PCRWR

Smart Land and Water Management Interventions for Pothwar Region

Research and Demonstration Farm,
Darkali Kalan, Gujar Khan Rawalpindi

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

Cbar	Centi Bar
FAO	Food and Agriculture Organization
FC	Field Capacity
IUCN	International Union for Conservation of Nature
MoWR	Ministry of Water Resources
ICARDA	International Center for Agriculture Research in the Dry Areas
MoST	Ministry of Science and Technology
Mha	Million Hectare
MAF	Million Acre Foot
PCRWR	Pakistan Council of Research in Water Resources
PWP	Permanent Wilting Point
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture

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Executive Summary

Pakistan is a predominantly arid to semi-arid country, where annual rainfall ranges from less than 250 mm to over 1000 mm. Agriculture sector contributes around 19% towards the country's GDP. About 40% of the total culturable area is Barani or rainfed. The rapid increase in the population and urbanization has put agriculture under immense stress to grow more food for the growing population. In rainfed or Barani areas, agriculture is solely dependent on rainfall.

The country is facing several challenges in the water sector. Increase in the crop production is essential to feed the growing population and to meet the country's food demands. However, the water productivity in the irrigated and rainfed areas are less than the optimal. To enhance the water productivity, appropriate technologies and interventions should be adopted. A main bottleneck in the adaptation of these interventions is the traditional mind set of the farmers and believing on different myths related to land and water management.

To guide the farmers and break some of their myths, Pakistan Council of Research in Water Resources (PCRWR) established a research and demonstration farm in Barani area to develop and validate land and water management interventions. The farm also showcases these interventions to the nearby farmers and a hub of knowledge for the farmers of other areas.

This report briefly discusses the interventions introduced at the farm and how these interventions are helpful to increase the water productivity and production of the area. These techniques consist of micro catchments for fruit plants, inverted wells for groundwater recharge, rainwater harvesting ponds, mini dams, rooftop rain harvesting, solar powered pumping arrangements, soil moisture sensors, tensiometers chameleon sensors to measure the soil moisture status. These interventions are really helpful to increase the crop production in the Barani areas to cope up with water scarcity and fulfil the requirements of different crops and orchards accordingly. These are tested technologies which may be beneficial for the farmers to uplift their livelihood and GDP of the country in the wake of climate change.

1 Introduction

Water Scarcity is a global phenomenon. As per UN-Water (2021), about 2.3 billion people live in water-stressed countries, of which 733 million live in high and critically water-stressed areas. FAO (2020) reported that 3.2 billion people live in agricultural areas with high to very high-water shortages of whom 1.2 billion people – roughly one-sixth of the world's population live in severely water-constrained agricultural areas. About 4 billion people, representing nearly two-thirds of the then global population experience severe water scarcity during at least one month of the year (Mekonnen and Hoekstra, 2016). Nearly half the global population are already living in potential water scarce areas at least one month per year and this could increase to some 4.8–5.7 billion in 2050. About 73% of the affected people live in Asia (69% by 2050) (Burek et al., 2016).

Pakistan is primarily an agriculture country with an area of 79.61 million hectares (Mha). However, only 22.11 Mha is cultivated (MINFAL, 2005). About 40% of this cultivated area falls in rainfed region. Biggest chunk of rainfed area is mainly concentrated in Pothwar Plateau with a total area of 2.2 Mha, out of which 1 Mha is cultivated. The topography of the area is undulating with varying altitudes from 300 to 600 m above the mean sea level. It lies between the rivers Jhelum and Indus, including Attock and Rawalpindi districts leaving some area of Murree, 75 percent of Chakwal district, 15 percent of Jhelum district and about 20 percent of Mianwali district. It is about 250 km long and 100 km wide with elevations ranging from 200 m along the river Indus to about 900 m in the hills north of Islamabad with an average elevation of 457 m (Ashfaq et al., 2007). Its approximate population is 10.37 million based on the census report of 2017 of the Pakistan Bureau of Statistics.

The agriculture in Pothwar region is far below the potential due to non-availability of assured irrigation supplies. Almost 70% of rainfall occurs in the monsoon season during summer and this rainwater is difficult to store for the whole year for crop use. Due to this, about 3.4 million-acre feet (MAF) of water is lost as surface runoff annually (Ashfaq et al., 2007). This water, therefore, is not available for agriculture. Moreover, due to uncertainty of rainfall, farmers normally minimize inputs to reduce the risk of loss in the event of drought and mainly depend on off-farm incomes for their sustenance. Also, the average land holding is generally low (1 hectare). The trend of division of land holdings and migration has disrupted the social balance in the area and is hindering further economic development.

Another issue in the region is soil erosion caused by high-intensity rainfall events, steep slopes and fragile soil. The consequences include loss of fertile layers of the soil, loss of vegetation, depletion of reservoirs capacity due to sedimentation and eutrophication including contamination of surface and groundwater (Ashraf et al., 2002). Thus, huge runoff potential is available where majority of land is unutilized and is prone to the risk of soil erosion. Therefore, it becomes imperative that the land and water are conserved and used efficiently in these areas.

Due to high variation in rainfall and non-availability of perennial source of surface water, the agriculture in this area is heavily reliant on groundwater. It is also necessary to monitor the groundwater levels and maintain a balance between abstraction and recharge. Water conservation and erosion control practices can improve agriculture production in the area. However, such practices may need to be tested at the farm level and disseminated to the farmers of the region. This would lead to develop a substantial change in the arid region resulting in higher food security, proper utilization of surface water, erosion control, keeping groundwater sustainable and ultimately uplifting socio-economic conditions of the farmers.

With the vision to adopt and promote water management technologies and techniques in the region, PCRWR established a Research and Demonstration Farm in 2009. Due to some reasons, it remained non-operational until 2014. Since July 2014, different interventions pertaining to land and water management have been implemented. The main objective of these research activities is to generate knowledge and create awareness among farmers through demonstration using the concept "seeing is believing". These interventions focus on water conservation, water storage, groundwater recharge techniques and erosion control practices etc.

2 Research and Demonstration Farm

The Research and Demonstration farm is located in Darkali Kalan of district Rawalpindi at 73.03° E and 33.30° N. It comprises an area of 175 kanals (22 acres) of undulating topography representing the characteristics of Pothwar region. This also includes 10 acres of cultivated area (Table 1).

Table 1: Land utilization status of the R&D farm, Darkali Kalan

Distribution of Land	Area		
	Kanals	Acres	Percentage
Land available for cultivation	82	10.3	47
Farm building, machinery shed/entrance	4	0.5	2
Clay dunes with natural vegetation (available for forestation)	45	5.6	25
Clay dunes with rills and gullies	12	1.5	7
Natural stream/nullah	32	4.1	19
Total	175	22	100

Remaining land is uneven with varying height of earth mounds and having steep topography. The farm soil is highly prone to erosion under the effect of rainfall; mostly in the form of high intensity-low duration pattern. The extent of soil erosion can clearly be seen in Figure 1 where the rainwater has eroded the soils to the extent that big chunks of land were eroded and made the land uncultivable.

Figure 1: Soil erosion at the farm (2009)

Prior to the interventions of PCRWR, the land was exclusively used for growing crops like wheat (*Triticum*) and mung (*Vigna radiate*) as there was no source of water for supplemental irrigation. To facilitate the research activities, two mini dams were constructed to harvest rainfall and stream water. Additionally, following facilities were made available at the farm:

- Farmhouse (2 rooms and a garage for tractor)
- Shed (6 m x 12 m) for farm implements
- Meteorological observatory to measure climatic data
- A dug-well with 1 HP solar-powered pumping system
- Construction of two mini-dams to harvest stream water
- Drip irrigation system for orchards
- Fruit orchards (citrus, fig, grapes, peach, pecan, persimmon, olives etc.)

3 Farm Soil

Better productivity depends highly on physical properties and health of soil. The Pothwar region is prone to soil erosion due to which soil fertility is very low generally less than 1% (Malik et al., 2019; Malik and Ashraf, 2023). In order to increase its productivity, it is necessary that the soil health is monitored regularly. Therefore, the key parameters of the soil health have been monitored to see their baseline values and changes over the time.

3.1 Soil Fertility Monitoring

The cultivated land was minimum tilled and green manuring crops like jantar (*Sesbania rostrata*) and mung (*Vigna radiate*) were cultivated during the fallow periods (after wheat harvesting) and chopped into the soil. The soil fertility parameters were monitored for organic matter percentage, pH, EC, available phosphorous and potassium on annual basis. The soil samples were mixed uniformly to develop composite samples of the farm for a better understanding of representative values of the fertility parameters. The results of the soil testing (2014-2020) are given in the Table 2:

Table 2: Soil fertility parameters measured at the farm

Year	EC (mS/cm)	pH	Organic Matter (%age)	Available Phosphorous (ppm)	Available Potassium (ppm)
2014	0.76	8.34	0.46	8.36	181.25
2015	0.84	7.43	1.04	9.34	140.00
2016	0.80	8.03	0.92	8.11	145.68
2017	0.77	8.00	1.12	10.34	190.56
2018	0.81	7.42	0.75	7.23	140.23
2019	0.75	7.28	0.82	8.01	112.65
2020	0.85	7.46	0.84	8.04	100.02

Percentage of organic matter is a good reflection of soil health. Good soil has organic matter percentage above 2%. However, it was as low as about 0.5% at the farm in 2014. Due to improvement of biological activities at the farm, the organic matter continuously improved at the farm and is now around 1% as shown in Table 2. Similarly, the pH values demonstrate that the soil is mostly alkaline. However, the initial pH value of the soil at the farm was 8.34 which has gradually reduced to 7.64 in the year 2020. During the period 2014-20, the crop residue was mixed in soil and organic matter was decayed at a speedy rate which improved the soil composition, resulting in neutralizing the soil. Generally, the local farmers are getting one crop (wheat) in a year with a cropping intensity of 100%, and the land remains fallow during rest of the year. Due to a number of activities, two crops are cultivated annually at the farm, including; wheat (*Triticum*), jantar (*Sesbania rostrata*) and mung (*Vigna radiate*). The latter two are leguminous crops that are helpful in nitrogen fixation in the soil. Moreover, if their residue is crushed into the soil, it improves organic matter content and other nutrients over the time. In some of the fields, kidney beans have been grown and mixed in the soil at the age of 65 days to improve soil fertility. The improvement in soil fertility has made it possible that wheat can now be grown under zero tillage conditions. Increase in the organic matter of the farm is result of such farming practices as seen in Figure 2.

