# **Evaluation of the Applicability of Drip Planner Chart for irrigation scheduling for the Small Micro-Drip Farmers:** Assisting and Advising the Extension Work in Lalitpur District of Nepal


**M. Sc. Thesis by Saroj Yakami**

**August 2009**

**Irrigation and Water Engineering Group**

WAGENINGEN UNIVERSITY

WAGENINGEN UR

# Evaluation of the Applicability of Drip Planner Chart for irrigation scheduling for the Small Micro-Drip Farmers: Assisting and Advising the Extension Work in Lalitpur District of Nepal

Master thesis Irrigation and Water Engineering submitted in partial fulfillment of the degree of Master of Science in International Land and Water Management at Wageningen University, the Netherlands


**SAROJ YAKAMI**


**August 2009**


**Supervisor(s):**

**Ing. Harm Boesveld**
Irrigation and Water Engineering Group
Centre for Water and Climate
Wageningen University
The Netherlands
www.iwe.wur.nl

**Mr. Kailash Sharma**
Head of Engineering
IDE/Nepal
Bakhundole, Lalitpur
Nepal
www.idenepal.org

## ACKNOWLEDGEMENT

I would like to take an opportunity to thank all the people who helped me from the very beginning to the end in my research.

Firstly, I would like to thank and show my deep appreciation to my Supervisors, Ing. Harm Boesveld, who helped me with his valuable remarks and observations during the research and Mr. Kailash Sharma from IDE Nepal who facilitates me with everything during the research time in Nepal.

Equal gratitude goes to Robert Yoder (head of technology design and dissemination IDE), Luke A. Colavito (country director of IDE Nepal), who welcomed me, facilitates me in every steps for easy going of research and made the work enjoyable and reasonable. Their presence and assistance make the journey to Ethiopia (for internship) and Nepal (for research) very exciting and unforgettable.

The research was impossible without supports from all the IDE staffs from Nepal, who encourage me every moment and the farmer, Jay Ram Basnet, who let his land for my research. I am thankful for their respective supports. I will remember your patients and welcoming hands for me along the road.

I would like to thank all of my friends whose encouragement is sincere. Special thank goes to Dipina Sharma and my little friend Pritha Dahal for editing my report.

And to my family thank you for your love, support and encourage to dream to face every challenges.

Thank you

**S. Yakami**

## ABSTRACT

Farmers, in mid hills of Nepal, are facing a lot of problems getting a sufficient water supply for their crops during the dry period. International Development Enterprises Nepal (IDE/N) works on the development and dissemination of low cost drip irrigation system for small holder farmers in mid-hills to save and use water efficiently. But farmers are irrigating on their own perception (they do not know whether they are under or over applying water) even in drip system. On the other hand the Irrigation and Water Engineering group of Wageningen University has developed a simple irrigation scheduling tool for the drip system called “Drip Planner Chart (DPC)”. It is a simple manual drip irrigation scheduling tool developed especially for the smallholder farmers. The aims of this research is to evaluate the applicability of DPC in Nepal with different environmental factors (i.e. climatic, physical conditions like soil) and drip kits available in Nepal. Based on the climatic data such as ETo (potential evapotranspiration), soil information, DPC was designed to provide advices to farmers regarding irrigation scheduling in drip systems. Four treatments is created to compare their effectiveness and efficiency. Number of corrections is used to adjust the present DPC in the Lalitpur district of Nepal. Lalitpur district is part of mid-hills of Nepal. The adjusted DPC allow saving lot of water on 90 day period as compared to the IDE/N crop water requirement method without any significant decrease in yield.

.

Keywords: *Drip Irrigation, small holder farmers, irrigation scheduling tool, DPC, applicability*

# Table of Contents

# LIST OF TABLES

## LIST OF FIGURES

## ACRONYMS

| | |
|---|---|
| ADB/N | Asian Development Bank/Nepal |
| AE | Application Efficiency |
| ANOVA | Analysis of Variance |
| APP | Agriculture Perspective Plan |
| CBO | Community Based Organization |
| CWR | Crop Water Requirement |
| DADO | District Agriculture Development Office |
| DEPROSC | Development Project Service Centre |
| DHM | Department of Hydrology and Meteorology |
| DoA | Department of Agriculture |
| DoI | Department of Irrigation |
| DPC | Drip Planner Chart |
| $E_{pan}$ | pan evaporation |
| ET | Evapotranspiration |
| ETo | Reference Evapotranspiration |
| FAO | Food and Agriculture Organization |
| FC | Field Capacity |
| FGD | Focus Group Discussion |
| FMIS | Farmer Managed Irrigation System |
| GDP | Gross Domestic Product |
| ha. | Hectare |
| HDPE | High Density Polyethylene |
| HI | Harvest Index |
| HVC | High Value Crops |
| ICIMOD | International Centre for Integrated Mountain Development |

| | |
|---|---|
| IDE/N | International Development Enterprises/Nepal |
| INGOs | International Non-Governmental Organizations |
| IWMI | International Water Management Institute |
| Lpm | Liter per minute |
| lps | Liter per second |
| mm | Millimeter |
| MUS | Multiple Water Use Services/System |
| NARC | Nepal Agriculture Research Council |
| NGOs | Non-Governmental Organizations |
| NITP | Non-Conventional Irrigation Technique Programme |
| OD | Outer Diameter |
| PE | Poly-Ethylene |
| pH | Percentage of Hydrogen |
| PRISM | Poverty Reduction through Irrigation and Smallholder Markets |
| PVC | Polyvinyl Chloride |
| RCBD | Randomized Complete Block Design |
| SAPPROS/Nepal | Support Activities for Poor Producers |
| SHFs | Small holder farmers |
| Sqm | Square meter |
| TAW | Total Water Available |
| TDR | Time Domain Reflectometry |
| VDRC | Vijaya Development Resource Centre |
| VSWSI | Visual Soil Water Status Indicators |
| WATSAN | Water and Sanitation |
| WP | Wilting Point |

# 1. INTRODUCTION

This Chapter includes two sections. The first section describe the overview of irrigation in Nepal that includes about the Irrigation status, micro-irrigation status especially drip irrigation and its suitability in Nepal. The second section is about the research background. It is about the past researches and Irrigation scheduling tools, overview of the research area and the problem statement. With this problem statement research objective and research questions were set.

## 1.1 Overview of Irrigation in Nepal

### 1.1.1 Irrigation Status in Nepal

Nepal has one of the most agriculturally dominated economies in Asia, with the sector employing around 66% of the population, and contributing an estimated 38% of GDP (APP, 2009). Irrigation plays a pivotal role in increasing agricultural production and productivity. The Agriculture Perspective Plan (APP) emphasizes on "well controlled and year round irrigation" for high cropping intensities and to introduce High value crops (HVC) varieties. Provision of the year round irrigation facility has been further stressed and incorporated in the Tenth five year plan[1] (2002-2007). Meanwhile, the Irrigation policy 2003[2] has been promulgated for the extension of irrigation facilities.

Nepal has a long history of irrigated agriculture mainly through Farmer Managed Irrigation System (FMIS). At present, about 75% of the total irrigated area is still under these traditional schemes. The Department of Irrigation (DoI), which was formed in 1951 AD, is the major institution involved in the irrigation development in Nepal. The Agriculture Development Bank Nepal (ADB/N) is another key actor for the development of small-scale

[1] Tenth five year plan: It is a government formulated plan which includes the development plan for whole five years in different sectors. And in the context of irrigation and marketing this plan indicates the implementation through I/NGO's, emphases on partnership with private providers, involvement of the private sector in input and output marketing

[2] Irrigation Policy (2003) envisages to reduce level of poverty by improving agricultural production and increased employment for the marginal farmers through the promotion of Non-conventional Irrigation Technology (NIT).

irrigation development. Over the past few years I/NGOs and private sectors have been introduced and have made important contributions in irrigation development at local level.

The agricultural land situated in the hill slopes and northern Terai lacks a reliable water source for conventional canal irrigation. However, there is still potential to irrigate significant portion of the rain-fed land through the development of small water sources, including rain water harvesting and the application of efficient irrigation systems like the drip and sprinkler systems. As sustainable agricultural development is dependent on the efficient use of irrigation water, various technological measures have been introduced in an attempt to grow more crop per drop. To raise the productivity of water, it will be necessary to deliver and apply water to crops more efficiently and to increase crop yields. This can be done by using drip, sprinkler, and other micro-irrigation systems (Upadhyay, 2004).

In view of this, DoI has established “Non-conventional Irrigation Technology Project (NITP)”, to develop and promote irrigation technologies like treadle pump, Sprinkler, Drip irrigation, rainwater harvesting, Irrigation tanks and ponds. The tenth five year plan and the Irrigation Policy 2003 has emphasized the use of these technologies that favor the smallholder farmers who are located in the water scarce areas for the production of high value crops. This will in turn contribute to the national goal of reducing poverty.

### 1.1.2 Micro-irrigation Development in Nepal

As small irrigation systems are also considered as micro-irrigation, the entire range of water acquisition, storage and application technologies are taken within the frame of micro-irrigation. This includes manual water lifting devices such as treadle pump, piped water systems, drip, sprinklers, and water harvesting tanks/ponds. And Department of Irrigation, Nepal defined the term micro-irrigation as Non-Conventional Irrigation Technology (NIT).

In the early 1980s’, small farmers development program of Agricultural Development Bank in Nepal (ADB/N) introduced shallow tube wells and treadle pumps in Terai, and the sprinkler, and the drip irrigation systems were introduced in hilly regions in different phases. They were promoting sprinkler, shallow tube well, treadle pump, dug well by providing certain amount of loan support and technical advices along with the subsidy. But the government curtailed its subsidy program and then, bank limited its function to lending only money.

