plant	Leaf surface, m^2/plant	Number of fruits, organs /plant	Number of cotton, boll/plant	General yield of cotton, g/plant
Background – watering norm 305 m^3/ha.					
0.15	181.3	0.562	21.2	12.0	64.6
0.30	170.8	0.521	16.8	10.2	54.2
0.45	169.3	0.523	14.9	8.8	47.6
Background – watering norm 857 m^3/ha.					
0.15	157.2	0.472	11.3	8.9	44.4
0.30	143.6	0.450	10.0	7.7	39.1
0.45	–	0.430	9.9	7.7	39.8

From table 8.4. we can see that on the background of both watering norms, the greatest productivity of cotton is observed when the moistening pipes are laid at the depth of 0.15 m from the surface of the soil. At the same time, the best results were obtained for the watering norm of 304 – 307 m^3/ha. In this case, the greatest mass of operational and the largest amount of side roots of first order were observed in the plowed layer of the soil.

This confirms the results of research of numerous authors (Dzhumankulov, 1977, Domullojanov 1988, 1992, Domullojanov et al, 1994, 1997, Domullojanov& Isomutdinov 1994) about the existing of relation between fruit maturation and the number of lateral roots of first order in the upper horizon of soil from one side and between fruit maturation, mass and surface area of operational roots from others.

In this experiment the presence of multiple correlation between forming of cotton yield per plant with the depth of penetration of the pivotal root and the dry mass of operational roots of one plant:

$$Y = 24.71 - 0.24h_K - 9.9G_K \qquad (8.4)$$

Where, Y – yield of raw-cotton, gram per plant.
h – the depth of penetration of pivotal root, cm.
GK – dry mass of operational roots, gram per plant.

Regression equation shows that it is necessary to create conditions, at which the plant forms the greatest amount of operational roots, which aid better nutrition and forming of greater cotton yield. According to Domullojanov, 1994 such conditions are created when the drippers are laid at the depth of 0.15 m at daily watering norm.

Different character of soil moistening for different depths, at which the drippers are laid and the amount of norm, and the related with it forming of above-the-ground and underground biomass of the bush, had significant affect on both water demand of cotton and its yield (Table 8.5.).

Table 8.5 Influence of the depth, at which drippers are laid and irrigational norm, water demand to the value of raw-cotton yield

Depth, at which the drippers are laid, m	Control layer depth, cm	Actual watering norm, m3/ha	Irrigational norm, m3/ha	Water demand, m3/ha	Yield of cotton, 1000 kg/ha	Coefficient of water use, m3 /ha
0.15	0 – 30	304	5,638	6,831	5,1±0,07	133,9
	0 – 30	303	5,623	6,820	5,08±0,01	134,1
	0 – 60	604	5,306	6,308	3,86±0,04	163,4
	0 – 90	885	5,499	6,259	3,67±0,04	170,5
0.30	0 – 30	307	5,999	7,208	4,49±0,01	162,8
	15 – 45	295	5,504	6,869	4,06±0,02	169,2
	0 – 60	582	5,155	6,090	3,62±0,08	168,7
	0 – 90	855	5,346	6,100	3,50±0,04	174,3
0.45	0 – 30	307	7,534	8,787	4,30±0,10	204,4
	30 – 60	287	5,098	6,531	4,03±0,11	162,0
	0 – 60	607	5,936	7,007	3,37±0,09	207,6
	0 – 90	827	5,215	6,007	3,45±0,09	174,1

$HCP_{05\%}$ = 0.27x100 kg/ha, $S_x^{0.5}$=0.088 t/ha

As it is seen from the table 8.5, the variation of yield (from 3.4 to 5.2 t/ha) points to significance of factors (the depth, at which the drippers are laid, watering norm), studied in the experiment, on their substantial affect on the process of forming of cotton yield. Relation of cotton yield (Y) with the watering norm (m) and the depth, at which the drippers are laid (H) is expressed as following:

$$Y = f(m, \quad H, \quad \theta) \qquad (8.5)$$

here θ – set of numerical parameters, dependent of the conditions of the experiment (level of agrotechnique, affect of the sort of cotton, soil, weather etc).

As the result of mathematical processing of data and definition of the coefficients of the equation (8.4) we will obtain the empirical relation:

$$Y = \frac{47}{H^{1.02} m^{0.11H^{-0.57}}} \qquad (8.6)$$

Average deviation of calculated values of cotton yield according 8.5, from the practically obtained data does not exceed 10%.

8-2-3 Definition of the distance between drippers

One of the parameters of SDI network, which define the number of drippers to be laid into the soil, is the distance between them. General length of drippers laid on 1 ha of land can be defined according to following formula:

$$\Sigma L = 10{,}000 / B \qquad (8.7)$$

where ΣL – overall length of drippers, laid into the soil, m/ha;

B – the distance between the drippers, m.

The distance between the drippers is defined by various calculated and experimental means (Akhrorov T.A., 20. Lev V.T., Nerziev H., 163. Ostapchik V.P., 217. Domullojanov Kh.D., Saliev A., Rahmatolliev R., 104).

Displacement of moisture from the nutrition surface of capillary system, created by the dripper to the periphery obeys the law of moisture transfer in capillary-porous bodies

$$q_n = -K\gamma\Delta w \qquad (8.8)$$

where q_n – density of moisture flow in the soil (amount of water transferred in a unit of time through iso-potential surface, normal to the movement of the flow);

K – coefficient of moisture permeability;

γ – density of porous medium, where moisture transfer is taking place;

Δw – moisture content gradient.

For particular case V.I. Kanardov (1972) based in this equation worked out the formula for calculating the distance between the drippers:

$$S = \left[0.43(q / K_f)^{0.5} + 1.3\alpha' \gamma_0 \Delta w / q_{уД}\right] \qquad (8.9)$$

where S – the distance between the drippers, m.

q – water expenditure by one pore of the dripper, m3/s.

K_f – coefficient of soil filtration, m/s.

α' – coefficient of moisture permeability.

γ_o – density of soil, t/m^3.

Δw = w_{RH} (1 – 0,7) – the difference in soil moisture, within which moisture is transferred.

$q_{уД}$ – specific expenditure of the dripper, $m^3/(h.m)$

Analysis of this formula shows that for all soil types, the values of all formula variable are constant except for $q_{уД}$ and q.