Figure 2: Soil fertility improvement activities at farm

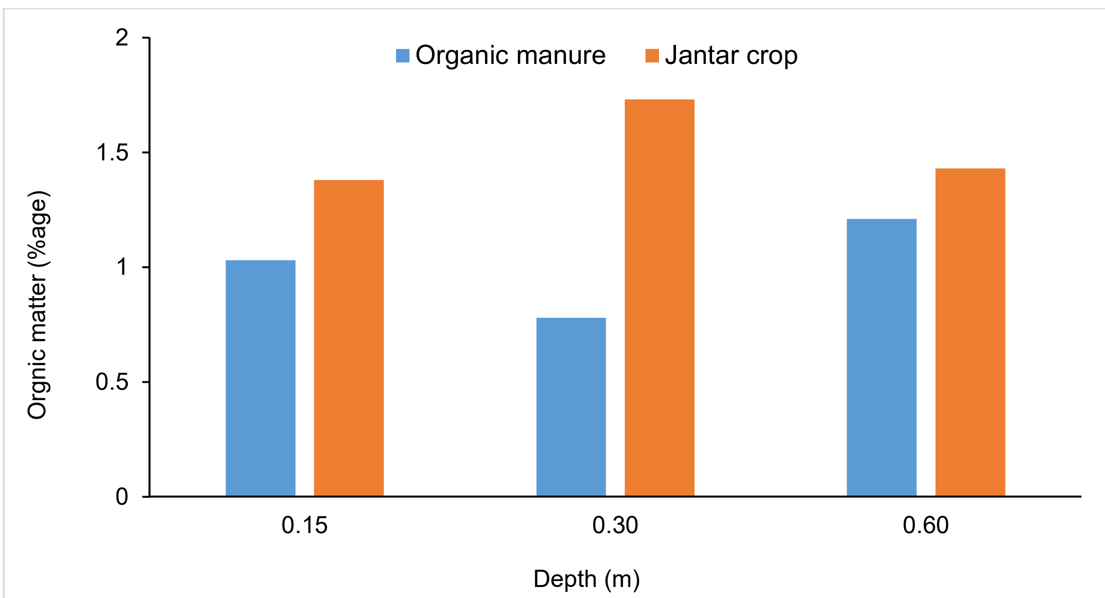


Figure 3: Soil fertility analysis after manuring

3.2 Soil Texture

Texture of soil is another important factor responsible for the productivity of land. Soil texture refers to the weight proportion (relative proportion by weight percentage of sand, silt, and clay) of the mineral soil separates for particles less than 2 mm as determined from a laboratory particle-size distribution. Soil texture is one of the most important physical properties since it influences water holding capacity, root growth, and overall moisture availability to the crops and orchards. The farm soil was analysed for texture at the Soil Physics Laboratory of PCRWR, Islamabad and the results are given in Table 3. The location of plots from where soil samples were taken is shown in Figure 4.

Table 3: Textural analysis of the farm soil

Plot #	Textural Class
1,5,10,17,18	Sandy Loam
2,16,19	Silt Loam
21	Loamy Fine Sand

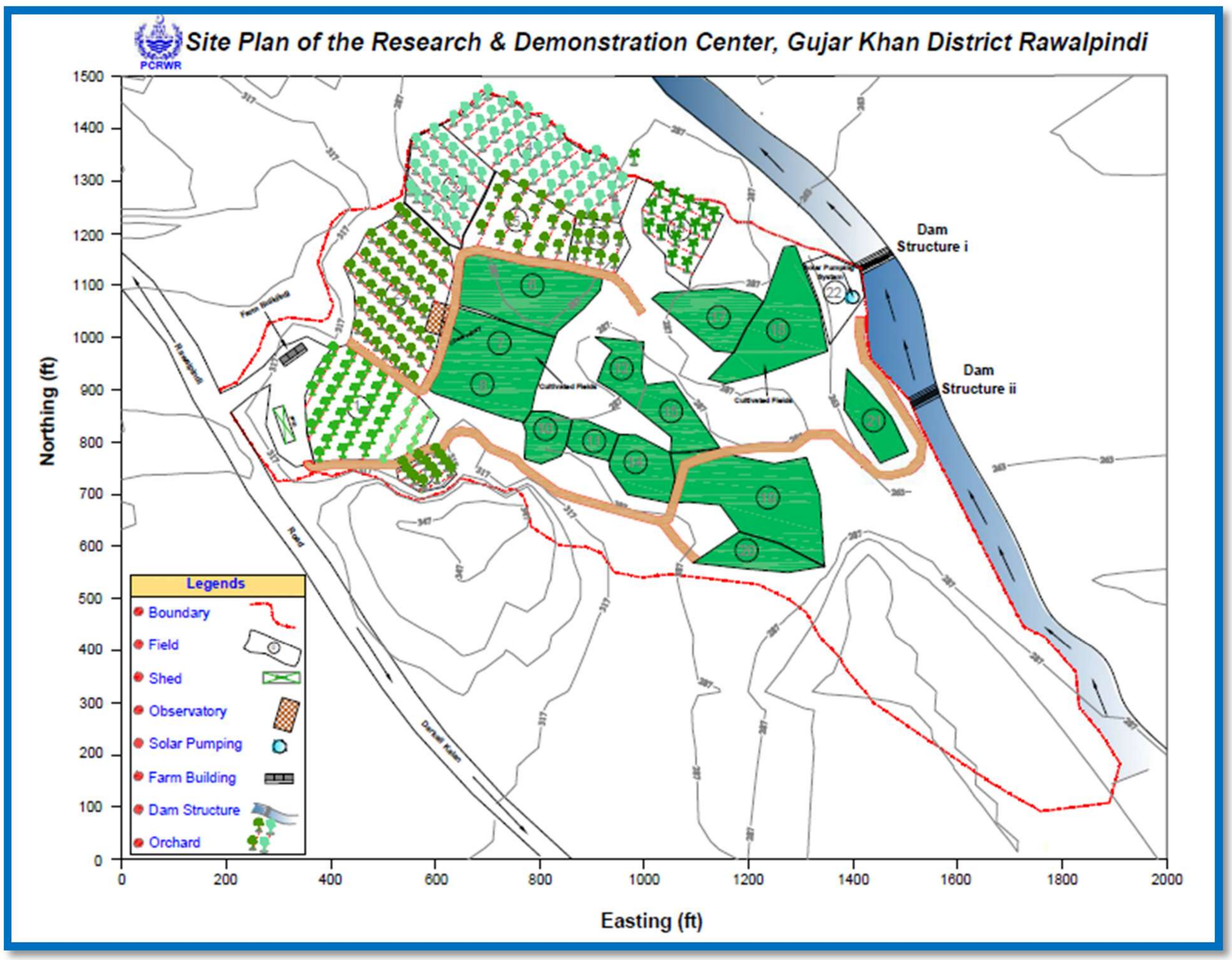


Figure 4: Soil sampling location of the plots at farm

Soil at the farm is mostly sandy and loam demonstrating low water holding capacity compared to other soil types. This soil has high drainage coefficient and hydraulic conductivity. Organic matter is also quickly decomposed in such soil due to better aeration. Soil of this type is easy to till, resistant to pH change and have low Cation Exchange Capacity (CEC). The soil particles are loosely bonded and hence more easily eroded by rain.

3.3 Soil Infiltration Rate

Infiltration is the process by which water on the ground surface absorb into soil. Infiltration rate is a measure of the rate at which soil is able to absorb rainfall or irrigation water. It is measured in inches per hour or millimetres per hour. The infiltration rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is an important characteristic of the soil which determines the prospects of in-situ rainwater harvesting and runoff generation under different rainfall events.