In the late 1980s', the International Development Enterprises Nepal (IDE/N) in collaboration with ADB/N and CARE Nepal began the program with the rower pump irrigation in the three districts of eastern Terai. Shortly after, treadle pumps were introduced by IDE. In 1995 IDE started the development of simple and low-cost drip irrigation technology targeting small farmers of the middle hills. Based on successful field testing, IDE assisted the establishment of private sector entrepreneurs for the production and delivery of the drip and sprinkler technologies. Some prominent NGOs involved in the development and promotion of micro-irrigation are SAPPROS/Nepal, DEPROSC and VDRC. Furthermore ICIMOD has also conducted action research in number of the water storage and application technologies.

The Non-conventional Irrigation Technology Project (NITP) in the department of Irrigation has supported to build more than 85 water schemes to irrigate over 1,800 ha command area. In recent years, NITP has demonstrated some good examples of partnerships with I/NGOs and the private sector in water acquisition, and technical support system for water application technologies. Likewise, the Department of Agriculture (DoA) under its small scale irrigation programs involved in supporting construction of cement or plastic lined pond irrigation, water lifting devices, such as, diesel pump sets, electric motors and treadle pumps. Besides this, various community based organizations (CBO), have been introducing micro-irrigation technologies in various locations all over Nepal.

It is estimated that approximately 42,000 ha. of land has already been brought under irrigation through NIT benefiting 162,000 households. Experiences of the micro-irrigation and water system development program have indicated substantial income generation, particularly through vegetable cultivation and sales. Other advantages includes enhancement in nutritional intake and increased reliability of water supply at the household level.

### 1.1.3 Background of Drip Irrigation System

Drip or trickle irrigation is a method of watering a precise amount of water to the plants, in the form of drops right at the root zone. This keeps the optimal soil moisture conditions thus maintaining the healthy growth and minimum stress to the crops. The application rate is slow which typically varies between 1 to 8 liters per hour. Water is dispensed through discrete emitting devices, known as drippers or emitters which receive water that is supplied under pressure via a network of the pipes. Drippers are located at a spacing to match with the distance between the crops.

Drip technology improves the irrigation efficiency by reducing evaporation from the soil surface, reducing or eliminating runoff and deep percolation. It also eliminates the need to drastically over-irrigate some parts of the field to compensate uneven water application. The application of fertilizer and other chemicals can also be optimized through the use of drip irrigation, weed growth can be reduced, and the salinity problems can be mediated (Skaggs, 2001)

Drip irrigation if it is well designed and properly managed has a potential to be highly efficient method among the available water application methods. In recent years, the popularity of the drip irrigation has been growing mainly because of its inherent advantages like saving water. According to **Haile, et al., 2003**, the role of appropriate technology in the form of affordable drip systems for improving the livelihood of small farmers is indisputable. For instance smallholder irrigation technology can significantly reduce the drudgery of watering. It can also help solving water management problems faced by smallholder farmers by making it easier and simpler to supply the right amount of water to their crops at the right place at the right time.

Drip irrigation can be adopted for irrigating various types of crops grown in rows. It is most commonly used for high value crops such as fruits, vegetables, sugarcane, flowers. Drip irrigation is most suitable in marginal lands where the soil quality is poor and where there is water scarcity to irrigate high value crops. In such conditions surface irrigation methods may not be feasible due to various reasons.  Drip irrigation is also highly suitable for high intensity farming conditions like green houses. However, the application of drip irrigation is not only limited for these set of conditions. As there has been an increase in the scarcity of water and there is a growing population drip can have a great potential for the future.

Drip irrigation is suitable for growing any type of row crops. Its importance is greater in water scarce areas and poor soil for growing high value crops.

The conventional drip system, shown in fig 1, is costly and technologically intensive which is not suitable to irrigate in situations of small plots which is a common farming context in the developing countries.

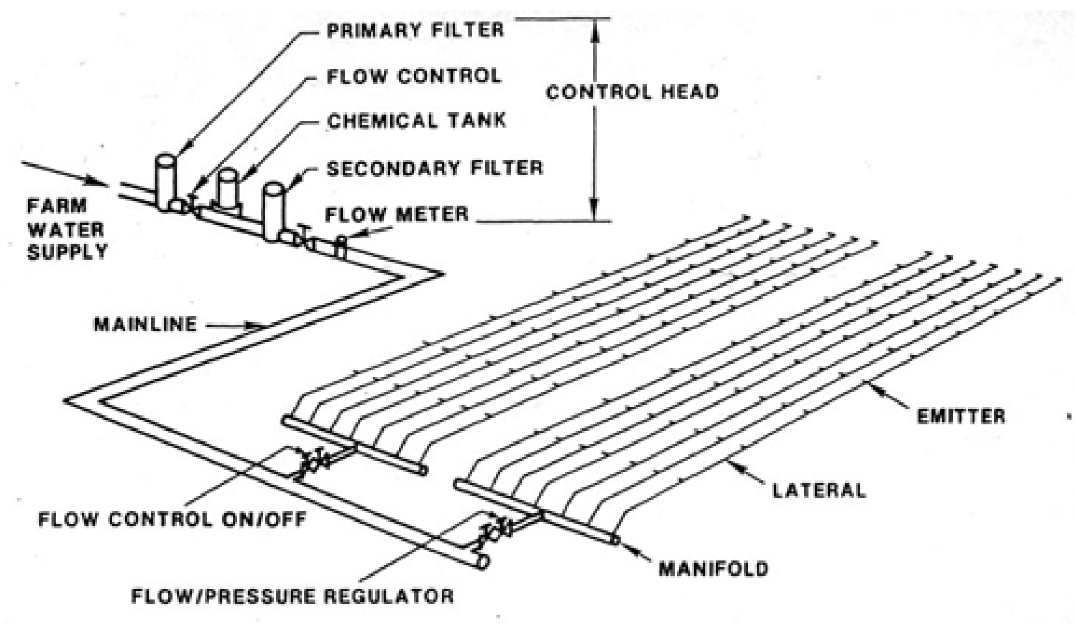



**Figure 1 Schematic layout of conventional drip irrigation**
**(Source: NITP, 2006)**

Considering these limitations of the conventional drip systems, in 1995, IDE developed a number of designs of simple and low cost drip irrigation kits (fig 2). This is appropriate and affordable for those smallholders.

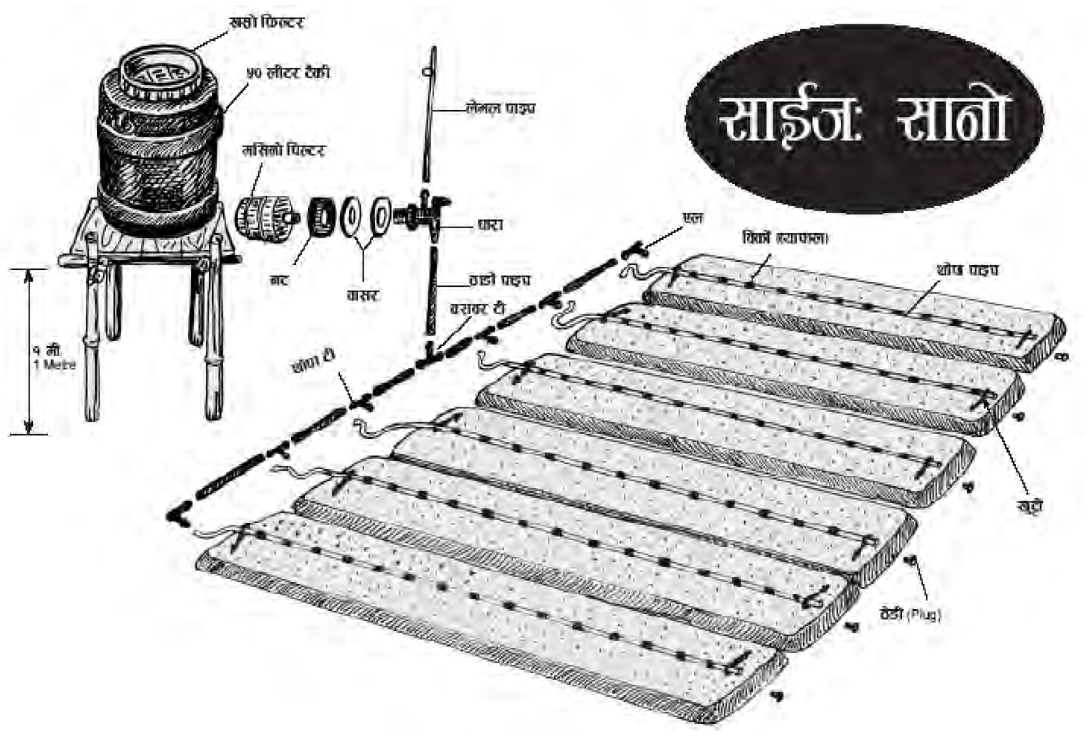



**Figure 2 Exploded View of Simple Drip irrigation**
(Source: IDE/Nepal)

The smallholder friendly drip kits have the following technical key features as described in Table 1.

**Table 1: Technical features of Simple Drip System**

| | | |
|---|---|---|
| a | Operating head (Water pressure) | 1 metre – 1.5 metre |
| b | Standard Sizes (based on irrigation coverage) | Five sizes: 80 Sqm, 125 Sqm, 250 Sqm, 500 Sqm & 1000 Sqm |
| c | Emitter discharge | 2.1 – 2.4 lph depending on the size of the system |
| d | Distribution Uniformity | Above 80 % |
| e | Materials used | Head Tank: 50 – 100 ltr HDPE Container<br>Pipes: PVC soft with pure granules<br>Fittings: HDPE pure & recycled raw –m. |
| f | Max. Length of the laterals | 12 metres |
| g | Pipe Diameter | Main Pipe: 12 mm OD, Lateral: 8 mm OD |

**(Source: IDE/Nepal)**

### 1.1.4 Drip System Components

The components of a typical unit of drip irrigation system can be broadly divided into the following:

a) Head Unit (Control Head/Head Tank)

b) Filters: Filter at the mouth of the head tank, at the outlet.

c) Pipe Networks: Main line set (Main and sub-main line), Drip pipe set (lateral)

d) Emitters and

e) Miscellaneous: Outlet set; Valves; joints (l-section, t-section), end plugs, legs to fix the laterals


**Figure 3 Components of the Drip Kits developed in Nepal**
(Source: IDE/Nepal)

### 1.1.6 Suitability in Nepali Context

Though Nepal is very rich in water resources, it is not properly utilized and well distributed. As the population is increasing day by day the irrigation development must be given higher priority to cope with the increasing demand of agricultural production. In Nepal, several large and medium irrigation projects have already been implemented but their output is reported to be very low.