In the case of use of drippers, when the value of *q* is very small, the first variable of the equation tends to zero, and it can be neglected ($q \approx 3x10^{-9}$ m^3/s), then the distance between the drippers depends on the duration of watering and thus on the volume of the water supplied into the soil. The volume is defined by multiplication of specific expenditure on the duration of watering

$$m_y = q_{уД}\, t, \qquad (8.10)$$

where m_y – volume of water supplied into the soil for 1 meter of the dripper or specific watering norm, l/m.

$q_{уД}$ – specific expenditure of water by the dripper, l/s.m.

t – duration of watering, *s*.

As the result of numerous researches V. I. Bobchenko (33, 34) and V. P. Ostapchik (217) also came to the conclusion that the actual distribution of moisture to the sides of the dripper for each soil type depends on the duration of watering and specific expenditure of the dripper. Fig. 8.7 shows the outline of moistening depending of the specific watering norm.

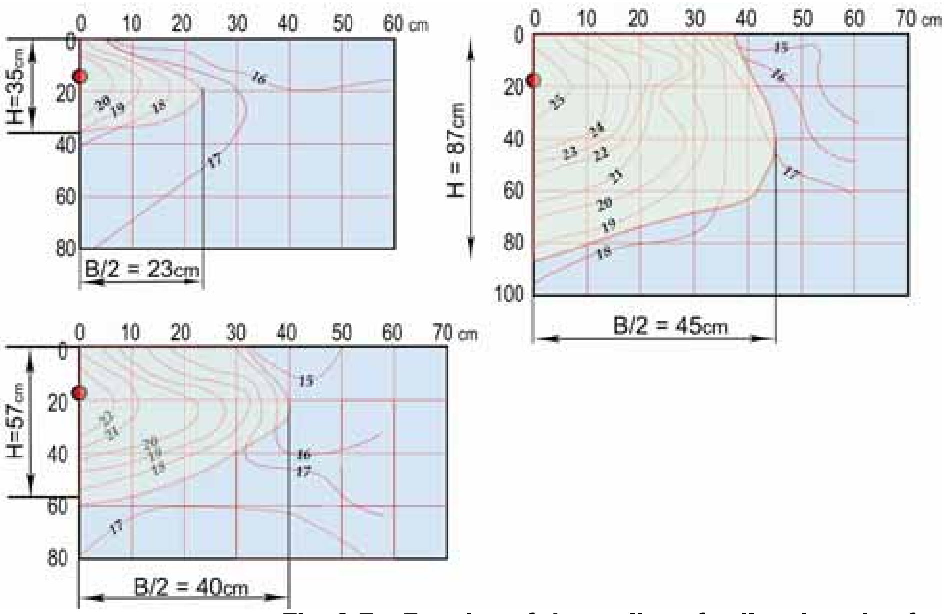

Fig. 8.7 Forming of the outline of soil moistening for various specific watering norms

As it is seen from the Figure, the change of moistening outline is clearly observed depending on the increase of specific watering norm. Having processed the data, the following dependencies were obtained:

1. Dependency of the dripper width on the specific watering norm:

$$B = 0.27\, m_y^{0.37} \qquad (8.11)$$

2. Dependency of the depth of moistening on the specific watering norm

$$H = 0.15 + 0.16\, m_y^{0.37} \qquad (8.12)$$

Comparison of experimental and theoretically calculated points of dependencies shows that the maximal deviation between them does not exceed 18%, and their average value is within 6 – 9% (Table 8.6.).

For convenience of using the dependencies (8.10, 8.11) m_y can be defined as watering norm m. Watering norm m is equal to the product of overall length of drippers on the volume of water supplied into the soil for 1 meter of their length (m_y)

$$m = 10\ m_y B^{-1}\ , \qquad (8.13)$$

From the equation (8.11) we can find m_y, substitute its value in (8.13) and solving in relation to B, we obtain the empiric formula:

$$B = 0.03\ m^{0.59}, \qquad (8.14)$$

where m – watering norm, which provides conjunction of moistening outlines, when the distance between the drippers is given, m³/ha.

Thus we find the depth of soil moistening depending on the watering norm:

$$H = 0.15 + 0.02\ m^{0.59} \qquad (8.15)$$

Table 8.6 Comparison of actual and calculated values of moisture distribution to the sides of the drippers and to the depth from the surface of the ground.

my	BΦ, M	Bp, M	ΔB=(BΦ – Bp) 100/Bp, %	HΦ,M	Hp,M	ΔH=(HΦ – Hp) 100/Hp, %
3.0	0.36	0.41	–12.2	0.31	0.35	–11.4
	0.38	0.41	–7.3	0.33	0.35	–5.7
	0.44	0.41	+7.3	0.37	0.35	+5.7
	0.44	0.41	+7.3	0.40	0.35	+14.3
16.6	0.740	0.765	–3.3	0.52	0.61	–14.8
	0.780	0.765	+2.0	0.56	0.61	–8.2
	0.80	0.765	+4.6	0.57	0.61	–6.6
	0.90	0.765	+17.6	0.64	0.61	+4.9
34.5	0.90	1.02	–10.0	0.81	0.77	+5.2
	1.00	1.02	–1.9	0.82	0.77	+6.5
	1.00	1.02	–1.9	0.85	0.77	+10.4
	1.04	1.02	+1.9 $/\Delta B_{cp}/$=6.4 %	0.89	0.77	+15.6 $/\Delta H_{cp}/$=9.1 %

These formulae are valid for change in watering norms from 50 to 500 m³/ha, and allow to select the distance between the drippers and the depth of moistening for given *(m)*, when it is necessary to provide moistening of entire space between the rows (for instance, for crops cultivation by using broadcast sowing) at the pre-watering soil moisture no less than 70% RH.

For row seeding of crops, the distance between the drippers should not be less than their value defined by formula 8.14.

Since the maximal cotton yield can be obtained during daily fertilizing norms, equal to daily evaporation for inter-row width of 90 cm (Sheynkin G.Y., Jumankulov H.D., Domullojanov H.D. et al., 364), optimal distance between the drippers during cotton production can be taken as equal to the width of its inter-row width, i.e. B = 0.9 m.