Infiltration tests were performed at two locations (Plots 5 and 17) to estimate the initial and final infiltration rates of the soil. Since the soil presented uniform characteristics across the farm, therefore two tests were enough to estimate the infiltration rates. The infiltration rate curves were developed using Horton's equation. The infiltration data was collected up to four hours continuous process and was fitted on Horton infiltration model having R^2 value 0.99 i.e., best fit to the Horton's curve. The final infiltration rate was observed as 9.76 mm/hr. The results of the infiltration tests are given in following Figures 5 and 6:

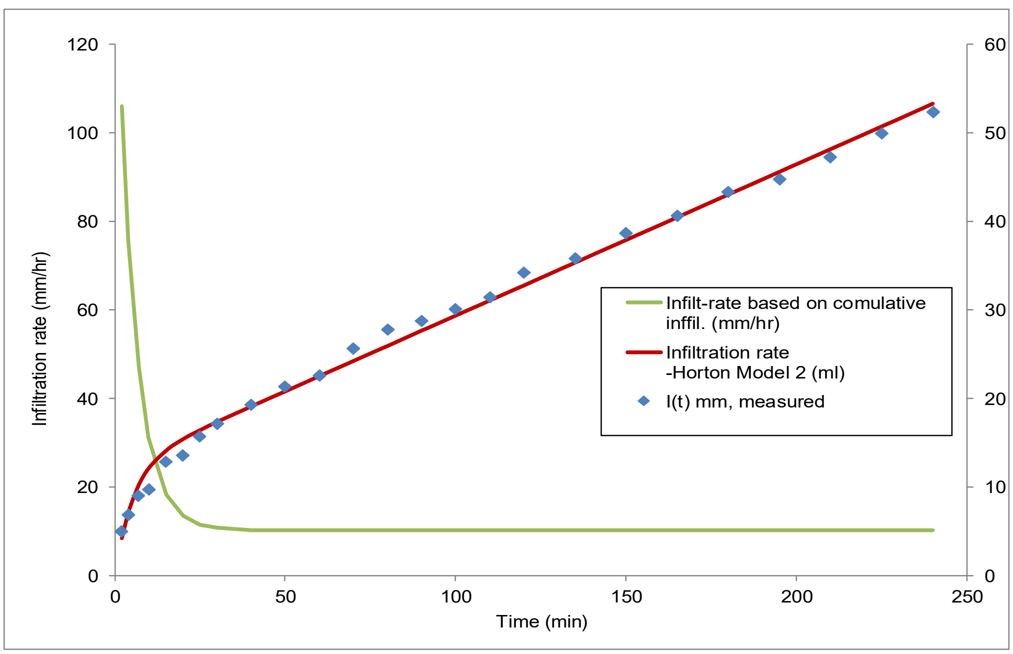


Figure 5: The measured infiltration rate curve for Plot 5

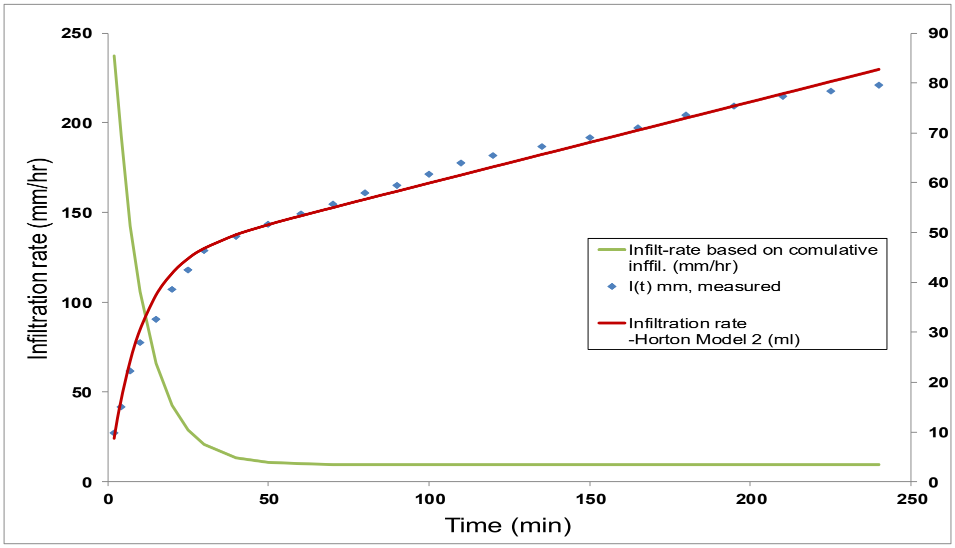


Figure 6: The measured infiltration rate curve for Plot 17

The results are justified as the soils are found to be demonstrating high infiltration rates (both initial and final), which is normal for sand and loam soil types. This is also validated with other work of PCRWR carried out to map the soil physical and hydraulic properties wherein the infiltration rate of Pothwar region for silt loam type soil averages ranges from 10-45 mm/hr (Malik et. al., 2019). Water holding capacity of such soils is, however, low as is evident from the final infiltration rates of the soil which is almost equal to the saturated hydraulic conductivity of the soils.

3.4 Soil Moisture Characteristics Curves (SMCC)

Irrigation needs of a plant depend on the plant type, soil texture and its moisture-retention characteristics. The moisture availability to the plant under the same environmental conditions is different under different soil types. Sandy soil has less water holding capacity, whereas the clay soil has the highest. A soil moisture-retention curve, therefore, is a prerequisite to determine irrigation needs of a particular plant. Normally, a plant exerts osmotic pressure through roots to extract moisture from soil under a tension below 15 bars (15000 cbar) called Permanent Wilting Point (PWP). The state when all the gravitational water is drained (at 33 cbar tension) is called the Field Capacity (FC). At this state of moist soil, plant is comfortable in extracting moisture from soil, and stresses as the moisture approaches to the PWP. It is therefore, recommended to apply irrigation as soon as the Available Moisture (AM = FC – PWP) depletes by 50% (150-200 cbars). Tensiometers normally work up to 80 cbar.

In this regard, soil moisture retention tests were performed using Hein's appratus. To perform experiment, five samples from different fields were collected and placed for 24 hrs for soaking. Afterwards, these were placed at the Heins apparatus and pressure-plate apparatus to measure moisture content at 1 to 15 bar suction. The results for three different plots having different soil types in terms of soil moisture characteristic curves are given in Figure 7:

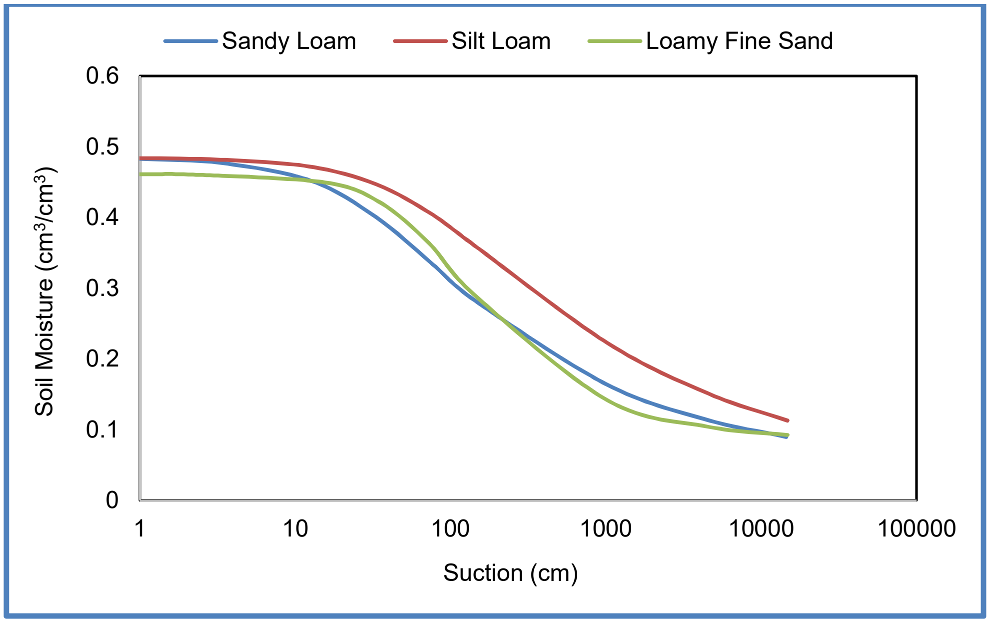


Figure 7: Soil moisture-characteristic curves of different soil types

The results have shown that soil type of Plot No. 5 was sandy loam. Saturated moisture contents Ɵs was 0.4188 and after withdrawing water from soil at 15 bar pressure the retained moisture contents Ɵr was 0.0209. The soil type of Plot No. 2 was silt loam. Saturated moisture contents Ɵs was 0.4839 and after withdrawing water from soil at 15 bar pressure, the retained moisture contents Ɵr was 0.02. The soil type of Plot No. 21 was loamy fine sand. Saturated moisture contents Ɵs was 0.4610 and after withdrawing water from soil at 15 bar pressure, the retained moisture contents Ɵr was 0.0832. These results are comparable with the soil physical properties mapped during detailed survey of Pothwar region by PCRWR. The soils of Pothwar region are mostly loam, clay and sand type (Malik et al., 2019).

The soil moisture characteristic curves as shown in Figure 7, reveal that water holding capacity of the soil is low and normally the gravitational water is drained quite early, after which the residual moisture content available in the root zone varies from 2 to 8%. This scenario suggests that, soil types at the farm require frequent irrigation because normally irrigation is required as the soil moisture percentage reduces below 15%.

Table 4: Summary of soil hydraulic parameters measured at the farm

Plot	Saturated MC (%)	Residual MC (%)
5	48	4
2	48	2
21	46	8

It was deemed essential to improve the soil water holding capacity through biological means. Soil organic matter is one of the key factors which can improve the soil water holding capacity. Organic matter is being improved through the cultivation leguminous crops and addition of composted material. The interventions have led to improve the soil moisture level from 7-10% to 13-15%.

4 Climatic Parameters Monitoring

Climate is the statistics of weather over the period of time. It is measured by assessing the patterns of variation in temperature, humidity, atmospheric pressure, wind, precipitation and other meteorological variables in a given region over the period of time. Climate differs from weather as weather only describes the short-term conditions of these variables in a given region. The parameters commonly considered to define climate are the mean annual precipitation and mean annual potential evapotranspiration.

The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies. Climate can be classified according to the average and the typical ranges of different variables, most commonly temperature and precipitation.

4.1 Weather Station

Measurement of the climatic parameters is a pre-requisite for irrigation scheduling. The measurement of daily sunshine hours, wind speed, maximum and minimum temperatures help to determine the potential evapotranspiration, which is used in determining the crops irrigation requirements. A state-of-the-art automated weather station (Davis, made in USA) has been installed at the farm through which these climatic parameters including rainfall are being measured, which in turn is used for irrigation scheduling (Figure 8).