Agriculture in Nepal is largely carried out under rain fed condition. It is estimated that out of 2.64 million hectares of cultivated land only about 1.76 million hectares are irrigable. Large irrigation schemes in Nepal are irrigating as little as 43% of the planned net area during monsoon and 17% in winter. In most of the cases, these schemes require high operation and have high maintenance cost which could not met. It results in further deterioration of existing infrastructures. (NITP, 2006)

The tenth five year plan also emphasizes the new technological developments in irrigation to increase the productivity and decrease poverty. Since there is no possibility of acquiring additional land, it is required to produce a high amount of crops per unit area of the land to meet the demand of the growing population. This can be achieved by having an adequate irrigation facility throughout the year that enables the cultivation of more crops. Interest shown by the farmers in crop diversification and an increasing population at the same time make it imperative to develop those techniques to meet the demand. While these techniques will provide irrigation facilities more efficiently, throughout the year and to those areas that are beyond the reach with traditional techniques. (NITP, 2006)

The hill region of Nepal, which occupies a vast proportion of the rain fed land of the country, is characterized by steep ground slopes and relatively water scarce areas. Development of surface irrigation in these ecological belts has limited scope due to technical reasons. Under these circumstances NIT such as drip and sprinkler irrigation are the most suitable technologies to enhance the agricultural productivity and economic promotion of the rural population. Similarly, in the North belt of the Terai (Bhawar Zone) where the water table is relatively deep, and the soil is mostly porous the relevance of the drip irrigation stands at premium level. Sprinklers, Treadle pumps, Water harvesting tanks are other NIT solutions in places where the coverage with surface irrigation does not seem a viable option. Though, the hills & Bhawar regions are highly suitable territories for the application of NIT, it is not limited only in these regions. In general NIT can have its potential applications in wide geographical area.

### 1.1.7 IDE Nepal

Founded in 1981, International Development Enterprises *(IDE)* has a global reputation as a non-profit and *Non-Governmental Organisation* with a focus on improving the livelihoods of the poor rural communities who are living on less than US$1-a-day. *IDE* follows a 'no subsidy' on sale of irrigation equipment, but instead is working hard to make the price of products affordable for poor farmers. *IDE*/Nepal has the same focus and initiative.

IDE-Nepal began in 1993 with an initial focus on developing a private sector supply chain for low-cost and human powered treadle pump technology in the Terai (southern plains) region. IDE Nepal has accomplished number of goals and still working on it. These works are listed below:

i. Developed a low-cost drip irrigation systems in 1995
ii. Mass marketed treadle pumps in the Terai region
iii. Promoted low-cost drip and micro-sprinkler systems in the middle hills of Nepal
iv. Linked storage tanks with water saving technologies to irrigate high value crops in the water scarce areas in middle hills
v. Designed and promoted Multiple Use Water Services/Systems in the hills to more efficiently provide water for all household needs both domestic and productive
vi. Developed and marketed low-cost household water purifiers.
vii. Promoted ground water markets (water sale) for low-cost irrigation by smallholders in the Terai.

The district covered by IDE Nepal is shown on the map below indicated in figure 4. Almost all the mid-hill regions are covered by IDE projects.


**Figure 4 Map of Nepal showing the IDE Project implemented districts**
**(Source: IDE Nepal)**

Since the inception, IDE/N program has assisted more than 240,000 farmers – helping farmers to generate an average net additional income of $150 per year. The programs have also resulted in the sale of more than 200,000 treadle pumps and 40,000 drip irrigation systems, enhancing the income level of more than 240,000 smallholder families (i.e. 1.4 million people).

<u>The IDE PRISM Approach</u>

In 2001, IDE redefined its organizational vision and approach recognizing the limitations in the scale/outreach of an almost exclusive focus on the supply chain of market chain development. So with the experience of 20 years, IDE develop a broad market-oriented development model- Poverty Reduction through Irrigation and Smallholder Markets (PRISM).

The new vision and model sets out a framework to develop an integrated market system for the rural poor with focus on sustainable natural resource management and gender/caste equity. The framework targets wealth creation along an input enterprise (on-farm and off-farm) & output segments of the value chain. It also mitigates multiple axes of constraints with targeted intervention services: technology, capacity, finance, information, infrastructure and policy.

Casting aside the traditional view of the rural poor as ‘recipients of charity’, IDE regards them as potential customers, producers & entrepreneurs.

## 1.2 Background of the Research

### 1.2.1 Past Research and Irrigation Scheduling Tools

The researches conducted in the past included in this chapter are replicated from my internship report by Yakami, S. & Zisengwe, LS. (2008) in Ethiopia.

Soil water tension is commonly measured using more user-friendly devices including tensiometers and electrical resistance sensors. Control of drip irrigation of sugarcane using ‘index’ tensiometers was found to be effective and simple in Mauritius (Hodnett, M.G., et al. 1990). These methods do not require measurement of rainfall or estimation of crop evapotranspiration. Irrigation scheduling can also be accomplished by calculating crop water use based on weather data. Such a system must be calibrated for local conditions and for particular crops and stages of growth. Estimates are also required on various parameters including soil water holding capacity and rooting depth. A balance sheet approach is then utilized to track water availability to the crop. (Wiedenfeld, B., 2003)

Irrigation support software must be able to assist farmers in making their decisions on how best to irrigate their crops and must offer simple and easily comprehendible output that the farmer can easily use to make his/ her decision. An example can be seen from the visual soil water status indicators (VSWSI) that were designed for larger farms. Three highly visible colours are used to display current soil water content relative to the two set points. White is used to show soil water content above the upper set point. Fluorescent blue is used to show soil water content between the lower and upper set point. Although the VSWSI is far more complex, it makes use of simple output which is vital given the demand of a strict irrigation scheduling routine and the consistent evaluations that are very difficult to achieve for farm managers who must oversee all their farming activities. The VSWSI is intended to serve as a guide for making in-field refinements to irrigation duration and interval as opposed to determining the actual irrigation schedule. There is a definite need for new tools and/or approaches to irrigation scheduling that foster wide scale adoption through ease of use. (King, B.A. *et al.* 2001)

Work done to evaluate four methods of irrigation scheduling for sugarcane under drip had some interesting output. The background of the research involved the analysis and evaluation of four different methods (pan evaporation ($E_{pan}$), evapotranspiration (ET), auto-tensiometers, and manual tensiometers) for determining the amount of irrigation water to apply. Wiedenfeld (2003) highlights the background of irrigation scheduling techniques from this research. There are several methods for determining both the timing and amount of water to be applied to sugarcane including direct soil water monitoring and calculated crop water use based on weather data. Volumetric water content can be determined gravimetrically, or using a neutron probe or time domain reflectometry (TDR). While these may be very accurate, all can be time consuming, expensive and require technical expertise, therefore are not frequently used for routine irrigation scheduling. The 4 techniques research showed that pan evaporation and ET are effective once they are properly calibrated by developing appropriate coefficients for a particular region. Pan evaporation has been used for a long time, but it is more difficult to obtain reliable data compared to ET data from automated weather stations. The research also showed that all the irrigation scheduling methods were effective, prescribing similar amounts of water for a given season. However, direct measurement using tensiometers gives the most accurate assessment of field conditions, but is expensive and labour intensive. (Wiedenfeld, 2003)

Some work has been done before in designing a simpler and cheaper scheduling chart. It is appreciated that in the absence of good guidelines, irrigation will be rather empirical and often characterized by an over-irrigation at the beginning and end of the season and under-irrigation during the peak period. Raes, D. et al. (2000) outline a methodology to develop and to present irrigation calendars that give farmers simple guidelines on how to adjust their irrigation during the growing season (i) to the actual weather conditions and (ii) when shortage in the supply of irrigation water occurs. In order that farmers adopt the guidelines, the calendar should be easy to consult. An example is worked out for drip irrigated tomatoes that are cultivated on a fluvisol in the region 344 of Tunis (Tunisia).