Study of the moistening outlines during daily watering norm equal to 50 m³/ha, shows good correlation between calculated values of width and depth of moistening with experimental data in Fig. 8.7.

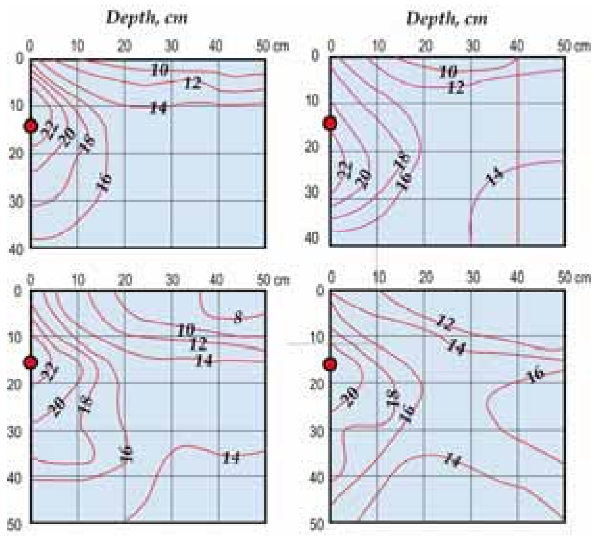

Fig. 8.7 Forming of moistening outlines during watering norm of 50 m³/ha, the distance between the drippers is 0.9 m and average specific expenditure 0.007 l/s.m.

8-2-4 Basis of optimal length of drippers laying

As the analysis of literature shows (Akhrorov, 1977 Kanardov, 1972, Karpiy, 1980, Laboda, 1968, Muhtarov & Kelesbaev, 1975, Sheynkin, 1991, Gordeev, Rakhmatilloyev, 2001 Rakhmatilloyev, 2003, 2004), the following rule must be observed to provide even distribution of moisture along the length of the drippers:

$i_r \approx i_n = h_w \,/\, \lambda_1,$ (8.16)

where i_r – average geodesic tilt.

i_n – average piezometric tilt.

h_w – loss of pressure along the length, m

λ_1 – the length of dripper, at which $i_r \approx i_n$ is observed, m

To define average piezometric tilt depending on specific expenditure ($q_{sp.}$) and the length of dripper (λ_1) we find ground (Q_n) and calculated (Q_p) expenditures of the dripper by the following equation:

$Q_p = Q_n \,/3^{0.5} = \lambda_1\, q_{yq} \,/3^{0.5}$ (8.17)

Using which we can define from the table (Shevelev F.A. and A. F. pp343) the value of average piezometric tilt. Using formulae 8.16 and 8.17, we can compose table in depending on q_y and λ_1, for different values of expenditure (Table 8.7).

Based on the data of Table 8.7 we composed a graph of dependency in=f ($q_{yq}\lambda_1$) for inner diameter of drippers d = 16 mm (Fig. 8.7).

For more comfortable use, the data from Table 8.7 is shown in the Fig. 8.9. Using Figs. 8.8 and 8.9, we can define the length of drippers, depending on specific expenditure, geodesic tilt and ground expenditure at allowed evenness of distribution along the length. To check the validity of our approach to defining the length of drippers in experimental conditions at i_r = 0.01 and $q_{yД}$ = 0.001 l/s.m we define the overall length. For this, according to Fig. 8.7 we find λ_1 = 90 m; define $Q_n = \lambda_1\, q_{yД}$ = 90·0.001 = 0.09 l/s. at given Q_n and $q_{yД}$ from Fig. 8.9 we find λ_e = 15.5 m. According to condition $\lambda_1 \le L \le \lambda_1 + \lambda_e$ we take L = 100 m.

Table 8.7 Calculation of piezometric inclination of drippers in dependence on $q_{sp.}$ and λ_1

$Q_{р}$, л/с	$Q_{п}$, л/с	$q_{уд}$	λ_1, м	$i_п$
0.04	0.0693	0.0014	49.5	0.00622
0.08	0.139		99.23	0.0213
0.12	0.208		148.6	0.0437
0.16	0.277		197.85	0.0727
0.04	0.0693	0.001	69.3	0.00622
0.08	0.139		139.0	0.0213
0.12	0.208		208.0	0.0437
0.16	0.277		277.0	0.0727
0.02	0.0350	0.0008	43.30	0.0047
0.04	0.0693		83.6	0.00622
0.08	0.139		173.75	0.0213
0.10	0.173		216.25	0.0316
0.12	0.208		260.00	0.0437
0.16	0.277		346.25	0.0727
0.20	0.347		433.75	0.108
0.02	0.0350	0.0006	58.33	0.00470
0.04	0.0693		115.50	0.00622
0.08	0.139		231.70	0.0213
0.10	0.173		288.30	0.0316
0.12	0.208		346.70	0.0437
0.02	0.0350	0.0004	87.50	0.00470
0.04	0.0693		173.25	0.00622
0.08	0.139		347.50	0.0213
0.10	0.173		432.50	0.0316

NB. The figure does not necessarily coincide with the formula 8.16 and 8.17.

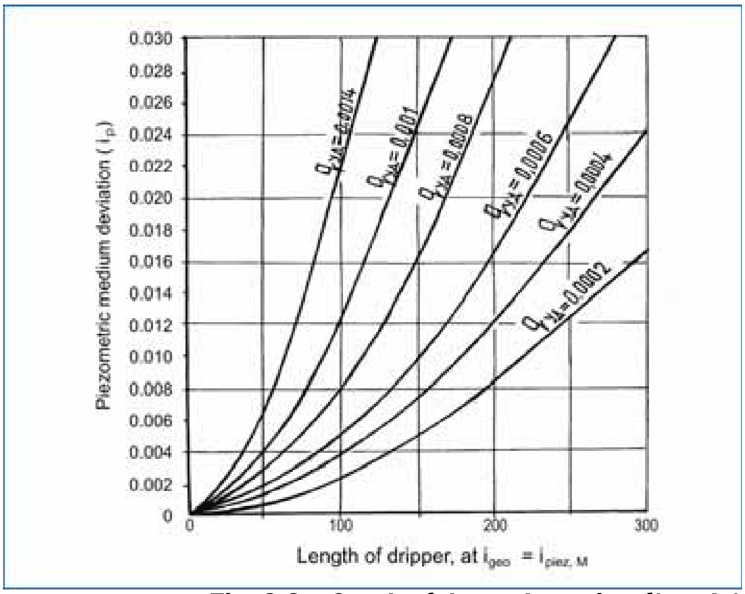

Fig. 8.8 Graph of dependency $i_п = f(q_{уд}, \lambda_1)$

Overall length of drippers, taking into account allowed unevenness of distribution can be defined through equation:

$\lambda_1. \le L \le \lambda_1 + \lambda_q$ (8.18)

The degree of evenness of distribution can be characterized by the coefficient

$K = q_o/q_k = (p_o/p_k)^a = 1.1$ (8.19)

where q_o, q_k – allowed specific water expenditures (consumption) at the start and the end of the dripper, l/s.m.

p_o, p_k – water pressure at the start and the end of the dripper, m

a – degree, characterizing the conditions of expenditure.