Figure 8: Weather station installed at the farm and receiver

Climate parameters such as rainfall, relative humidity, mean daily temperature and windspeed are used to calculate reference evapotranspiration values (ET_o) which is then used to determine the consumptive use of a particular crop or crop water requirement by multiplying ET_o with crop coefficients. This relation will be discussed in details in the proceeding sections. In Figure 9, climate parameters measured to plan irrigation are plotted for August 2021.

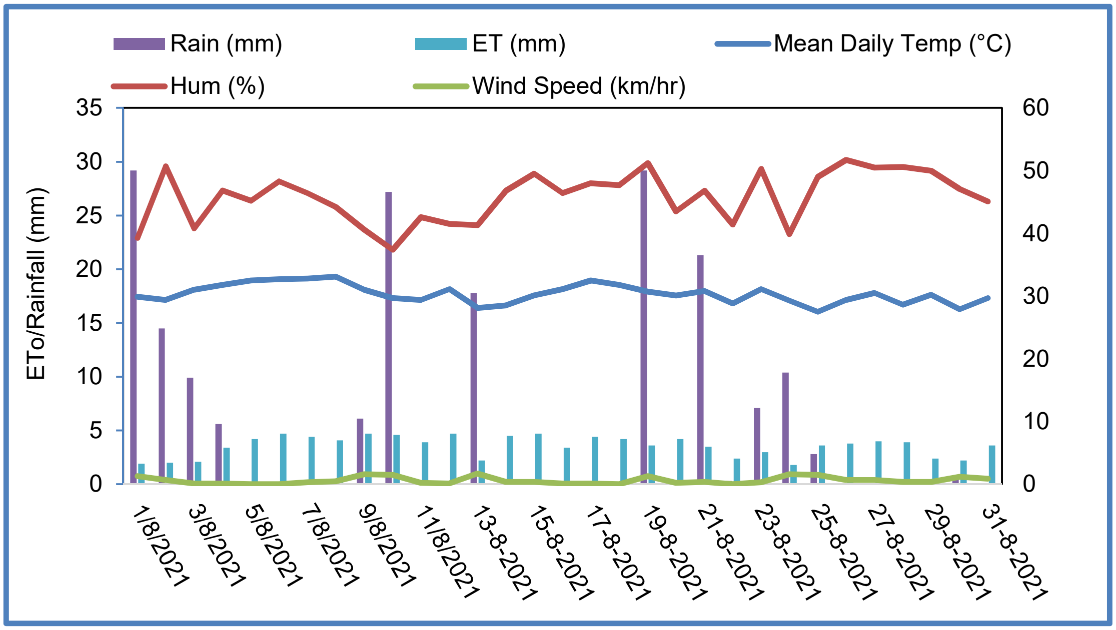


Figure 9: Climatic information monitored through weather station - August 2021

4.2 Evaporation Measurement

Evaporation is a continuous process from the soil surface and water bodies. The evaporation measurement setup has been established at the farm to calculate the evaporation rate. Generally, evaporation is measured in the field by using pan evaporation method. In this technique, a Marriote-bottle is coupled with the evaporation pan. This Marriotte bottle in fact controls the water level in the pan and indicates precisely the water that has been evaporated from the pan through a graduated scale on the bottle. The record of pan evaporation measurements is being maintained on daily basis. Usually, the reading has been taken in the evening around 4 pm to measure the exact evaporation rate in the last 24 hours. The recording of pan evaporation data shows that the average evaporation rate was 4-5 mm/day during September. During the month of October, the evaporation rate recorded was 3-3.5 mm/day. During November, it was 2-2.5 mm/day, during December 1-2 mm/day and 1 -1.5 mm/day during January.

This evaporation data under multiplication with the crop coefficient value of a particular crop fairly measures the crop water requirement (consumptive use). Thus, supplemental irrigation can be planned as per crop requirement of the crops grown at the farm and applied well in time by incorporating the rainfall record.

Figure 10: A view of the evaporation pan with Marriote Bottle

4.3 Tensiometers

Measurement of soil-water and plant relationship is another method to perform irrigation scheduling. Tensiometer is the instrument to determine this relationship and helping farmers to make irrigation decisions accordingly. It is suction based instrument and is independent of soil type. A number of tensimeters are installed at a depth range of 0.3 to 0.9 m to monitor the soil moisture suction. Daily readings are taken and the supplemental irrigation is scheduled for fruit orchards and field crops to avoid under and over irrigation. These instruments are fabricated at PCRWR's Lahore office.

A tensiometer has three main parts, a suction cup at the bottom of a vertical tube and a graduated pressure gauge attached to at the side of a vertical tube. The pressure values at the suction gauge ranges between 0-72 centibars. The reading in the range of 0-14 centibar reflects wet conditions which shows absolutely no irrigation requirement, 14-58 centibar indicates appropriate moisture level, whereas 58-72 centibar shows that soil is semi dry and irrigation is required. The readings above 72 centibar reflects dry condition and indicates that irrigation is promptly required without any further delay (Figure 11).

Figure 11: Installation of tensiometers pattern and views of installed tensiometer at farm

Thus, this gadget helps in determining the soil moisture conditions indirectly beneath the earth surface and reflects on site irrigation requirement. For more details, the reader is referred to the manual developed by Ashraf (2015).

4.4 Chameleon Sensor

The function of Chameleon moisture sensor is similar to a tensiometer with an advantage of being a farmer friendly tool which provides information moisture content of soils at multiple depths through sensors simultaneously. This sensor also helps to determine where the roots are actively taking up water giving farmers an insight on when to irrigate and how much water to apply. It is developed by Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia.

A chameleon moisture sensor is an array for four sensors; three moisture sensors designated to be installed at three different depths of effective rootzone of a plant, fourth sensor is a temperature sensor installed with middle depth. The installation depth of these sensors very crop to crop but mostly installed at 15, 30 and 45 cm of depths. The sensor part remains in the field and may be connected to a reader to check the value of moisture tension being experienced by the plant. When connected to a reader, the sensors communicates the current level of soil moisture in a practical manner using three coloured lights. If the soil is dry, it indicates red light, if the soil moisture is sufficient, a green light shine, and if the soil has been over watered the light appears blue as shown in below Figure 12.

Chameleon reader has the capability to store the crop data and it may be uploaded on a web portal if the reader is connected with mobile wifi internet. Data of the sensor is stored in their designated irrigation bays creating the moisture pattern over the cropping period.

Figure 12: A view of the Chameleon field reader and sensor installed in field

Moreover, Chameleon shows moisture situation on screen by showing various colours against various layers of soil. A Chameleon sensor has been installed at peach orchard of the farm. The results indicate the soil moisture condition at three different depths (20, 45, 60 cm) and indicates moisture level. The peach orchard was irrigated using the information based on the Chameleon sensors. The recorded data sheet of Chameleon sensor from the farm for one year is shown in Figures 13 and 14.

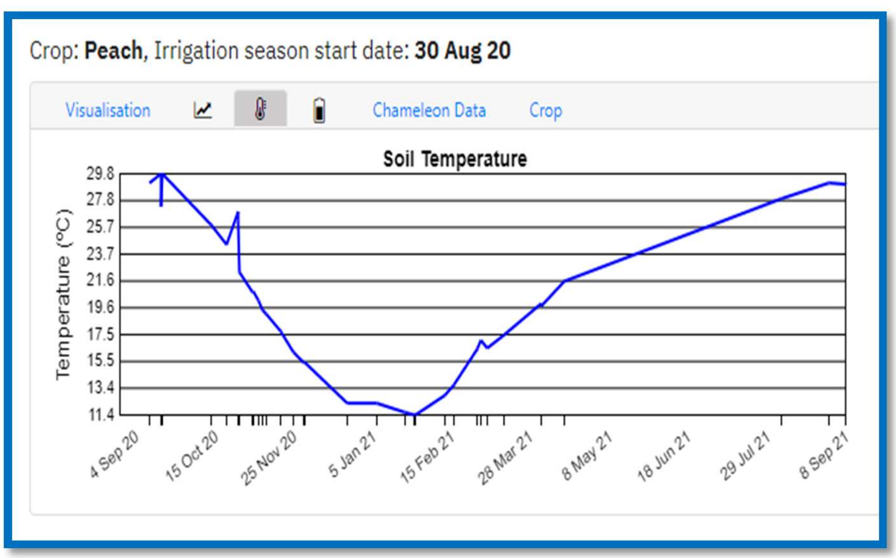


Figure 13: A view of the Chameleon sensor soil temperature data

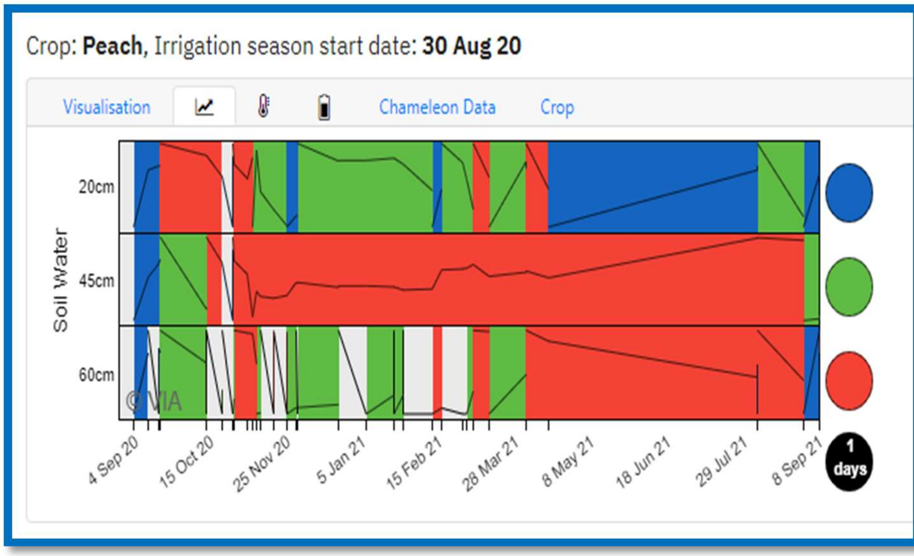


Figure 14: A view of the Chameleon sensor soil water data

5 Irrigation Scheduling

Irrigation scheduling is the process of applying irrigation water to the plants by maintaining the optimum moisture level in its root zone for its optimal growth. It can be summarized "when to irrigate and how much to irrigate". In the previous sections of this report, different soil tests and soil moisture measurement instruments are discussed. The key aim of these efforts is to apply scarce water at the farm through scientific methods. Like all PCRWR farms, Darkali Kalan farm offers an opportunity to researchers to test different methods of irrigation scheduling. Presently, farmers in the region are mostly reliant upon direct rainfall or harvested rainwater in the form of small ponds. In some areas, groundwater is also available. Due to lack of knowledge about irrigation scheduling, farmers keep on applying water even when a crop does not need irrigation. This is not only the wastage of water but also wastage of precious nutrients that are leached down with the excess water. Therefore, irrigation scheduling should be an integral part of any irrigation scheme. It helps in achieving high and good quality yield, high water productivity (yield/applied water) with no damage to the soil and applying water at reasonable cost (Ashraf, 2015).