By taking into account the common irrigation practices of the farmer, the irrigation method and the climatic data (ETo, rainfall etc), soil data (FC, WP, TAW) and crop data (different stages of crop), the paper presents how irrigation calendars are developed. Subsequently the paper describes how the information can be synthesized on a single chart. The chart presents guidelines (i) to adjust the irrigation interval to the varying climatic conditions during the growing season and (ii) to select the irrigation duration as a function of type, layout and efficiency of the drip system. (Raes, D. et al., 2000)

The development of irrigation calendars requires a good knowledge of the meteorological conditions of the region and more in particular of the reference crop evapotraspiration ($ET_o$) and rainfall levels that can be expected in a 10-day period. The reference crop Evapotraspiration is derived from 10-day climatic data of the region by means of the FAO Penman-Monteith equation (Allen, R.G., Pereira, L.S., Raes, D.,& Smith,M., 1998). Since the objective of irrigation is to provide the crop with the right amount of water to ensure its full productivity, it is essential to acquire the right climatic data for any particular location and correlate this with the design of the scheduling chart. For the design of the irrigation calendars, the application depth is considered as fixed. Fixed application depths in combination with a variable irrigation interval result in an efficient use of the irrigation water. The selected value for the fixed application depth depends on the soil type, crop type, irrigation method and equipment. (Raes, D., *et. al* 2000)

Maisiri, N. et al. (2005) states that on-farm irrigation was carried out at Zholube irrigation scheme in Zimbabwe to compare a drip irrigation system with a conventional irrigation system in terms of crop and water productivity. In this research work, Irrigation scheduling was done differently in two systems. In a conventional system farmers followed the daily practiced irrigation system. But in case of drip irrigation they followed the Zambian and Nepalese farmers and (FAO, 2003) to provide watering guidelines i.e. filling of the tank twice a day once in the morning and once in the afternoon to irrigate vegetables which require 1 l/day/plant. The results showed that drip irrigation system had higher water productivities regardless of the type of fertilizer treatment that was applied. (Maisiri, N. et al. 2005)

The research already done and described above about the different methods of scheduling the irrigation seems to be unreachable to the farmers. The Probe, tensiometers et cetera are out of reach for the small farmers as these equipments are very technical, expensive. IDE deals with the pro-poor farmers who are struggling to feed themselves and illiterate. Their goal is to assist and upgrade the living standard the pro-poor farmers with easy, understandable and affordable technology. So, IDE is in search of the hardware and software for irrigation scheduling that will be really is supportive/beneficial to assist/improve the livelihood of the pro-poor and which meet the philosophy of IDE “easy, understandable and affordable”.

**Drip Planner Chart (DPC):**

According to Clyma 1996, many small farmers also lack the financial means to buy expensive equipment and many have no computers to run the models on. It is suggested that farmers need simpler, cheaper and more comprehensive support tools to achieve improved irrigation management at the farm level. Irrigation and Water Engineering group of Wageningen University and Research Centre has recently introduced manual tool for scheduling irrigation via. a Drip system. The idea of developing DPC is to introduce a very simple, portable, user-friendly irrigation scheduling tool for the small holder farmers (SHFs) using drip system. The two sides of the DPC is shown in Figure 5.

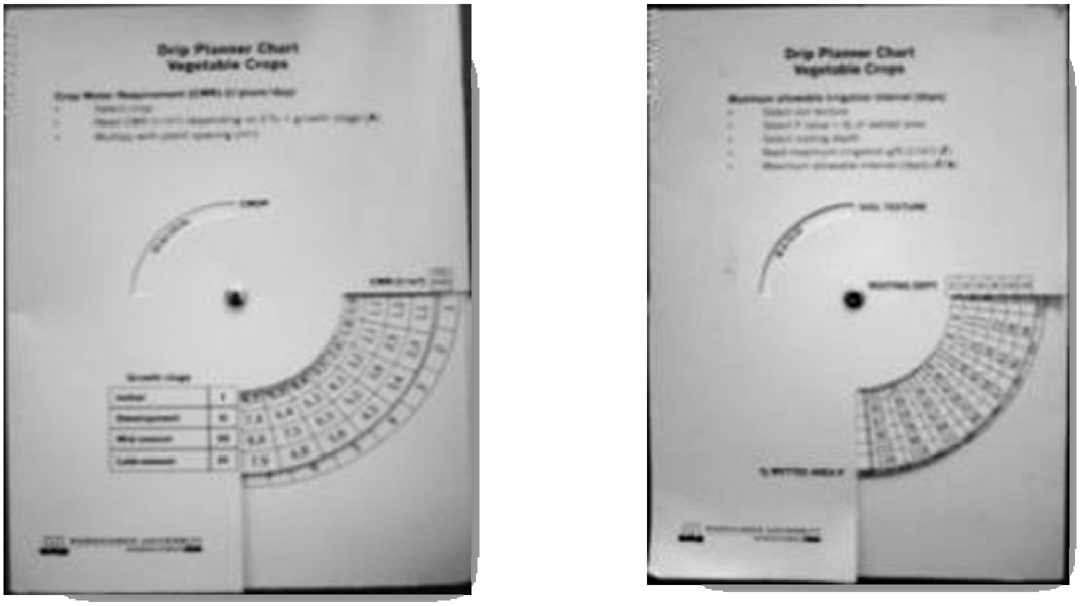



**Figure 5: The two faces of the Drip Planner Chart (left) the crops & climatology data and (right) the soil information (Boesveld, 2008)**

The further research on DPC was held in Nepal and Zambia for further refinement on the present DPC. The context (climate, soil) is different for those two regions.

**Water Mark Sensors and Soil Matric Potential/Crop Relations**

Water Mark sensors are electrical resistance sensors for estimating soil water tension (suction) and consist of a porous body in which a pair of electrodes is embedded *(Fig. 8)*. Either the sensor itself is made of $CaSO_4$ (known as gypsum or hydrated plaster of Paris) or there is a pellet of $CaSO_4$ embedded in the sensor body. The sensor may be buried at any desired depth in the soil. (IAEA, 2008)

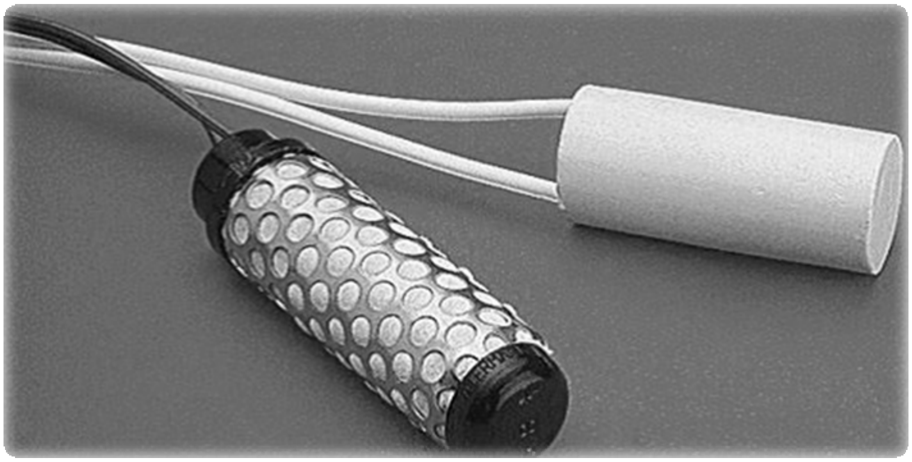


**Figure 6: Electrical resistance sensors used in the field trial**
(Source: (IAEA, 2008)

The porous sensor exhibits a water retention characteristic in the same way as does the soil. As the surrounding soil become wet and dries, the sensor also becomes wet and dries. A two-wire lead from the sensor is connected to a meter, which is used to read the sensor resistance using an alternating current, usually at 1 kHz or more. (IAEA, 2008)

Electrical resistance of the block is related to the soil matric potential i.e. the energy the plant must exert to remove water from the soil), expressed in centibars (cb). For the sake of later data analysis to evaluate the actual levels of moisture for any soil type using the pF-curve relations, 1cb is equivalent to 1kPa.  A potential 1-10 cb indicates that the soil is saturated (almost no energy is required to remove water). As the soil dries caused by plant uses or through evaporation, the centibar readings rise. When the readings reach a threshold value unique for each plant and soil texture, irrigation is required or the plant will be excessively water-stressed. (Neibling, H.( P.E))

The following is a general guide for interpreting the Watermark readings.

| | |
|---|---|
| "- - " = | Dry or non-conditioned |
| 0-10 cb = | Sensor Saturated soil |
| 10-30 cb = | Soil is adequately wet (except for coarse sands which are beginning to lose water) |
| 30-60 cb = | Usual range for irrigation (except heavy clay soils) |
| 60-100 cb = | Usual range for irrigation in heavy clay soils |
| 100-200 cb = | Soil becoming dangerously dry for maximum production. |

(**Spectrum Technologies, 2009)**

The Watermark soil moisture sensor has been calibrated for a soil temperature of 70 $^{o}$F. For slightly greater accuracy, the moisture tension values can be adjusted to seasonal temperature fluctuations. The decrease in the moisture tension readings by 1% for each degree Fahrenheit greater than 70 $^{o}$F. Likewise, increase by 1% for every degree less than 70 $^{o}$F. (**Spectrum Technologies, 2009**)

The Datalogger can be programmed (and usually comes pre-programmed) to record data every 8 hours for the convenience of ‘hands-off’ data collection i.e. the periodic data can later be downloaded onto a PC or laptop. On the other hand one can opt to directly read off the data from the logger and record it onto a recording sheet of some sort. I chose the latter approach.

Some research has been carried out to evaluate different soils and crops as well as the matric potential levels effective to ensure successful growth and maturity of these crops. These levels are presented in Table 2. The IDE manual presents the following relations of crops and soil matric potential levels;

**Table 2: Crops and their minimum matric potential thresholds for successful water management:**

| Crop | Preferred soil moisture | Critical moisture period |
|---|---|---|
| | *Matric potential (cb)* | |
| **Beans (snap & dry)** | 45 | Flowering |
| **Cabbage** | 34 | Head development |
| **Corn (sweet)** | 45 | Silking |
| ***Onion*** | *25* | *Bulbing and bulb expansion* |
| **Pepper** | 45 | Transplanting flower up to $^{1}/_{2}$" fruit |
| **Potatoes*(Irish)*** | 35 | After flowering |
| **Sweet potato** | 200 | Fruit and last 40days |
| **Tomatoes** | 45 | Fruit expansion |

Source: (Sanders, D.C, 1997)

### 1.2.2 Farmer Practices

A study from Eritrea points out that -the manuals supplied with the kits suggest irrigation with 2 buckets/barrels per day for highland areas. On this basis, farmers provide 1 bucket/barrel in the morning and 1 in the afternoon throughout the growing period. But there are 4 distinct stages in the life cycle of a plant: the initial stage, the mid-season stage, the late season stage, and the harvest stage. At each stage, crop water requirements are different- (Haile, A. M, Depeweg and H & Stilhardt H., 2003)

A study in Kiambu, Kenya, compared water use efficiency under current practices with an alternative that uses the same amount of water (2 barrels/buckets), but for a different fixed schedule of 7, 2, 2, and 14 days during the 4 growing stages, respectively; the latter practice saved about 40% of the water consumed by the former- Haile et al. (2003). It makes it even more relevant to design a scheduling chart that can be useful for farmers given that adequate scheduling can bring some water savings. Several methods are available for farmers to use to determine the amount of water to allocate to their crops. However these methods are not always easily comprehendible or easily accessible for small farmers. This indicates the requirement of the relevant method that is simple, understandable, affordable et cetera.