According to (Vdovin & Volinin, 1976) the elements of drip irrigation system should be calculated taking into account formula (8.18) as following:

$I_{\tau+1} - i = P_o/\ \gamma\ \lambda\ (1 - 1/K^{1/a})$ (8.20)

where $I_{\tau+l}$ – relative volume of overall losses, m;

i – angle of the dripper;

λ – the length of the dripper, m.

When $i = 0$ (8.19) can be written as:

$\lambda_e = Po/\ \gamma\ I_{\tau+1}\ (1 - 1/K^{1/a})$ (8.21)

whereλ_e – extra length of the dripper, at which allowed evenness of moistening along the length is observed, m.

γ – density of water, t/ m^3.

With the help of formula (8.21) extra length of the dripper at the coefficient of unevenness K=1.1 during constant diameter of the dripper, can be calculated. Relative volume of overall losses is recommended to calculate according to formula (Vdovin N. I., Volinin M.A., 1976):

$I_{\tau+l} = \lambda_o\ V_o^2/2qd\ [1 - (V_{Kp}/V_o)^3]\ B/3 + (16\ V_{Kp}^3\ )/(R_{e\,Kp}\ 2qd\ V_o)$ (8.22)

Where λ_o – coefficient of hydraulic friction, defined by formula: $\lambda_o = 0.25/R_e^{0.226}$, valid when the value of Reinold's number $R_e < 16{,}000$;

V_o – initial velocity of water in the dripper, m/s;

V_{Kp} – the velocity, appropriate to critical value of Reinold's number $R_{e\,Kp}$ =2,300;

d – inner diameter of the dripper, m:

B – correction to the coefficient of hydraulic friction with the change in average velocity $B = 1.0{+}1.09$, in our calculations $B \approx 1$:

q – acceleration of free fall, m/s^2;

R_e – Reinold's number, defined by formula: $R_e = V_o d/\nu$;

ν – coefficient of climatic viscosity; at the temperature of water 20 °C $\nu = 1.01 \cdot 10^{-6}$ (Example of calculations on hydraulics , 1977).

In the equation (8.20) coefficient a is unknown to us, to define it, we built a graph based on our field experimental data $q_{уД} = f(P)$, at the depth of laying the dripper 0.15 m from the surface of the ground (Fig. 8.8). As it is seen from Fig. 8.8 a =1.293. Substituting the value of a in (8.20), taking $K = 1.1$, we obtain the formula for defining extra length, providing allowed evenness of distribution for our conditions:

$\lambda_e = 0.071\ P_o\ /\ \gamma\ I_{\tau+l}$ (8.23)

Using the equations (8.22), (8.23) and graph $q_{уД} = f(P)$, we can compile Table 8.8 on dependency $\lambda_e = f\ (Q_n, q_{yg})$.

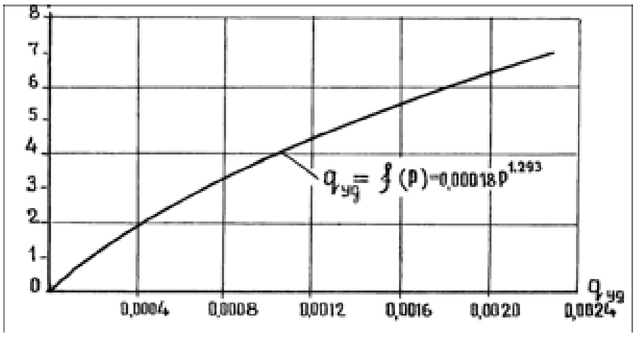

Fig. 8.9. Dependency of change of specific expenditure of drippers from the pressure of water at the depth of 0.15 m.

Table 8.8 Extra length of drippers (λe) depending on ground and specific expenditure

Q_n, l/s	$J_{T+Л}$ by formula 5.21	$q_{уД}$, l/s.m				
		0.0004	0.0006	0.0008	0.0010	0.0014
		λ_e, m				
0.04	0.007	19.3	25.4	32.4	38.0	49.7
0.06	0.0107	12.6	16.6	21.3	25.0	32.6
0.08	0.0136	9.9	13.0	16.7	19.5	25.5
0.10	0.0167	8.0	10.6	13.6	15.9	20.8
0.14	0.0222	6.1	8.0	10.2	12.0	15.7

For more comfortable use, the data from Table 8.8. is shown in Fig. 8.9. Using Figs. 8.7 and 8.9, we can define the length of drippers, depending on specific expenditure, geodesic tilt and ground expenditure at allowed evenness of distribution along the length. To check the validity of our approach to define the length of drippers in experimental conditions at i_r = 0.01 and $q_{уД}$ = 0.001 l/s.m we define the overall length. For this, according to Fig. 8.7 we find λ_1 = 90 m. define $Q_n = \lambda_1\, q_{уД} = 90 \cdot 0.001 = 0.09$ l/s. at given Q_n and $q_{уД}$ from Fig. 8.9 we find λ_e = 15.5 m. According to condition $\lambda_1 \leq L \leq \lambda_1 + \lambda_e$ we take L = 100 m.