At the farm, four different methods have been used to design supplement irrigation. As the farm is situated in an arid region, supplement irrigation is very important for better crop health. These methods include Tensiometer, Chameleon Sensors, Pan Evaporation and Gravimetric. With the help of information attained from these methods, soil moisture has been determined and based on this, supplement irrigation for the respective crop has been planned.

5.1 Crop Water Requirement

Crop water requirement refers to the amount of water needed by a crop during its entire growing season to achieve optimum growth and yield. It is affected by various factors such as the crop type, soil type, climate, and stage of growth. Crop water requirement is usually expressed in terms of the amount of water needed per unit area (such as mm/ha). The depth of water needed to meet the water losses through evapotranspiration (ET) of a diseases free crop growing in large fields under non restricting soil conditions including water and fertility while achieving full production potential under the given growing environment (Ashraf, 2015).

Water requirements of the given crop can be determined using a crop coefficient that integrates the combined effects of crop transpiration and soil evaporation into a single crop coefficient, according to the following relationship:

$$ET_c = K_c \times ET_o \text{ ------------------------------ } (1)$$

Where:

ETo is reference crop evaporation, Kc is crop coefficient, and ETc is crop evapotranspiration or crop water use.

After the crop water requirements are known, next step is to determine the irrigation requirement that equals the crop water requirement minus effective rainfall. The crop coefficient values are determined through Lysimeters. The Council has also determined K_c values using its network of lysimeters in Pakistan (Soomro et al., 2018; Rao et al., 2016).

6 Orchards

An orchard is an intentional planting of trees or shrubs that is maintained for food production. Orchards comprise fruit or nut producing trees which are generally grown for commercial production. Orchards are also sometimes a feature of large gardens, where they serve an aesthetic as well as a productive purpose. A fruit garden is generally synonymous with an orchard, although it is set on a smaller non-commercial scale and may emphasize berry shrubs in preference to fruit trees. Most temperate-zone orchards are laid out in a regular grid, with a grazed or mown grass or bare soil base that makes maintenance and fruit gathering easy. To introduce orchard farming in the area various fruits types have been grown at the farm as mentioned in Table 5. The different stages of orchard plantation and growth starting from 2014 to 2023 have been shown in Figure 15.

Table 5: Different fruit plants planted at R&D farm

Sr. No.	Plants Name	Botanical Name
1.	Oranges (Red Blood, Grapefruit, and sweet lemon)	*Citrus X sinensis*
2.	Grapes (King ruby, Vitro black, and Sugra one)	*Vitis vinifera*
3.	Olives	*Olea europaea*
4.	Fig (Black ball)	*Ficus carica*
5.	Pecan Nut	*Carya illinoinensis*
6.	Beauty Plum	*Prunus domestica*
7.	Apricot	*Prunus armeniaca*
8.	Hood Pear	*Pyrus*
9.	Persimmon	*Diospyros kaki*
10.	Peach (Early grand)	*Prunus persica*
11.	Pomegranate	*Punica granatum*
12.	Phalsa	*Grewia asiatica*
13.	Loquat	*Eriobotrya japonica*
14.	Lemon (China, Desi, Eureka)	*Citrus lemon*
15.	Besides a number of wild trees exist like pillo, pilchi, sukchain, kachnar and cactus etc.	

Figure 15: Stages of plants from 2014 to 2023

7 Crops

Two crops are grown on 2 hectares land of the farm annually including wheat (Triticum), jantar (Sesbania rostrata) and mung (Vigna radiate). Pre and post crop data is collected to analyze the soil conditions and water productivity under different experiments. Some glimpses of crops grown at the farm are shown in Figure 16.

Figure 16: A view of the crops at R&D farm

7.1 Wheat (*Triticum*)

At the farm, around 1.6 ha of land is allocated for crop experiments. Wheat is grown every year under various experimental setups such as under existing barani environment, under precisely levelled fields and with or without tillage practices etc. A detailed research study titled "Growing of wheat applying water conservation practices in the Pothwar Region." was conducted during 2012-13.

This three-year research study identified that, cultivating wheat (*Triticum*), with deeper tillage is effective for obtaining more yield of the crop. Deep tillage is also helpful in better root growth and aeration of the soil. During 2017-18 wheat season, the average yield of wheat in Pakistan was around 2840 Kg/ha which can be subcategorized as yield in rainfed areas and yield in irrigated areas. The national average yield of rainfed wheat and irrigated wheat was 1200 Kg/ha and 3000 Kg/ha respectively (PARC, 2018). Table 6 shows that under deep tillage treatment without the use of fertilizer, PCRWR was able to obtain yields upto 70% more than the national average of the rainfed areas. This can be attributed to better root growth and aeration of the soil under this treatment.

Table 6: Productivity of wheat under different treatments

Treatment	Yield (kg/ha)	Rainfall (mm)	Treatment	Yield (kg/ha)	Rainfall (mm)
Shallow tillage (without fertilizer)	1295	402	Deep tillage (without fertilizer)	1720	402


Figure 17: Some views of the experimental wheat grown at the farm

7.2 Plantation on Slopes

Soil erosion primarily originates from bare slopes. The slopes can be stabilized by plantation as roots act as binding agents for soil particles. Species having strong and intruding roots may be preferred for this. Cactus, beri (*ziziphus jujube*), phalsa (*Grewiaasiatica*), plum (*Prunussalicina*), etc. were planted on fragile slopes. It helped mitigate the primary soil erosion.

7.3 Sisal (*Agave sisalana*)

Sisal is hard plant that can easily grow in the hot climate all-round the year as well able to grow in the arid regions. In addition, it is a natural fiber plant and fiber can be extracted from its leaves. Moreover, this is an environment friendly plant which has no need of watering on regularly basis. Besides its fiber used in carpets, paper, cloth filters handicrafts and especially in various automobile industry (Naveen et al., 2019).

7.4 Cactus (*Cactaceae*)

There are many types of Cactus found in various part of the country mostly in warm weather regions. Cactus can grow in sandy and loamy soil. A well drained soil should preferably be used for its better growth. The best season of planting is spring or summer, particularly in arid and semi-arid areas.Its potential as key role in land rehabilitation, cheap and easy erosion control work as artificially border fence and also provide feed resource for wildlife and livestock (Henry and Le, 1996).

Figure 18: Plantation on slopes to reduce primary erosion

8 Green Building at the Farm

8.1 Solar System

Pothwar region is blessed with abundant sunlight throughout the year. In order to make the farm green, the farm office is powered by solar power. The system has been designed on average 6 sunshine hours/day. During these hours the system is capable to deliver its rated power. Initially, the power requirement of the farm was determined as given in Table 7.

Table 7: Power requirements of the farmhouse at the R&D centre

Electrical Appliance	Nos.	Requirements (Watts)
Ceiling fan (30 watts)	2	60
Pedestal fan (15 watts)	1	15
Energy saver (15 watts)	3	45
Energy saver for toilet (5 watt)	1	05
Total		125

The system however, starts generating some power with sunrise and continues till sunset. Four mono-crystalline panels were used, which were installed at the roof at 30 degrees inclination. Each panel is 1 m^2 measuring 0.68 m x 1.29 m. The panels are connected in parallel to give out 12 volts supply. Each panel is 130 watts so the total rated power of the system becomes 520 watts. Hence the average daily energy production by the panels becomes 2880 watts-hrs.

Figure 19: A view of the installed panels on the rooftop

Determination of the battery requirement is a crucial step in designing of the solar-power system as it has to consider the aspects of economy and optimization. Twelve-hour backup for appliances was mandatory during night time. Moreover, the cushion for a shady day necessitated to increase the backup time to 24 hours, beyond which the system becomes uneconomical. The backup of system has been calculated as per the detail given in Table 8.