### 1.2.3 Overview of Research Site

The research was held in Chapagaon-6, Lalitpur district situated in the south of the capital city Kathmandu. Geographically, the research site lays N 27.59008$^0$ Latitude and E 085.324630 Longitude which is about 1500 m above sea level. The area of Lalitpur district is about 385 sq kms (District Profile of Nepal 2007/08). The map of Lalitpur district with the research site indicated by black eclipse is shown if Figure 7.

The total population of Lalitpur District according to Census 2001 is 337785, where Male: 172455 & Female: 165330 and the projected population in 2008 was 407870 with male 208236 and female 199633. (District Profile of Nepal 2007/2008).

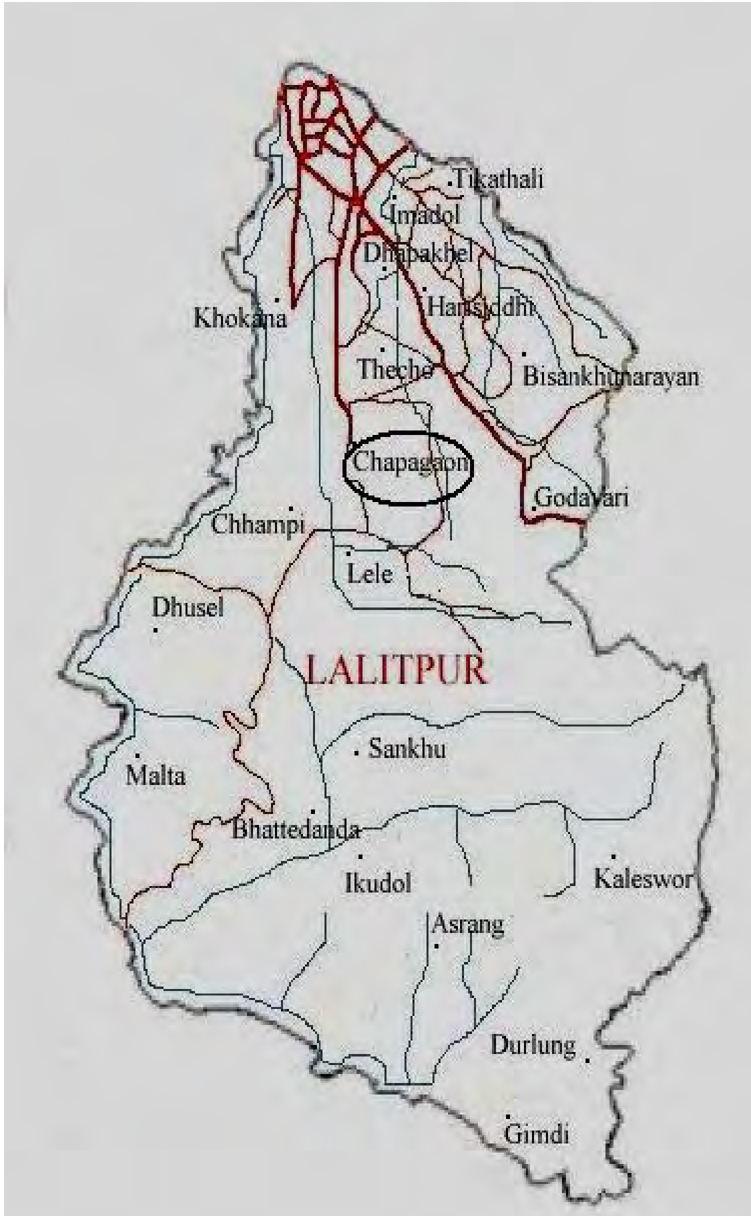



**Figure 7 : Map of Lalitpur District**

***Land Classification***

Agriculture is the major economic activity in the middle hills of Nepal. Land is classified into three types, depending on the type of crops that can be grown on it: Since rice is the primary crop for the Nepalese, the most important land is khet, which is terraced with bunds for growing rice and is commonly the only land that is irrigated (often with Farmer Managed Irrigation Systems). Bari is sloping land that is sometimes terraced to reduce the slope and generally is not irrigated but is used to grow all types of rain-fed crops. The steep slopes and wasteland is called kharbari and is used for growing fodder and thatch.

Use of bari and khet is based on location in relationship to the homestead —bari close to the homestead can more easily be used for vegetables that require protection from predators and pilferage. Khet close to the homestead is more likely to be used for potatoes or other vegetables during the dry season if it is close enough for easy access since more labor is required than for traditional cereal crops. Bari is the most prevalent land type in the middle hills region. And despite a lack of access to canal irrigation, it has great potential for increased crop growth with micro-irrigation because the technology can be used on sloping land without danger of erosion. For this reason, the productive portion of the MUS projects in Nepal took the form of micro-irrigation of vegetables on bari land close to the homestead.

***Rainfall Analysis***

The data from 1968 to 2005 (i.e. 38 years) was collected for Lalitpur District at Khumaltar weather station from the Department of Hydrology and Meteorology (DHM). The Khumaltar Weather Station is representative of the research site at Chapagaon for the weather data. Figure 8 represents the mean average monthly rainfall at the research area.

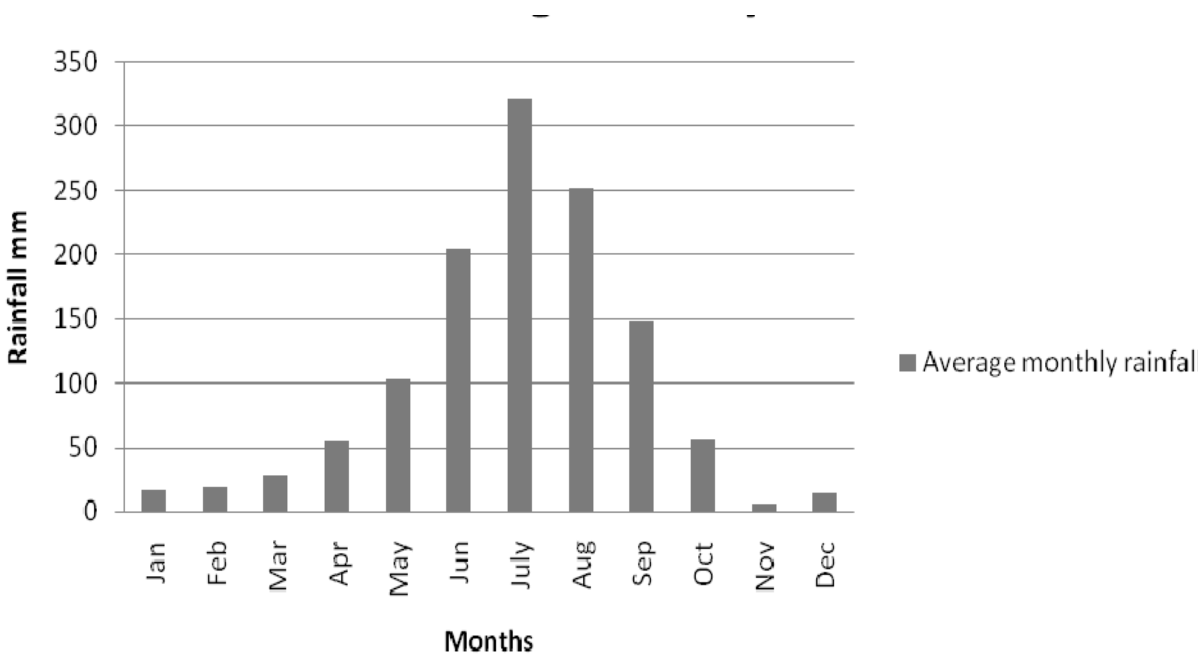



**Figure 8: Mean Average Monthly Rainfall.**

The data for monthly total rainfall of 38 year was collected and arranged in ascending order. Then dependable rainfall was calculated in such a way that the probability of occurrence is 4 out of 5 years return period of rainfall (see appendix 1). The dependable rainfall and effective rainfall data is shown in Figure 9 and Appendix 2. As effective rainfall ($R_{eff}$) is different from the dependable rainfall (i.e not all the dependable rainfall is effective rainfall), it is calculated as 80 percent of the dependable rainfall, as there is losses (runoff, evaporation, deep percolation et cetera). Figure 9 shows the graphical representation of dependable and effective rainfall of the hydrological year.