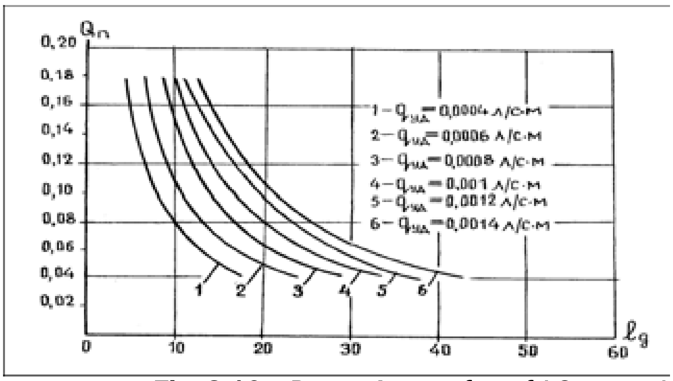

Fig. 8.10 Dependency of.e = f (Qn,q,,...g)

Comparison of actual and calculated piezometric lines shows that their average deviation constitutes 7% with the deviation from 0 to 14.9% (Table 8.9).

Table 8.9 Factual and calculated values of inclination piezometric lines on length of laying of microporous drippers L = 100 m

$q_{уд}$, l/s.m	in actual	in calculated	$\Delta_{in} = (i_{nф} - i_{np})\ 100/\ i_{np}$, %
0.00041	0.0027	0.0028	-3.6
$q_{уд,л/с.м}$	in fact	calculated	$\Delta_{in} = (i_{nф} - i_{np})\ 100/i_{np}$, %
0.00041	0.0027	0.0028	-3.6
0.00045	0.0035	0.0032	+9.4
0.00048	0.0040	0.0036	+11.1
0.00049	0.0040	0.0036	+11.1
0.00052	0.0041	0.0039	+9.1
0.00054	0.0042	0.0041	+2.4
0.00057	0.0054	0.0047	+14.9
0.00060	0.0050	0.0050	0.0
0.00067	0.0055	0.0060	-8.3
0.00067	0.0053	0.0060	-11.7
0.00074	0.0067	0.0070	-4.3
0.00074	0.0068	0.0070	-2.9
0.00082	0.0083	0.0088	-5.7
0.00090	0.0097	0.0100	-3.0
0.00100	0.0098	0.0120	-11.7
			$cp\Delta i_n$ = 7.3 %

This data demonstrate practical application of tables composed by N.M. Shevelev, 1995 for defining drippers made from polyethylene.

To evaluate the degree of evenness of forming and distribution of characteristics along the length of the drippers, let us define coefficient of variation (*V*) by Dospekhov (109) according which, variation is thought negligible if *V* = 10%, average if *V* = 10 – 20%, and significant if *V* = 20%.

Table 8.10 Basic biometric characteristics of cotton along the length of drippers depending on the variants of the experiment (1977)

Main characteristics at the end of vegetation	L=100 m. supply of water from one end		L=50 m. supply of water from one end		L=100 m. supply of water from two ends	
	$X \pm S_x$	V, %	$X \pm S_x$	V, %	$X \pm S_x$	V, %
Density of plants, thousand/per 1 m	83.6±3.19	10.8	74.2±78	6.8	80.8±16.9	5.9
Numbers of ball. th./per one plant (IX)	12.8±0.17	3.8	13.63±0.06	1.3	13.03±0.09	2.04
Average weight of one ball. g	5.32±0.03	1.6	38±0.03	1.6	5.36±0.06	3.2
Yield of raw-cotton, t/ha	5.68±0.22	9.7	5.45±0.14	7.4	5.64±0.14	6.9
Average moisture of soils at the layer 0 – 50 cm. % RH (Ha 30 IX)	67.1±2.48	14.3	68.4±3.18	14.7	70.1±2.99	16.7

As it is seen from Table 8.10, variation of number of cotton boll per one plant and average mass of one capsule along the length of all variants is negligible, i.e. *V* < 10%. In the case of supplying nutritional solution from one end, at *L* = 100 m, as the density of cotton bushes along the length varies more than 10%, the yield of cotton according to its coefficient of variation was of average variation. In two other cases, the yield of cotton along the length varies negligible, i.e. *V* = 6.8 – 5.9%.

Calculation of coefficient of evenness of moisture (K_{moi}) along the length, by the formula of Khristianson shows that K_{moi} is very large and has the value of 98.7 – 97.4%

In 1980 the experiment were repeated with the length of the drippers 100 m and supply of nutritional solution from one end, to check the evenness of forming of yield of cotton, at negligible variation of cotton bush density along the length. In this experiment during the vegetation 113 waterings with general norm of 6,158 m^3/ha were given. Average daily watering norm constituted 54.5 m^3/ha. As the conducted calculations at the end of vegetation shows, at negligible variation of density along the length (*V* = 3.2%) sufficiently even yield is formed along the length of 100-meter-long drippers (Table 8.11).

Table 8.11 Distribution of moisture and cotton yield along drippers

Characteristics	Portions, m 0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	Average V, %
Density of plants per 1 ha	97.7	100.5	100.	98.9	98.9	93.9	102.5	97.7	97.8	102.2	99.66±1.02 V = 3.2 %
Moisture in the layer of 0-30 cm, m^3/ha	1,090				1,140				1,155		1,128.3 V= 4.1 %
Number of capsules (cotton boll) per 1 plant	13.0	13.2	12.9	12.4	13.2	13.6	12.8	12.5	12.6	12.9	12.9±011 V =2.8 %
Cotton yield, t/ha	7.10	7.41	7.23	6.91	6.92	7.76	7.56	6.84	6.86	7.32	7.19±0.10 V=4.45 %

From the calculation of average values of soil moisture within folders it is clear that they vary negligibly along the length and increase from the start of the drippers to its end. The reason for this phenomenon is that during watering, micropores are clogged by particles in the water. Pore clogging in its turn leads to decrease of specific expenditures and decrease of piezometric pressures from the start to the end of the micropore dripper. Increase of piezometric pressures to the end of the drippers to certain extend influences their permeability in the end and thus increases the soil moisture. However, the process of increasing of specific expenditures leads to intensive clogging of micropores and stabilization of expenditure along the length.

From this it was concluded that when using drippers in SDI system, the process of change of specific permeability, piezometric pressures and the degree of micropore clogging depending on the pressure, always tends to be in dynamic equilibrium.