Table 8: Computation of backup time and battery requirement for the system

Description	No	Total
A. Night time load		
Energy savers (15 watts)	1	15 watts
Ceiling fans (30 watts)	2	60 watts
Backup time (hrs)	-	12 hrs
Energy requirement	-	900 watt-hrs
B. Day time load		
Ceiling fans (30 watts)	1	30watts
Pedestal fan (15 watts)	1	15watts
Backup time (hrs)	-	12hrs
Energy requirement	-	540 watts-hrs
C. Total daily energy requirement (A+B)	-	1440 watt-hrs*
D. Battery		
Requirement for 24 hrs backup & 10% losses		1600 watt-hrs
Installed (200 Amp-hrs)		2400 watt-hrs
E. Maximum Allowed Battery Depletion		65%**

**Half of the average daily energy production, **50% is recommended. However frequent reoccurrence of complete cloudy day in summer was found least likely.*

The power to the electrical appliances is always routed through the battery and not directly from the panels. This is due to the fact that panels' power supply is variable depending upon the incident radiation. The power supply from the battery is however constant. Charge controller is a device which regulates the battery charging rate. When the battery is fully charged, it disconnects charging from the solar panels. Similarly, it synchronizes the battery charging rate depending upon the charge status of the battery and load.

Figure 20: Charge controller regulating the battery charging rates

In addition to the above appliances, a power inverter is installed which allows resident staff charge their cell phones and some table fans during the daytime.

8.2 Rooftop Rainwater Harvesting

It is a technique in which rainwater is captured from the roof surface and stored in tanks for subsequent uses. Rainwater from the roof is collected by connecting its outlet to storage tanks (300-500 US gal) through gravity. A screen is attached to the outlet to prevent leaves and trash entry. The volume of collected water depends upon roof size and slope, rainfall and the uses. The stored water can be used for domestic purposes and kitchen gardening. The water harvested from office building is being used for the nursery. The rooftop harvesting system has been developed at the farmstead of the farm. The dimensions of the rooftop of the farmstead are 8.25 m x 11.6 m = 95 m^2.

Usually, the maximum event of rainfall does not exceed from 50 mm and the runoff coefficient is assumed as 0.8. Thus, runoff generation at rooftop against this moderate level of rainfall event is calculated as: 95 m^2 x 50 mm x 0.8 /1000 = 3.8 m^3. Thus, total volume generated in a rainfall event = 3.8 x 1000 = 3800 litres.

It shows that the storage tank requirement is about 1000 gallons with the occurrence of 50 mm rainfall. At the farm, two tanks having capacity of 200 gallons each are coupled. These two tanks having total capacity of 400 gallons store the water generated against normal rainfall events. The portable additional tanks (2 Nos.) having accumulative capacity of 1000 gallons is separately available to transport the excess water to other areas.

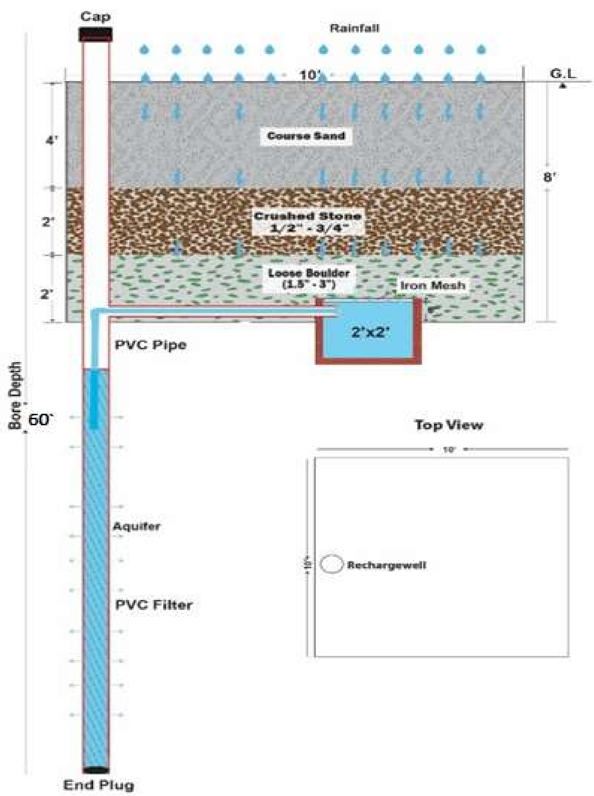
Figure 21: Farmstead rooftop rainwater harvesting system

8.3 Managed Aquifer Recharge

Groundwater recharge is a hydrologic process where water (rain or reclaimed) percolates downward from surface to ground. This natural process takes decades and centuries to form an aquifer. Pothwar region has high potential of rainwater infiltration due to its soil characteristic but the pace of natural recharge process is slow through which water enters an aquifer. Recharge occurs both naturally (through the water cycle) and through managed recharge processes (i.e., "artificial groundwater recharge"), where rainwater and or reclaimed water is routed to the subsurface through necessary amendments in the landscape.

The Council has developed a simple and smart technique to recharge the aquifer quickly. The runoff from the farm catchment is substantial during the monsoon and remain un-utilized and wasted through runoff. This runoff water is being stored in the rainwater harvesting pond which is then injected into groundwater through an artificial recharge well, keeping its quality fresh by allowing it to pass through a number of filtration medium composed of boulders, gravel and fine sand layers. Such nature-based solutions have been introduced by using simple techniques for improving groundwater recharge. A schematic diagram for groundwater recharge well is given in Figure 22 (c).

(a) (b)



(c)

Figure 22: View of the Groundwater Recharge well before (a) after (b) at the farm and schematic diagram of recharge well (c)

In order to monitor the water-table depth and the impact of managed aquifer recharge, Piezometers are also installed. The depth to water table was measured relative to the ground surface using water level indicator having a graduated tape/cable with bell sounder and light indication that indicate water-table depth (Figure 23).

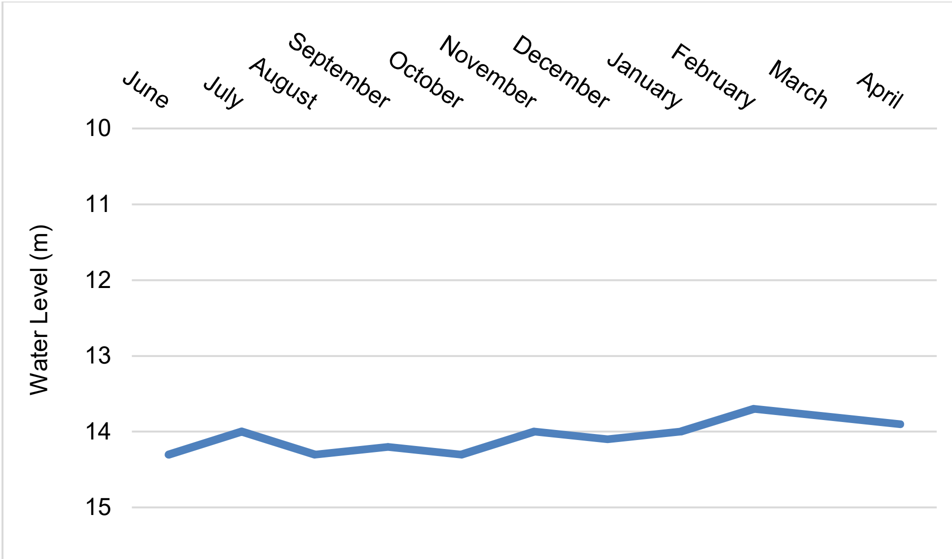


Figure 23: Impact of recharge on the groundwater table at the farm

8.4 Micro-Catchments

Micro-catchment is a specially designed retention pit for an area with slope and dikes to increase runoff and to concentrate it in planting basins. Maximum amount of runoff gathers near the root zone, infiltrate and stored in soil profile. Micro-catchments enhance the water availability to the plant 3-4 times of the amount of annual rainfall runoff on normal land surface. A number of fruit trees can be exclusively grown in rainfed areas whereas micro-catchment significantly reduces the supplemental irrigation requirement.

For designing a micro catchment, the ratio of catchment area (C) to cultivated area (CA) is very important. The catchment area is the area from where runoff is generated and transported under the slope to the cultivated area where plants have been planted. The soil type, vegetative cover, slope and catchment size effect the runoff. Cultivated area is normally taken equal to the canopy of the plant (Ashraf, 2015). Moreover, the efficiency factor takes into account the inefficiency of uneven distribution of water within the field/basin as well as losses due to evaporation and deep percolation. If the catchment area is smooth, level or compact, the efficiency factor will be higher. The efficiency factor normally varies from 0.5 to 0.7. Below Eq. can be used to calculate C and CA ratio.

$$\frac{C}{Ca} = \frac{\text{Crop water requirement} - \text{desi} \quad \text{rainfall}}{\text{Design rainfall} \times \text{runoff coefficient} \times \text{efficiency factor}} \text{..........(II)}$$

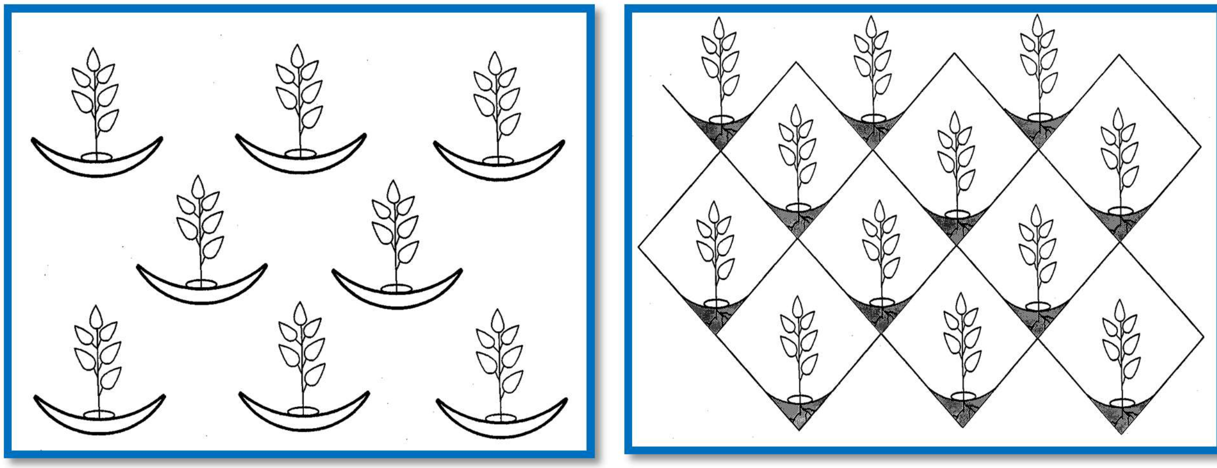


Figure 24: Square shape and semi-circular micro catchments for rainwater harvesting

A number of fruit trees may be exclusively grown on rainfall in the areas having rainfall from less than 200 mm to over 1000 mm/year. Micro-catchments were developed around citrus, grapes, cactus, plum and other fruit trees etc. in half-aged moon shape to significantly lower their irrigation requirements. These are semi-circular type and relatively on levelled surface. However, on hill slope, circular micro-catchments have been developed. Overall, 1600 micro-catchments have been developed at the farm. These micro-catchments are providing better moisture contents to the plants, increasing soil fertility by trapping organic matter coming from the catchment. Furthermore, time to time mulches are also applied in micro-catchments that help reduce surface evaporation. A few glimpses of micro-catchments are shown in Figure 25.