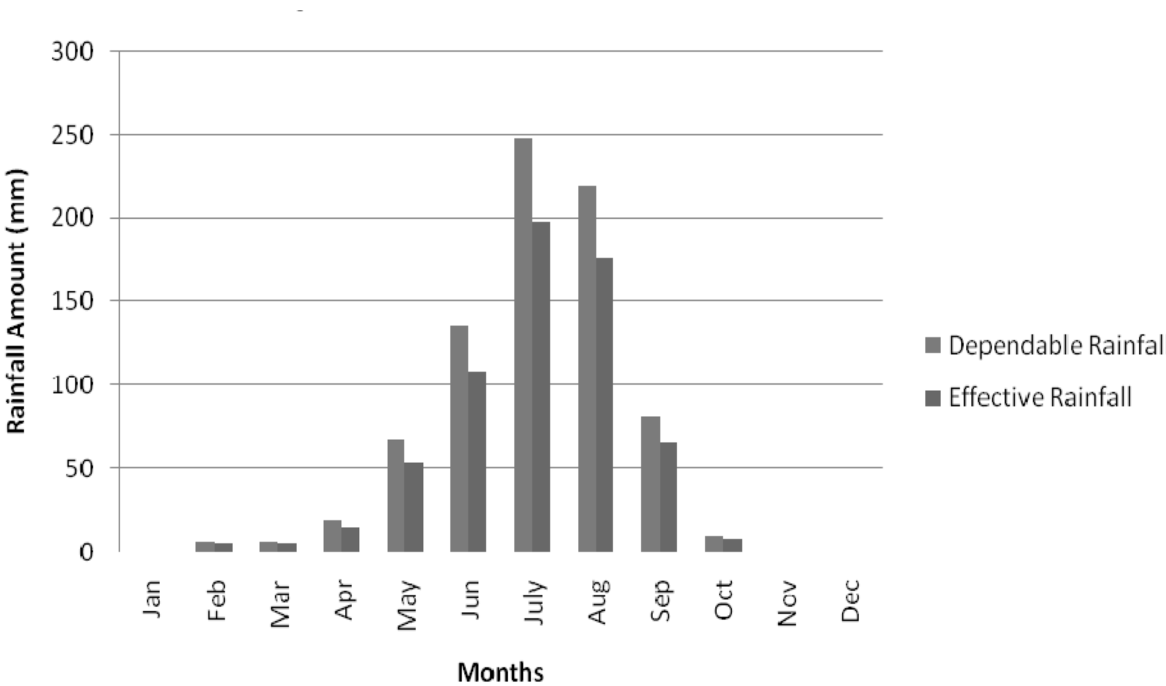



**Figure 9 Hydrograph of Dependable and Effective Rainfall**

From the Figure 9 we can observe that the effective rainfall is effective from May and last upto September i.e. for around 5 months. And the rest of the seven months of the year there is no sufficient water for the agriculture via. rainfall. So, if we can develop irrigation technology, farmers can grow crops in these 7 months. There will be high possibility of improving agriculture and farmers' economy. And if we can introduce an efficient means of irrigation, farmers can irrigate more lands which, in turn, results in higher production with the available water. The distribution of rainfall in a year is quite erratic (i.e from no rain to high).

Figure 10 demonstrates the seasonal rainfall variation from the year 1968 to 2005 AD. The seasonal rainfall distribution is not uniform.

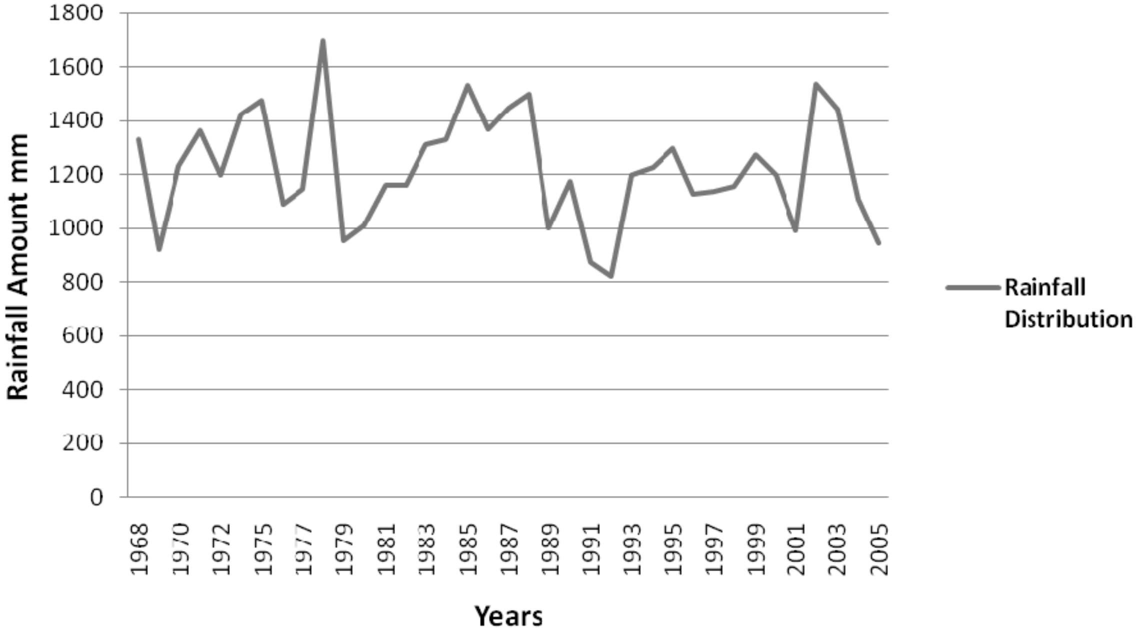



**Figure 10 Seasonal Rainfall Distribution of Lalitpur District**

**(Data Source: Department of hydrology and Meteorology)**

If there is a reliable means of water resources during the dry season, one can use MIT's (Micro-irrigation technologies), which require a small amount of water to produce crops and is a kind of soil and water conservation measure. Especially in the mid hill of Nepal, drip irrigation best suits the geography even the efficiency of system is quite less than that in flat land.

### *Water Resource*

In the middle hills, the only reliable sources of water are the springs that are used for drinking and irrigation. The priority is given to drinking water. If there is sufficient water for drinking then the excess water is use for irrigation purpose. While in the middle hills, water from snow melt is mostly inaccessible because rivers draining have cut deep into the valleys. The possibility of accessing this water can be possible only through the construction of a long canal or through pumping. Both techniques are very expensive way of extracting water from the snow melt. This is similar at the research site and the IDE project area in Lalitpur District.

In many cases the discharge from springs is seasonal, and where their water is captured for domestic use, these springs no longer feed into the streams. Domestic water uses include drinking, cooking, washing utensil, bathing, cleaning house, flushing toilet, and watering livestock.

For Irrigation, in the middle hills of Nepal, most of the water comes from small rain-fed side streams. These streams have seasonally high discharge variability. And they might have no water in the dry season which is the pre-monsoon time. The variable seasonal rainfall distribution highly influences the availability of domestic water and the growing seasons of Nepal. The settings described in one season could change completely in another season as well as from one year to another. So, if there is sufficient water available for the irrigation, farmers can grow three crops in a year. Unfortunately, farmers in the middle hills do not have a permanent source of water for irrigation and should dependent on rainfall for crops.

Because of this reason the MUS[3] (Multiple Water Use Services/Systems) concept was introduced. IDE/Nepal had worked on connecting farmers with inputs including provision of micro-irrigation technologies, on capacity building on HVC (High value crop) production, and on connection to markets for sale of the products (a value chain approach) but had never involved in developing water sources for farmers before MUS project. Farmers with micro-irrigation technology from IDE/Nepal used the drinking water for irrigation purposes which is limiting as drinking water systems were not designed for providing water for irrigation purposes. So, in 2003, using WATSAN drinking water design program the irrigation system was designed which is based on the idea of gravity-flow domestic water systems in the hills. Then after the concept of hybrid domestic water irrigation system, which not only provides domestic water but also enables the expansion of micro-irrigation technology use and saves precious water collection time that could be used for vegetable cultivation. **(Mikhail, M. & Yoder, R. 2008)**

[3] multiple-use water systems in a general sense, as well as the Multiple-Use Services project funded by the Challenge Program on Food and Water with the International Water Management Institute as the lead and implemented by International Development Enterprises (IDE-Nepal) in Nepal

In a situation when it is possible to use the available irrigation water efficiently without water shortage to the plant, farmers can grow more crops in their land which in turn improves their household and improves the income generation source from the crops grown on their land.

***Soil Analysis***

Three soil samples were collected from the research site i.e. only from the research plot. The soil sample was collected such that represented the two end of the plot and the third one in the middle of the field. The soil sample was sent to the Soil Science Division of Nepal Agricultural Research Council (NARC) for analysis. And it was found the texture of soil is loam with clay=25%, Silt=43% & Sand=32%. And FAO categorized the soil as Medium type with the use of Cropwat Program. The soil is reddish brown in colour. The pH (percentage of Hydrogen) value of soil in the research site was 5.

***Cropping Patterns***

<u>Cropping During the Pre-monsoon Dry Season</u>

This is the hottest season of the year and it is the season prior to the monsoon. It is the dry season. So it is also known as Pre-monsoon dry season. Only a small portion of rainfall occurs in this season. Mostly farmers grow maize in this season when reasonable rain showers occur. The optimal time for maize planting is March and early April. When there are no rain showers, then farmers leave the land fallow. If irrigation is available for bari land, vegetable production becomes possible, extending the cropping intensity of bari land to three crops per year. Cabbage, Cauliflower, garlic, onions, and chili peppers have been taken up as cash crops grown on bari.

<u>Cropping During the Monsoon Rainy Season</u>

Since most of the rainfall occurs in the monsoon season, it is the peak cropping period. Recently the trend has been to use small spring-fed streams as the major sources of irrigation water. Where these are available, they are generally used to grow rice on khet land. The bari fields near the houses in the village are used to grow rain-fed maize intercropped with beans during the monsoon season.

Fruit and vegetable cultivation is traditionally subsistence, with a small percentage of farmers periodically selling a few vegetables in the market. Farmers generally do not irrigate vegetables but simply cast a few seeds near their households and let them grow with minimal cultivation effort.

Cropping During the Post-monsoon Winter Season

Even though only about 5 percent of rainfall occurs in the post-monsoon season, residual moisture from the monsoon period and low evapo-transpiration due to mild temperatures allows farmers to cultivate some crops in this season. While the temperature is optimal for growing wheat, and residual moisture at sowing time is good, lack of rainfall limits the productivity of wheat cultivation. Wheat or mustard were traditionally planted on the bari, but due to a decrease in wheat prices potatoes or garlic/onion crops are gradually replacing wheat in the post-monsoon season.