To confirm these conclusions they conducted special experiment with the drippers laid at the depth of 0.15 m from the surface of the ground, wit the length of 120 m. To give different parts of the dripper different tilts, it was laid in 6 parallel zigzags, each with the length of 20 m. Watering were at optimal regime (Saliev & Isomutdinov S.,). Altogether there were 71 waterings with the general norm of 6,565 m^3/ha, and average volume of water, which leaked into the soil through 1 meter of the dripper was equal to 0.4 m^3.

The results showed that specific expenditures at pressure change till 0.8 m have negligible variations (*V*=2.6%). This fact confirms the process of stabilization of specific expenditure along the length of the dripper during the irrigational term.

8-3 Parameters of watering and scheme of drip irrigation installation

Basic parameters of watering network of DI system include water expenditure and sprinkler types, the distance between them in irrigational pipe, the length and the diameter of irrigational pipe and also the distance between the irrigational pipes. To provide even distribution of moisture, the sprinklers should be installed in such a way that during watering, the moisture outlines overlap along the length of irrigational pipe. On the other hand, the expenditure of the sprinklers should be appropriate to absorbing capacity of soil to avoid formations of pools of water and surface drain. In ideal case of moistening of soil by DI during non-significant watering term has the shape of hemisphere, and during significant watering term it has the shape of cylindrical surface, which in lower part is restricted by a hemi-sphere.

Research of J. Keller & D. Carmali, 1978 shows that the diameter of moistening by DI depends on water-permeability of soil. On light soils it is equal to 1.4 m, on medium. 1.8 m, and on heavy soil 2.25 m. According F.V. Unguryanu (1983) maximum diameter of moistening during very large watering norms does not exceed 3.0 m. D.V. Gershunov et al. (1983), H.G. Pirov & V.M. Kolyadich (1988), N.K. Nurmatov (1991), M.Y. Khrabrov (1999) discovered that the relation of diameter and the depth of moistening on loamy soils is equal to 1.0 – 1.6. According to our data on moderate loamy soils the relation of width and depth of moistening constitutes about 1.5. This research allows proposing that during irrigation of cotton the diameter of cylindrical surface of moistening is equal to the distance between the sprinklers along the length of the pipe (BK), and maximal depth of moistening HyB is restricted by the distance from the surface of the ground to its lowest point. Having generalized our research on DI of cotton we propose maximal specific expenditures of watering pipe, expenditures of the sprinklers depending on the water-permeability and granule- metric composition of soils (Table 8.12).

Table 8.12 Maximal specific expenditures of watering pipes and sprinklers depending on the water-permeability and granule-metric composition of soils during DI of cotton

Water-permeability (granulemetric composition of soils)	Formed speed of absorption (KyCT), m/h	Maximal specific expenditure of watering pipe, l/s.m	Maximal expenditure of the sprinklers, l/h
Increased water-permeability (light powerful loam)	0.01 – 0.006	0.0030 – 0.002	8 – 10
Medium water-permeability (medium sized loam)	0.006 – 0.003	0.0016 – 0.0012	6 – 4
Decreased water-permeability (heavy loam with medium streaks)	0.003 – 0.002	0.0010 – 0.0007	3 – 2

Movement of moisture to the side and into the soil layers from the sprinkler depends on duration of water supply or on watering norm (m, m^3/ha). The distance between the sprinklers (B_K) during their maximal expenditure initially can be defined according to following dependencies:

for light loamy soils – $B_K = 0.05\ m^{0.45}$ (8.24)
for medium loamy soils – $B_K = 0.03\ m^{0.6}$ (8.25)
for heavy loamy soils – $B_K = 0.02\ m^{0.7}$ (8.26)
and the depth of moistening by formulae:
for light loamy soils – $H_{yB} = 0.07\ m^{0.45}$ (8.27)
for medium loamy soils – $H_{yB} = 0.02\ m^{0.6}$ (8.28)
for heavy loamy soils – $H_{yB} = 0.008\ m^{0.7}$ (8.29)

On the planning stage the parameters of soil moistening should be verified. The length of watering pipes is defined using the dependencies of hydraulics of variable mass during constant even distribution of water along the way. Usually the length of the pipe at its diameter of 16 mm is taken as equal to 100 m on light and medium soils and 150 m – on heavy soils. Operational pressure of the pipes constitutes 10 – 30 MP_a.

An important element of irrigational network of DI is the scheme of laying watering pipes, which significantly influences the cost of irrigation. The experience of western countries shows that watering pipes of DI system of cotton are usually laid through inter-row width at the distance of 1.8 – 2.0 m.

To define the scheme of laying of watering pies in the conditions of medium loamy soils of Tajikistan Republic special field experiment was conducted, where cotton was sown according to the schemes 60x20 – 1 and 90x15 – 1, and watering pipes were laid along each row and through inter-row width. Thus the distance between them constituted 0.6; 0.9; 1.2 and 1.8 m. Main criteria of evaluation of effectiveness of schemes of watering pipes is expenditure of irrigational water and cotton yield. The results of the experiment show that during DI water expenditure for production of one ton of cotton is 1.4 – 2.4 times less than during watering along the furrows. During DI of nutritional solutions maximum yield of cotton was obtained when cotton was watered every other 3rd day, in the case when the pipes were laid along each row. Observations show that in the case of cotton inter-row width of 0.6 m large generative mass is formed, light regime of cotton decreases. The consequence of this is decrease in cotton yield compared to inter-row width of 0.9 m (Tables 8.13 and 8.14).

Table 8.13 Irrigation norms, cotton yield depending on various schemes of laying of watering pipes and the watering frequency for cotton growth with an inter-row width of 0,9 meters

Scheme of laying of watering pipes, m	Watering frequency	Watering norm, m^3/ha	Cotton yield, t/ha.	Expenditure of water for production of one ton of cotton, m^3/t
Every other row, at the distance of 1.8 m	Every 9 days (E9)	4,290	4.00	1,072.15
	Every 6 days (E6)	4,620	3.60	1,283.3
	Every 3 days (E3)	4,950	4.70	1,053.2
	Every day (E1)	5,280	3.60	1,466.7
Along each row, at the distance of 0.9 m	Every 9 days (E9)	4,290	3.76	1,308.5
	Every 6 days (E_6)	4,620	4.02	1,149.3
	Every 3 days (E_3)	4,950	5.46	906.6
	Every day (E_1)	5,280	3.42	1,543.9

When programming cotton yield at the level of up to 4.0 t/ha during DI watering pipes should be laid along every other row at the distance of 1.8 m, and when programming cotton yield at the level of 5.0 t/ha and higher the pipes should be laid along each row at every 0.9 m. It is best to use sprinklers of Katif[29] type or watering pipes with built-in sprinklers with compensator of water pressure. Such construction of watering pipe allows re-using it numerous times without damaging it, during cotton production.