Figure 25: Micro-catchments around trees for rainwater harvesting

The micro catchments play a key role in the growth of plant. A well-designed micro catchment for a particular plant considering its canopy size, water requirement etc. keep it alive under barani environment (no supplemental irrigation). If the catchment area is smooth level or compact, the efficiency factor will be higher. The micro catchments may be of different shapes and sizes depending upon plants type, slope, soil type rainfall and topography (Ashraf, 2015). Micro catchments not only help in storing the water in the soil profile but also helps in controlling the soil erosion. A benefit-cost ratio of micro-catchments in the orchards is given in Table 9. Developing micro-catchments on half a hectare and with 800 mm average annual rainfall, it may store around 1 million gallons of rainwater in root zone which is equivalent to the operating a diesel operated pump for 200 hours. Therefore, this method of rainwater harvesting is not only eco-friendly but is also cost effective. Moreover, its management is also easier compared to a diesel operated tube well that requires high cost of operation and maintenance.

Table 9: An economic analysis of the micro-catchments of the farm

Item Cost	Specifications	Nos.	Cost (Rs.)
Labour	Rs. 100/M.C.*	2000	200,000
Total			200,000
Benefit			
Annual Rainfall	0.8 m (800 mm)		-
Micro-catchment area	0.83 m^2		-
Catchment area/M.C.	2.42 m^2 (1:3)		-
Total catchment area	4,850 m^2		-
Annual water harvesting	3,965 m^3 (1.05 million US gallons)		-
Equivalent diesel pumping cost/saving	Capital + O & M Cost 5 HP pump has to operate 200 hrs		450,000
Benefit-cost ratio at 3 years useful life			2.25

*Micro-catchment

8.5 Solar-coupled Drip for Orchards

Pothwar is ideal for the use of drip irrigation system due to (i) scarcity of water (ii) undulating lands (iii) growing high-value orchards and the (iv) dry environment. However, despite many efforts by the public-sector organizations drip irrigation could not become popular in the region mainly due to overdesign and complicated system involving many unnecessary components. This has led to increase capital and operational costs. Therefore, PCRWR designed a simple, smart, eco and farmer's friendly gravity fed drip irrigation system using solar energy. The system was installed on 31st March, 2015 in pursuit of shifting to renewable energy sources for irrigation. As the discharge of the solar-powered pumping system is small, therefore, it is sustainable only if coupled with high efficiency irrigation system.

The first component of the system lifts water from the source to high storage tanks placed at 5 different elevated stations of the farm. In the second step, water is diverted to plants through simple drip system under gravity as shown in Figure 26.

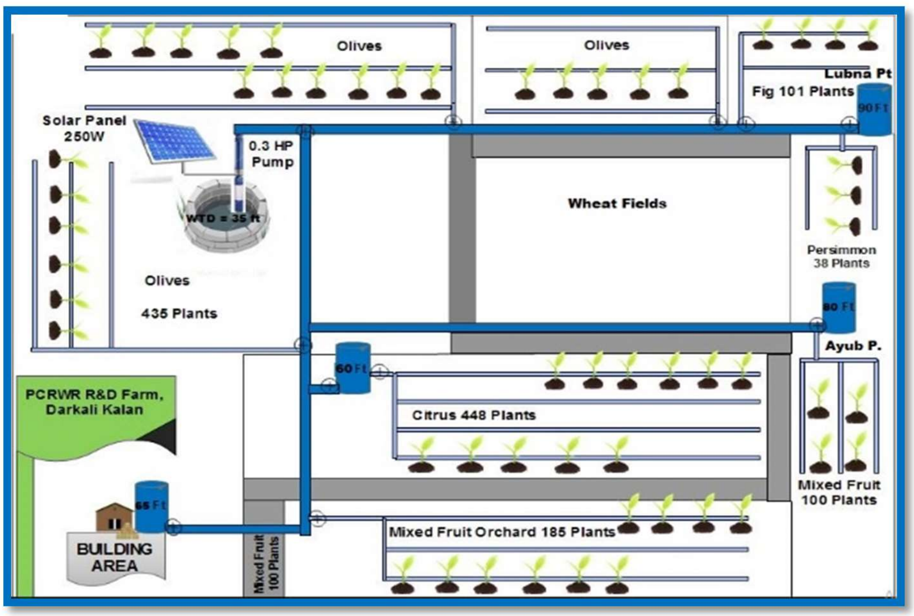


Figure 26: Schematic diagram of the solar-powered drip at the farm

There are 2 installed systems at the farm, one at the dug well near the olive orchard and the other near the dam. The system comprises a single panel 260 watts portable system occupying 1.64 m^2 area having adjustable inclination. The total depth of the well is 12 m with a diameter of 1.2 m with. It maintains a water column of about 3 m. The quality of the well water is good with an EC of 800 μS/cm. The water is lifted by connecting the panel at its ideal orientation to tap maximum sun energy with a 0.3 HP pump. The water lifted from here is used in citrus orchard through a 3 m high plastic tank having capacity of 500 gallons.

There are about 1,600 orchard plants scattered throughout the farm on around 3.2 ha, therefore, plants can only be irrigated by drip. Accordingly, the water stored in the plastic tanks has been routed to the plants by drip-lines. The drip-lines were punctured near the plant roots to insert pressure-compensating emitters. The system is extremely efficient giving out less than 10% water losses and is easy to operate and maintain. The panel is connected to pump whenever lifting is required. It takes almost 3 hours to fill a 500 gallons tank. Therefore, the valves are opened to route water to specific orchards where plants need irrigation. Irrigation requirements of the plants are sensed by using the instruments discussed herein before.

Figure 27: Views of the older solar-powered drip at the farm

The system was insufficient to meet irrigation needs of the farm. Therefore, a new dugwell downstream of the dam was constructed in 2017 to fulfil irrigation needs. This dugwell captures seepage of the dam. A view of the fresh dugwell and solar system installed near the dam as given in Figure 28.

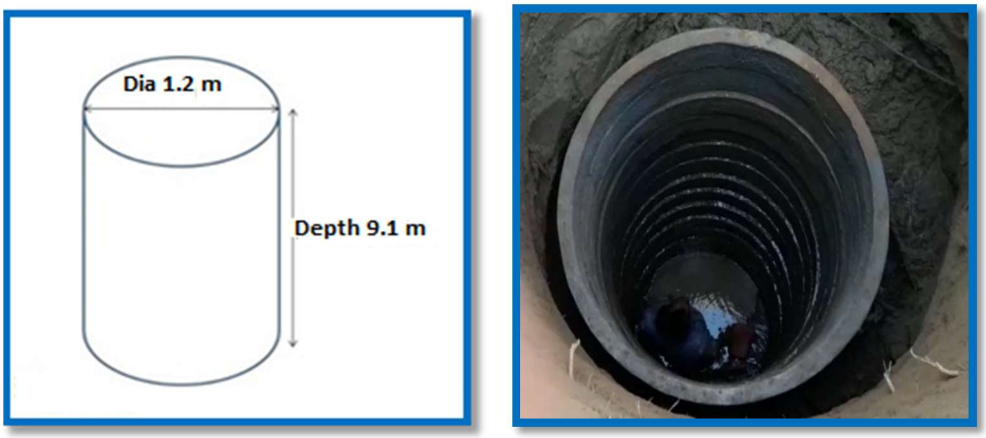


Figure 28: Dug well installed at farm in 2017

This solar-powered pumping system is catering most of the irrigation needs of the farm. It is 2 panelled system. Being in vicinity of the dam, water does not dry up in the well and maintains a water column of 6 m throughout the year. The specifications of the installed system are given in Table 10.

Table 10: Solar Pumping system specification

Sr. No.	Item	Description
1	PV Modules	Q Cell Polycrystalline panels, IEC certified 61215/61730/61701 (500 watts = 250 watts x 2)
2	Solar Pump	Lorentz DC submersible pump PS600 (1 HP), Made in Germany
3	Pump Controller	Lorentz pump controller (70 KW) Model PS600, Made in Germany
4	UL certified Combiner box	Rust proof mountable box for housing and locking of the pump controller
5	Stand	Inclination and rotation adjustable, rust proof mounting frame with concrete foundation for maximum PV output
6	Steel wire	15 m for safe hanging of the pump in the dug well
7	DC cable and delivery pipe	14 m (99.99% pure copper wire required from the pump to the panel) and delivery pipe from the pump to the mainline

8.6 Surface Water Harvesting

Most of the erosion in the region is caused by natural waterways draining substantial amount of water collected from rills and gullies. The water may be intercepted by channelizing and diverting to the adjacent depressions at regular intervals. The natural waterways of the entire farm were marked and cost-effectively channelized in trapezoidal section having diversion points to the low-lying ponds dug for storage. It also acted as seepage ponds for groundwater recharge. The following activities were accomplished to capture the stormwater at the farm.