***Live Stocks***

Most of the households in the villages of the middle hills generally have livestock such as buffaloes, cows, and goats and some villages also raise poultry and pigs.

In this area of Nepal two livestock-feeding systems are used most often: sedentary and stall-fed. In the sedentary system, livestock graze around the perimeter of the village during the day and return to the village in the evening. Livestock is also sometimes grazed away from the village; however, restrictions can limit this (Cooke 2000). Where all land is cultivated, animals are not allowed to graze. Goats are generally kept in the house or in a shed to keep them away from crops during cultivation. So grazing away from the village mainly applies to cattle, buffalo, and goats and includes foraging in the forest and on postharvest cultivated land and fallow land. The animals feed on crop residues from paddy, maize, millet, wheat, mustard, soybean, and vegetables; grasses; and tree fodder from both forest trees and those owned by the farmer (Pariyar, 2007).

Livestock watering in Nepal is considered as part of domestic water allocation; if the domestic water supply is sufficient and nearby, a family will collect water from it for theire livestock. However, the domestic supply is often inadequate for all needs. Usually if an irrigation supply is nearby, households will bring water from the irrigation canal to the animals. If the irrigation supply is further away, families will take their animals to drink from the irrigation canal. If there is no water supply infrastructure, but a stream is available, households will take the livestock to the stream once or twice per day to water. If there is water scarcity and none of the above options are available, households will move the animals to a separate location. In this instance, a small group of families will jointly build a corral for their livestock and have a few boys from the families stay there to take care of the animals (**Mikhail, M. & Yoder, R. 2008**).

### 1.2.4 Problem Statement

The present techniques and technology available for irrigation scheduling are very technical and expensive for the small poor farmers. They even do not meet the philosophy of IDE, (i.e. user-friendly and affordability) who are working for the livelihood development of the smallholder farmers. The available technologies for scheduling are unreachable to the poor farmers. So, there is a need to introduce new affordable software for micro-drip irrigation so that it will be applicable for the extension work and end users (farmers) and also meet IDE philosophy.

With this problem statement, the following research objective and research question were set.

### 1.2.5 Research Objectives

1. To evaluate the applicability of the DPC as an advisory and extension aid for small farmers using drip technology kits from IDE by testing it against field variables e.g. $ET_c$ variations in Nepal.

2 To establish the direct impact of climatic and physical conditions on the DPC design/layout in Nepal.

### 1.2.6 Research Question

How applicable is the Drip Planner Chart in advising and supporting extension work for small micro-drip farmers in scheduling their irrigation in Nepal? How is this applicability impacted by local climatic and physical conditions facing small farmers in Nepal?

### 1.2.7 Sub-Questions

1. How relevant and dependable is the advice from the DPC for irrigation scheduling and for the smallholder farmers in Nepal?
2. What are the current Irrigation Practices in the research area?
3. How do soil-water conditions correlate with the DPC advice?
4. What are the impacts of local climatic and physical conditions on the design of the DPC?
5. What is the applicability of an adjusted DPC from a different climate to the research area and to the farmers?
6. What are the limitations of the DPC from technical and the users' point of view?
7. Which scheduling tools are currently in use by farmers in the research site? How comparable (in terms of simplicity, understandability, efficiency, workability) is the DPC to those tools?
8. What are the difficulties to adopt the technology at field level?
9. What are the perceptions of the farmers' on a new scheduling technology?

10. What will be the impacts (i.e. in terms of ease, accessibility, usability) on micro-drip technology when a new irrigation scheduling tool, like the DPC, in the research area is introduced?

# 2. METHODOLOGY

This chapter explains about methodology and data generation techniques that helped in gathering the required information.

## 2.1 Field Trials

The field trials involved the plot size design with a view to ensure the random selection of the treatments in all the replications. This included a randomize selection of treatments in each replication. Significance of the field trial was generated by using a statistical tool called The Analysis of Variance (ANOVA) using “GenStat” program. The tool is used to see the variation in the treatments to know about the significance of using different treatments. The procedure in the field trial is described in detail below:

### 2.1.1 Treatment and Replication

Four treatments were generated for the research trial to see the effects of different water allocation from the initial stage up to the harvest stage of the crop. For this research, cabbage was selected. Four treatments are listed below:

T1 = Farmers Practices’
T2 = IDE Approach/Recommended
T3 = Daily Scheduling Irrigation according to DPC (Daily DPC)
T4 = Interval Scheduling Irrigation according to DPC (Intv. DPC)

Note: T= Treatment and it indicates the different amount of water allocated using drip system. In an ideal case, the amount of water application in T1 & T2 should be the same. But in the ground, the amount of water applied by farmers is different from the IDE recommendation.

The crops life is divided in to four stages. These stages are initial stage, Developmental stage, Mid growth stage, and Harvesting stage.

Five replications were formulated for ease statistical analysis of the research.

Justification of the Treatments and Replications

IDE/Nepal is working on Drip Irrigation for many years already. To ease the farmers' life, IDE/Nepal calculated the amount of water required for their drip kits. The recommended amount of water for a very small drip kit (kit size of 80 $m^2$) plot is shown in table 3 below. So, it was necessary to create IDE recommendation as a treatment against DPC.

**Table 3 Recommended amount of water for small drip kit of 80 $m^2$ available (4 lateral lines each with 20 emitters)**

| Season | Month | Water(lt) | Volume (No. of Tanks)* |
|---|---|---|---|
| **WINTER** Planting: Oct Harvesting: Jan | Oct | 100 | 2 |
| | Nov | 150 | 3 |
| | Dec | 200 | 4 |
| | Jan | 150 | 3 |
| **SPRING** Planting: Feb Harvesting: Apr | Feb | 100 | 2 |
| | Mar | 300 | 6 |
| | Apr | 250 | 5 |

*** 50 litre tanks**
**(Source: IDE, Nepal)**

Most of the time Farmers' irrigation practices do not meet the right amount of water to the crops at different stages. Either under-application or over-application is common, and this might have negative effects i.e. reduction in the yield and waste of water. So, it was very important to closely look at the farmers approach, but at the same time it was essential to monitor and adopt the farmers approach as a treatment in the research. I incorporated the farmers approach as a treatment against DPC in my research.

To minimize the error during the statistical analysis, 4 treatments and 5 replications were established.

### 2.1.2 Plot Size Design

A plot of approximately ½ ropani[4] (250 $m^2$) was leased for the research work at Chapagaon, Lalitpur. In the research plot, 80 $m^2$ drip kit was customized to fit the required design for the research work. Three 100 litres tanks, each serving two blocks, were used as a water distribution tank. One 500 litres tank was used as a reserve tank. The plot design, position of 500 litres reserve tank and three 100 litres distribution tanks is depicted in Figure 11 and 12 below.


**Figure 11: Water Distribution through the water tanks**

[4] 1 ropani = 500 m2


**Figure 12: Field Trial showing the setup of the drip system.**

The dimension of each block is 4 X 6.5m. Each block comprised 4 laterals of 6 m long. The spacing is maintained at 1 m between the laterals. But the drip kits available in Nepal have 12 m long laterals and the space between the laterals is maintained at 1.5 m. There is a valve to control water in each lateral. YR variety of cabbage was planted on 11th February 2009 for the field research trial.

Randomized Complete Block Design (RCBD) was used to avoid experimental bias. The block design of the field trial is shown in Table 4 and appendix 3.

**Table 4: Block/Plot Design using RCBD**

| Research Site: Tahakhel, WN 6, Chapagaon, Lalitpur | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Block 1** | | | | **Block 2** | | | |
| T1 R1 | T2 R1 | T3 R1 | T4R1 | T2 R2 | T4 R2 | T3 R2 | T1 R2 |
| **Block 3: Destruction Plot**** | | | | **Block 4** | | | |
| T1 | T2 | T3 | T4 | T3 R3 | T2 R3 | T1 R3 | T4 R3 |
| **Block 5** | | | | **Block 6** | | | |
| T2 R4 | T3 R4 | T4 R4 | T1 R4 | T4 R5 | T1 R5 | T2 R5 | T3 R5 |

*: T = Treatment; R = Replication

**: It is not actually a replication. It is just developed to see the different parameters like wetting pattern, rooting depth, etcetera without destroying other experimental blocks/plots.

### 2.1.3 Analysis of Variance (ANOVA)

The statistical software, *GeneStat* was used for the ANOVA. One way Analysis of variance was conducted to analyze the yield of the crop form the research trial.

**Table 5: ANOVA for RCBD design proposed for research work**

| SOV | Df | SS | MS | F |
|---|---|---|---|---|
| Rep | (r-1)= **4** | $\sum(Y^2_j/t)-CF$ | $Rep_{SS}/4$ | $Rep_{MS}/Error_{MS}$ |
| Trt | (t-1)= **3** | $\sum(Y^2_i/r)-CF$ | $Trt_{SS}/2$ | $Trt_{MS}/Error_{MS}$ |
| Error | (r-1)(t-1)= **12** | $Err_{SS}= (Total_{SS}–Rep_{SS}–Trt_{SS})$ | $Err_{SS}/8$ | |
| Total | (tr-1)= **19** | $\sum Y^2_{ij}-CF$ | | |

**(Source: RCBD, 2009)**

The degree of freedom on the Error for the RCBD design is **12**. For RCBD evaluation it is necessary that;

- Each replicate is randomized separately.
- Each treatment has the same probability of being assigned to a given experimental unit within each replicate.
- Each treatment must appear at least once per replicate.

Conclusions will be drawn on the work using statistical analysis software i.e. *GeneStat*.