Table 8.14 Irrigational norms, cotton yield depending on various schemes of laying of watering pies and the watering frequency for cotton inter-row width of 0.6 meters

Scheme of laying of watering pipes, m	Watering frequency	Watering norm, m3/ha	Cotton yield, t/ha.	Expenditure of water for production of one ton of cotton, m3/t
Every other row, at the distance of 1.8 m	Every 9 days (E9)	4,290	2.77	1,548.7
	Every 6 days (E6)	4,620	3.00	1,540.0
	Every 3 days (E3)	4,950	4.17	1,187.0
	Every day (E1)	5,280	3.49	1,512.9
Along each row, at the distance of 0.9 m	Every 9 days (E9)	4,290	3.81	1,126.0
	Every 6 days (E_6)	4,620	3.90	1,184.6
	Every 3 days (E_3)	4,950	4.72	1,048.7
	Every day (E_1)	5,280	3.69	1,430.9

8-4 Conclusion and Discussion of Section 8

Use of modern technology of irrigation allows in Tajikistan to reach very high levels of cotton yield, which exceed existing yields 2 – 4 times, under the natural potential, temperature sum, and soil fertility.

Fundamental conceptual approaches to developing the technology of programming of cotton yield based on focused watering to obtain 3 – 5 t/ha of thin and medium fiber cotton sorts during irrigation along the furrows, and also the technology of programming of cotton yield for SDI and DI, intended to obtain 4 – 8 t/ha of medium fiber sorts of cotton were formulated. These technologies take into account the principle “special technology to each field” and their basic elements are functionally interconnected and mathematical models and algorithms of calculations were developed for planning and installing them.

It has been concluded that the level of cotton yield depends on pre-watering moisture and the depth of calculated layer of soil for each phase of cotton development. Mathematical model for moistening the soil during irrigation along the furrows, SDI and DI were developed, dependencies for calculating watering norm, decade values of water consumption deficiencies were obtained. Algorithm of planning and correcting of watering of medium-fiber sort of cotton within the cotton yield limits from 3 to 8 t/ha and fine-fiber cotton – from 3 to 5 t/ha were developed.

Dose calculation and terms of introduction of fertilizers were proposed for programmed levels of yields on the basis of balance of basic nutritional materials in the soil. It was defined that during SDI coefficient of use of nitrogen on the average constitutes – 0.88, phosphorus – 0.68 and potassium – more than 1. To obtain 1 ton of cotton yield, 47 – 35 kg of nitrogen, 14.5 – 11 kg of phosphorus and 61.1 – 43.1 kg of potassium is used. Parameters of use of fertilizers during SDI exceed the same values during watering along the furrows

29 Flow-regulated button dripper by Plastro Irrigation Systems Ltd. ensuring constant flow rates along long-run driplines or in the most challenging topographical conditions., but sometimes clogging.

for nitrogen 2, 3 times, for phosphorus – 5.7 times and for potassium – from 1.5 to 5.13 times. Based on processing the obtained data, they worked out empirical dependencies of extraction of fertilizers from the soil by cotton yield on the amount of watering norms. The dependencies are defined by the formula of length of straight line.

Basic requirements and principles of organization of focused irrigation were verified, and they allowed to develop analytical dependencies for defining expenditures of field channels, taking into account the water loss for field tilt of 0.01 – 0.05 during sufficient or limited number of irrigators. The size of cotton farms or a group of water consumers depending on the level of water-permeability of soil and constant flow of water for providing focused irrigation were proposed.

The experiment showed that during SDI and DI of cotton optimal inter-row width constitute 0.9 m, for the level of yield up to 4 t/ha, watering pipes of DI should be laid through inter-row width, and for large yields – in every inter-row along the row of plants. Drippers should have up to 3,000 micropore with the size of 4 – 20 m, water expenditure 0.12 – 0.14 l/s for 100 m, they should be laid under every row at the depth of 0.1 – 0.15 m from the surface. During SDI for medium argillaceous soils and during DI for light, medium and heavy loamy soils dependencies of water distribution into the soil to the sides and to the depths from the dripper or the sprinkler were defined, which allows to calculate the distance between the sprinklers or drippers.

For building moistening network, elements of technology and operational organs for trenchless dripper installation were developed. Operational organs allows to simultaneously install four rows of drippers at the depth of 0.10 – 0.15 m with the distance between them up to 0.9 m.

Conduction of multi-variant experiments with SDI and DI allowed obtaining empirical formulae for defining the density of cotton bushes from the level of programmed yield. The maximal yield of cotton during SDI and DI can be obtained at the density of cotton bushes of 70 – 75 thousand plants per 1 ha.

Results of calculation of energy expenses show that general expenses of overall energy of stationary part of irrigational network and well constitute 36,973.4 – 14,899.6 MJ/ha. Use of water for irrigation from a well will lead to increase of general energy expenses for supplying water 8.6 – 12.5 times. Optimal area of module field, providing minimal energy expenses for water supply can be taken as equal to 9 – 12 ha with the sides of 300x300 or 300x400 m. Generally, overall energy expenses depending on the programmed level of cotton yield and methods of irrigation, when water is supplied from external source and machinery collection of cotton constituted 80,817 – 134,403 MJ/ha, and the same parameters with water supplied from a well reached the level of 107,180 – 159,786 MJ/ha.

During manual collection of cotton the energy expenses increase on average for 8 – 10%. The expenses concerning irrigation of cotton take up approximately 20 – 33% (on average 28%) from overall energy expenses when water is supplied from external source and 37 – 44% (on average 41%). when water is supplied from a well. Energy expenses of cotton production technology for the level of yield of 3.5 t/ha during machinery collection of cotton and self-flowing source of irrigation are most effective ($\eta_2 > 1.0 > \eta_1$), and starting from the level of 6 t/ha, energy-conserving ($\eta_1 > 1.0$). New methods of irrigation increase coefficient of effectiveness of energy expenses 1.58 – 1.82 times compared to the technology of cotton production with watering along the furrows.