- Construction of 4 rainwater harvesting small ponds/tanks along with silting basin and 76 m long conveyance channel.
- Rehabilitation and enhancement of storage capacity of a dam.

Figure 29: Stormwater harvesting ponds

Four storage ponds, four silting basins and a water conveyance channel of 76.2 m long were constructed. The salient features of the ponds/tanks are given in Table 11. Out of 4 ponds, 3 are in series to harness runoff from adjoining areas of the farm.

Table 11: Specifications of the ponds constructed for Stormwater harvesting at the farm

Sr. No.	Pond type	Soil Strata	Dimensions (m)	Storage Capacity (m)
1	Partially pacca with natural slopes	Sandy loam: 0.91 m Sandy clay: 1.98 m Sandy loam: 2.74 m Sandy clay: 3.65 m	6 x 6 x 3.6	1.3
2	Partially pacca with artificial slopes	-do-	6 x 6 x 3.6	1.3
3	Kacha with natural slope	-do-	6 x 6 x 3.6	1.3
4	Kacha with artificial slopes	-do-	6 x 9.1 x 3	1.64

Figure 30: Stormwater harvesting at the farm

8.7 In-Situ Rainwater Harvesting

Pothwar's uneven topography leads to rapid drainage of water to the low-lying areas resulting in loss of water, soil and nutrients. Cultivation of crops with drill develops little furrows. Their orientation is kept transverse to natural flow direction. It reduces flow velocity, maximizes rainfall retention and thus reduces soil and nutrient losses. Yield of wheat and mung cultivated in this way was double than the neighbouring farmers.

Figure 31: In-situ rainwater harvesting through slope transverse ploughing

8.8 Biodiversity

Biodiversity is a comprehensive umbrella term for the extent of natural variety or variation within the natural system; both in number and frequency. It is often understood in terms of the wide variety of plants, animals and microorganisms, the genes they contain and the ecosystem they form. The biodiversity we see today is the result of billions of years of evolution, shaped by natural processes and, increasingly, by the influence of humans. As the farm is developed on eco-friendly interventions, it helped improved the biodiversity.

8.9 Ecosystem Services

Ecosystem services are defined as the processes and conditions of natural systems that support human activity. (Johnston and Robert, 2018). Biodiversity plays an important role in ecosystem functioning and provides a number of ecosystem services. It plays a major role in mitigating climate change by contributing to long-term sequestration of carbon in a number of biomes. Through biodiversity, the sequential balance of CO_2 and O_2 is maintained. A square kilometre of coastal ecosystem such as mangroves forests can store up to five times more carbon than the equivalent area of mature tropical forests. However, these areas are being destroyed three to four times faster than forests, releasing substantial amounts of carbon dioxide into the atmosphere and the ocean, and contributing to climate change (IUCN, 2012).

The loss of biodiversity and the related changes in the environment are now faster than ever before in human history and there is no sign of this process slowing down. Virtually all of Earth's ecosystems have been dramatically distorted and altered by anthropogenic activities and continuously converted to agricultural and commercial areas. Many animal and plant populations have either declined or totally vanished. Loss of biodiversity is caused by a range of drivers. A driver is any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. Important direct drivers affecting biodiversity are habitat alteration, climate change, invasive species overexploitation and pollution.

The conversion of barren land into productive land by planting trees and crops is also helpful in ecosystem restoration. Being a representative of the Pothwar area, this farm is also acting as the new home for rare species of birds, bees and other insects. Numerous types of birds, insect species have been found here which is very helpful in ecosystem restoration in the area which are not found in the neighbouring areas. Figure 32 highlights some of the outcomes of the ecosystem restoration.

Figure 32: Some views of ecosystem restoration activities at farm

8.10 Dissemination Activities

The farm is a model for showcasing integrated land and water management technologies and practices to the stakeholders. Therefore, great emphasis was given to disseminate the knowledge generated with the concept of *seeing is believing* and *learning by doing* the things. Thousands of farmers, agriculture service providers, professionals, planners and policy makers visited the farm. These not only included the national stakeholder but delegations from international organizations were also shown the different techniques and interventions carried out at the farm. These included delegation of researchers from

African-Asian Rural Development Organization (AARDO), UNESCO, UNICEF etc. Moreover, regular recreational and plantation drives are also a part of the activities carried out at the farm where families are also invited to inculcate the importance of these interventions in the youth. Some highlights of these events and delegation visits are shown at Annexure 1.

9 Overall Findings

The farm presents a classic example of integrated land and water resources management, simple, smart, low-cost and eco-friendly technologies in the rainfed areas of Pakistan. The following are some of the major findings:

i. Undulated lands and wastelands can be made productive without disturbing the soil structure i.e. without scraping and levelling the lands. Scraping the lands accelerate the rate of erosion thus eroding the top most productive lands.

ii. Proper vegetation / deep rooted plants especially drought tolerant plants e.g. sisal, cactus etc. are greatly helpful in controlling erosion and to improve landscape. Furthermore, the developed rainwater harvesting ponds store the runoff water along with controlling erosion and improving groundwater recharge.

iii. Small ponds constructed at the farm continuously help in recharging the groundwater of the farm and surrounding area and also provide a source of supplemental irrigation to the plants as per requirement through solar system. Due to this setup, the operational irrigation cost is practically zero.

iv. The soil should not be kept fallow after wheat harvesting. The experiments on green manuring by cultivating jantar (*Sesbania rostrata*) and mung (*Vigna radiate*) crop are very successful as these have increased the fertility level of the soil to a great extent. Besides keeping the soil covered during the monsoon, the soil organic matter has been improved. It was about 0.5% before and has now been increased to around 1%.

v. The micro catchments developed for harvesting the rainwater under the plants canopy can reduce supplemental irrigation requirements to a substantial level. Water availability for plants during scarcity period is ensured and this has a great impact on health and productivity of the plants.

vi. Tillage provides an excellent opportunity for the rainfed areas to increase the crop yield without application of any fertilizer.

vii. Simple, smart, gravity fed drip irrigation system coupled with solar energy has huge potential of upscaling. Particularly for the small land holders.

viii. The open wells constructed at the farm are great sources of fresh water to the plants. These wells fulfil the irrigation requirements of plants and farmhouse.

ix. The new technology gadgets like tensiometers and chameleon sensor installed at the farm are helpful in monitoring the soil moisture and planning for the supplemental irrigation requirements.

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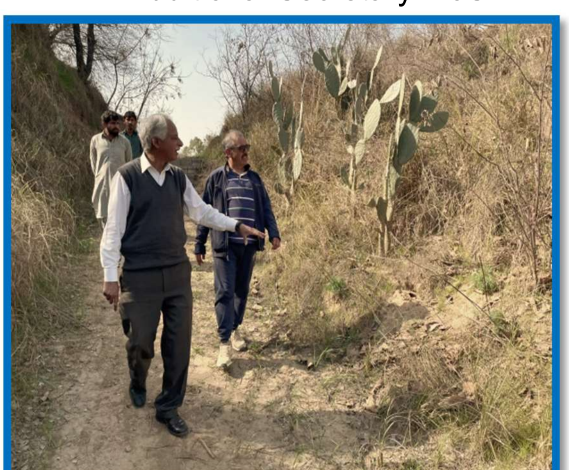
Annexure 1

Some glimpses of R&D farm Darkali Kalan

Federal Secretary MoST Mr. Fazal Abbas Maken visiting the farm

Additional Secretary MoST Dr. Qasir Majeed Malik visiting the farm



Federal Secretary MoST Dr. Akhtar Nazir visiting the farm

Visit of delegation of AARDO to the research farm

Engr. Arslan Mumtaz demonstrating the research activities to progressive farmers and water management officers from Punjab

Plantation day at R&D farm Darkali Kalan

Development of Farm from Past to Present (2009-2022)

Before

After

Before

After

Before

After

Before

After

Before

After

Before

After

Before

After

Before

After

Before

After

Before

After

Before

After

After construction of pond

After filling the pond with rainwater

About PCRWR

PCRWR is an apex body of the Ministry of Water Resources and is mandated to conduct, organize, coordinate and promote research on all aspects of water resources including irrigation (surface and groundwater), drainage, soil reclamation, drinking water and wastewater. It has eight regional offices located at different agro-ecological zones and each centre conducts research on water-related issues of the respective zones. These Regional Offices are located at Lahore, Bahawalpur, Tandojam, Quetta, Peshawar, Karachi, Gilgit and Muzaffarabad. Besides these eight Regional Offices, PCRWR has a setup of 24 water quality testing and research laboratories in major cities of the country. This includes ISO-17025 accredited National Water Quality Laboratory having its own Laboratory Information Management System (LIMS). PCRWR has all types of infrastructure such as soil and water testing laboratories, groundwater assessment equipment, research farms to conduct and disseminate the research. It is the only organization in Pakistan that owns drainage type lysimeters in Lahore, Tandojam, Quetta and Peshawar. PCRWR has done considerable work on crop water requirements, tile drainage, soil reclamation, on-farm water management technologies, rainwater harvesting, artificial recharge, groundwater assessment and management, skimming wells, drinking water, and indigenous development of water testing and treatment tools, salinity and moisture sensors. To help in developing the capacity of in-service professionals and fresh graduates, PCRWR has also a well-equipped National Capacity Building Institute in Islamabad to provide short and long term trainings on all aspects of water.

PAKISTAN COUNCIL OF RESEARCH IN WATER RESOURCES

PCRWR

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