Technology of programming cotton yield on the basis of organization of focused irrigation allows to increase productivity for 27 – 30%, decrease irrigational norm for 15 – 20%, and also introduction of fertilizers, taking into account the content of nutritional materials in the soil to their extraction, provides extra pure income of around 394 – 637 dollars/ha.

In the conditions of SDI and DI the yield is increased 1.5 – 2.5 times and the expense of irrigational norm for production of 1 ton of cotton 2.0 – 2.6 times less, than during watering along the furrows. In vegetation period with SDI and DI number of operations decreases 3.3 times. SDI of cotton with the aid of drippers provides extra pure income from 800.3 to 360.9 dollars/ha, and DI of cotton depending on the programmed level of yield 229.4 – 836.3 dollars/ha. The use of perspective constructions of irrigational systems for farms allows to increase KPD of network up to 0,9-0,95, KPD of watering technique . to 0,8-0,9, and KZI – to 0,92-0,97. The results of introduction of differentiated technology of irrigation along long through furrows shows that the evenness of moistening along the length of furrows constitutes 0,85-0,9, and KPD of irrigation 0,75.0,85. Extra pure income constituted compared to control field 232,9 dollars/ha. Differentiated technology of irrigation along through furrows was introduced on general area of 6,000 ha in Yavan district. Overall extra pure income from introducing this technology constituted over 1,3 million dollars.

9 Discussion and conclusion

Food assistance may temporary satisfy the Afghan's hunger, but it shall not resolve the absolute scarcity of food production. Long-term reconstruction and rehabilitation of domestic agriculture is crucial solution in Afghanistan. This is the main purpose of this paper.

The international operation will fund a series of rapid impact programs designed to reconstruct basic infrastructures such as irrigation systems. Nevertheless, these irrigation systems require much water from watercourses including Amu Darya and its tributaries such as Kokcha and Kunduz Rivers, and Pyandzh River. Afghanistan has not participated in the interstate agreement for trans-boundary water resources of Amu Darya.

It is easy to infer what may happen next. Conflicts between Afghanistan and the Central Asian Republics may occur. In the worst case, these conflicts might bring another tragedy to Afghanistan. Therefore, it is inevitable to arrange the interstate coordination for trans-boundary water use among all riparian states before the rehabilitation plan for Afghan irrigation systems is promoted.

There are some preconditions to make this proposal feasible as of engineering technology, political economics, international legitimacy and international law. We are suggesting practical resolutions that address the issues related to international legitimacy. We believe Afghanistan should be integrated within the framework of Amu Darya Basin water resources agreement to avoid inter-state water conflicts and to provide a stable and reasonable political climate for further reconstruction efforts in Afghanistan.

There are four conditions necessary to attain equitable, reasonable, and optimal utilization of Amu Darya river water resources among all riparian states. First of all, sophisticated interstate agreements for water use must be signed. Second, all riparian states: Uzbekistan, Tajikistan, Turkmenistan, and Afghanistan must participate in the agreement. Third, an independent institution with superior authority for water use of all participants must be founded. Without these conditions, we shall not be able to achieve effective reconstruction assistance to Afghanistan. Fourth, some of the Afghanistan Reconstruction Funds must be allocated to co-improvement of water use efficiency and agricultural development for all riparian States.

An independent juristic body is required to settle an interstate dispute. Existing institutions such as ICWC (Interstate Commission for Water Coordination), ICAS (Interstate Council on the Aral Sea Basin), and IFAS (International Fund for the Aral Sea) are not juristic institutions and are not able to prescribe interstate water law, do not have authority of compulsory execution, and settle disputes. They are not legislative organizations either. Since Central Asian Republics did not have a place for dispute settlement, a serious dispute occurred between Kyrgyzstan and Uzbekistan in 1997 due to the difference in seasonal water demands. Kyrgyzstan finally decided that most of its water resources would be introduced into hydroelectric power generations in 2001 to complement energy shortage.

To settle this kind of dispute, all riparian states must entrust authority of water allocation to the independent juristic institution whose major objective is to achieve equitable and optimal water resources allocation among all riparian states based on the sophisticated international water law. The institution should consist of independent judges and agents independent from riparian states. They can be of foreign origin such as Russia or Japan. Without the settlement system of dispute, it is very difficult for riparian states to achieve peaceful optimal water resources allocation.

With our short discussion on all the social, economical, political, and humane perspectives of the opium issue, the importance of providing a competent system of irrigation for the farmers living in north Afghanistan could not be overemphasized, considering the potentials of Amu Darya river to support a healthy and strong agriculture on its left bank.

Also credit must be offered to local farmers to help them escape the debt trap. Many farmers are in debt to local drug lords who are demanding they grow poppy. Even farmers who cultivate cereals are struggling to feed themselves, as their entire crop is taken to repay the debts they have accumulated. Apart from a long-term restructuring plan, they also need immediate assistance.

Participants

This research, involved collaboration with Uzbek, Tajik, and Japanese researchers, was to complement the required information and to prepare the necessary steps for establishment of sustainable agricultural development in the region and to assist with the ongoing process for the development of riparian states in Central Asia. The followings were the participants of the expedition:

Munimjan Abbdusamatov – Chief of Specialized Inspection of the State Control on Water Use and Preservation of Water Resources, State Committee for Environmental Protection and Forestry; member of the Engineering Academy of the Republic of Tajikistan.

Kristina Toderich – Dr., Department of Desert Ecology and Water Resources Research, Samarkand Division of Academy of Sciences of the Republic of Uzbekistan.

Timur Khujanazarov – Tashkent State Technical University, Uzbekistan.

Rahmonkul Rahmatilloev – Dr. Engineer – hydro-technician, Republican Center for Farm Privatization Support under the Government of the Republic of Tajikistan.

Abdulhair Muminov- leader of Mumin Farm, Kumsangir District, Tajikistan.

Abdumukim Boboev- leading agronomist of Mumin Farm, Kumsangir District, Tajikistan.

Matluba Fuzaylova– Researcher, Inspection of the State Control on Water Use and Preservation of Water Resources, State Committee for Environmental Protection and Forestry of the Republic of Tajikistan.

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