## 2.2 Amount of Water Applied

The amount of Water applied at different time in different stages of the cabbage for all the treatments is tabulated in Table 6. The water calculation, for all treatments, was made based on the smallest drip kit size available in Nepal. The smallest drip kit size available in Nepal is for 80 $m^2$ plot. It consists of 12 m long 4 laterals and each lateral have 20 emitters. It serves 80 plants at a time.

**Table 6: Amount of water applied in 80 $m^2$ plot (for 80 plants) in different treatments**

| Month | Stages | Farmers' Practice | Daily DPC | IDE recommended | Intv DPC | |
|---|---|---|---|---|---|---|
| | | | | | Amount | Interval (days) |
| **Feb** | **Initial** | 50 | 25 | 100 | 25 | 1 |
| **March** | **Initial** | 50 | 30 | 100 | 30 | 1 |
| | **Dev** | 50 | 45 | 100 | 200 | 4 |
| | **Mid** | 80 | 65 | 300 | 400 | 4 |
| **April** | **Mid** | 80 | 85 | 250 | 400 | 3 |
| **May** | **Mid** | 80 | 85 | 250 | 400 | 3 |
| | **Late** | 80 | 85 | 250 | 400 | 3 |

* - same amount of water applied as in Daily DPC

The calculation procedure for the amount of water applied for all treatments are elaborated below

### 2.2.1 Amount of water applied in Farmers' Practices

An interview with few farmers nearby the research site and analyzing the data provided by the farmers, the amount of water allocated was determined. The detail about water allocation in farmers' practice is discussed in the sub-title "Interview with individual farmers".

### 2.2.2 Amount of water applied according to IDE recommendation

The calculation procedure/steps of amount of water recommended by IDE is elaborated in Table 7:

**Table 7: Calculation procedure of CWR used by IDE**

| | |
|---|---|
| Months | |
| Pot Evapotranspitation, ETo, mm/day | |
| Growth Stage | |
| Crop Coefficient, Kc | |
| Crop Evapotranspitation, ETc, mm/day | **ETc = Kc * ETo** |
| Ground Coverage Factor, Kr | |
| Crop Evapotranspitation, ETf, mm/day | **ETf = Kr * Etc** |
| Crop Evapotranspitation, ETc, mm/month | **ETc = ETf * 30** |
| 80 % Reliable Rainfall, Pe mm/month | |
| Effective Rainfall, Peff, mm/month | **P eff = Pe * f** |
| Irrigation need mm/ month, Im | **Irrigation need mm/month = ETc (mm/month) - P eff** |
| Net Irrigation need mm/ day | **Net Irrigation = Irrigation needed (mm/month)/30** |
| Gross Irrigation need mm/ day | **Gross Irrigation= Net irrigation/application efficiency** |
| Daily water Requirement/Ropani, Wg, Ltr. | **Daily water requirement per ropani (Wg)= gross irrigation * 500** |
| Gross Water Req. neglecting rainfall, mm/day | **Gross Water Req. neglecting rainfall (mm/day) = ETf/0.85** |
| Daily Water Req. negleting rainfall Wg1 Ltr. | **Daily water requirement neglecting rainfall per ropani (Wg1)= gross irrigation neglecting rainfall * 500** |
| Daily Water Req. in average condition, Wg2, Ltr. | **Daily water Req. in average condition = (Wg + Wg1)/2** |

**Note:**

**Effective Rainfall, Peff= Pe X f f= 0 if Pe< 5 mm/month**

**f= 0.85 if Pe= 5-100 mm/month**

**f= 0.70 if Pe>100 mm/month**

**Gross Irrigation Need = Net irrigation / 0.80 (Assuming the application efficiency of Drip systems as 80 %)**

### 2.2.3 Amount of water applied by Drip Planner Chart

i. Daily DPC

The major part of crop water consumption is returned to the atmosphere by evapotraspiration and just a small portion is used for photosynthesis. Therefore, plant evapotraspiration is the basis for a crop water requirement estimation. Crop evapotraspiration depends on ETo and the Crop Coefficient (Kc)

$$ETc = Kc \times ETo \text{ ……………………………………………………… (i)}$$

Where,

ETo = Reference Evapotraspiration (Table 8 shows the value of ETo of Khumaltar weather station)

Kc = Crop Coefficient (Kc values change within different crop growing stages). The Kc values for cabbage and other important cash crops are given in Table 9 below .

**Table 8: ETo value from Hydrology and Meteorology station at Khumaltar, Lalitpur**

| **Month** | **ETo value** |
|---|---|
| | **Climwat (Khumaltar Hydrology & Meteorology Station)*** |
| January | 1.80 |
| February | 2.40 |
| March | 3.30 |
| April | 4.30 |
| May | 4.60 |
| June | 3.90 |
| July | 3.60 |
| August | 3.40 |
| September | 3.30 |
| October | 3.00 |
| November | 2.30 |
| December | 1.80 |

Source: CLIMWAT Database

*: Meteorology and Hydrology Station at Khumaltar, Lalitpur nearby the Research Site

**Table 9: Kc Values of different crops at different Stages (Pereira *et al*., 1998)**

| **Crops** | **Kc values for different stages** | | | | **Remarks** |
|---|---|---|---|---|---|
| | **Initial** | **Developmental** | **Mid** | **Late** | |
| Cabbage ** | 0.7 | 0.85 | 1.05 | 0.95 | 90 days variety |
| Tomato | 0.6 | 0.87 | 1.15* | 0.70-0.90 | |
| Cauliflower | 0.7 | 0.85 | 1.05 | 0.95 | |
| Pumpkin | 0.5 | 0.75 | 1 | 0.8 | |
| Cucumber | 0.5 | 0.75 | 1* | 0.8 | |
| | | | | | |

**(Source: FAO 56 paper)**

***** Beans, Peas, Legumes, Tomatoes, Peppers and Cucumbers are sometimes grown on stalks reaching 1.5 to 2 meters in height. In such cases, increased Kc values need to be taken. For green beans, peppers and cucumbers, 1.15 can be taken, and for tomatoes, dry beans and peas, 1.20. Under these conditions h should be increased also.

- Initial stage which refers to crop germination to the almost 10% crop cover in the field.
- Crop development stage which, starts after initial stage to the point of attainment of full ground cover. The Kc-values of this period were extrapolated using the Kc-values of initial and mid growth stages. Extrapolation was dependent on the number of days of the stage per crop.
- Mid season stage which is from attainment of effective ground cover to maturity and
- Late season stage from maturity to harvest.

So, the Crop Water Requirement (CWR) is

CWR = Kc * ETo/AE …………………………………………… (ii)

Where, AE = Application Efficiency = 80% (assumption made for drip irrigation)

For the research Cabbage was chosen. The growth length is different for different varieties. So the growth length of the YR variety of cabbage for different stages is shown in Table 10 below:

**Table 10: Length of Crop Developmental stages**

| Crop | Crop Length (days) | | | | Total days |
|---|---|---|---|---|---|
| | Initial | Developmental | Mid | Late | |
| Cabbage | 15 | 20 | 40 | 15 | 90 |
| Day | 19th feb- 5th March | 6th -25th March | 26th March – 5th May | 6th – 20th May | |

**(Source: FAO 56 report)**

Other corrections used in case of daily DPC treatment:

1. Wetting fraction (fw): part of ground wetted by irrigation. It is used only in the initial stage of the crop. fw= 0.45 for drip system.
2. Ground coverage factor (Kr): used from the developmental stage only.
3. Percentage correction: A percentage correction of 70% was used from the mid growth stage of a crop

Adjusted water allocation by DPC

In the initial stage, Water allocation =Kc * (ETo*fw)/AE

Water allocation in other stages = (Kc * ETo * Kr * percentage factor)/AE

(Percentage correction of 70% was used in the mid and late season growth stage)

ii. DPC Interval application (Intv. DPC)

1. Crop selection from one wheel of the Drip Planner chart (for the research I chose Cabbage)
2. Selection of the maximum irrigation gift (F) in l/m2 from the second wheel with reference to the rooting depth and % wetted area (P).
3. CWR is gained from the first wheel with reference to the ETo value of the area for specific month and the growth stages.
4. Maximum Allowable interval (days), G= F/CWR. (The interval is taken just smaller than the G to avoid leaching of water out of the root zone. If G=3.4, the interval is chosen 3 days.)

### 2.3 Measurements

**Yield measurement**

The cabbages were not ready at the same time. As such, the harvest was done in two phases. First harvest was done on 13th of May and second on 23rd of May 2009. Figure 13(a) showed the involved IDE staff and farmers during the harvest time for weighing and recording data & figure 13(b) showed the harvested crop ready for packing and to be taken to the market.

**Soil Moisture Measurement & Sensor Set-up**

Data from the Data logger which record the soil matric potential via water mark sensor was recorded every day. Daily observation was done to monitor the situation of the water availability for the plants. It measures data in centi-bar (cb).

Figure 13(a)

Figure 13(b)

**Figure 13 Snap shot during the harvesting time (a) IDE staffs and farmer busy harvesting and weighing the harvested cabbage. (b) The harvested cabbage ready to take to the market**

Each data logger records reading for 6 sensors. Altogether there were 4 data logger with 24 sensors. 20 sensors were installed at 20cm depth (one in each treatments of all block) and rest 4 in 40 centimetre depth in one block. During the installation of sensors, it was made sure that they were not placed directly under the dripper. This helped to avoid distorted reading.

**Other Measurements:**

In all treatments of the entire block, plant height and number of leaves were recorded for randomly selected plants on a weekly basis.

## 2.5 Secondary Data Collection

1. Rainfall data from Department of Hydrology and Meteorology was collected The data were then proceeded for analysis.

2. The Potential Evapotraspiration value (ETo) was obtained from CLIMWAT database. The present reference evapotraspiration data could not be obtained from the meteorology station because it was not available for the research period due to the unavailability of Pan Evaporation Data from the research station. The long year average data was supposed to be the most reliable alternative source to use. For the research, the ETo value of Khumaltar Meteorology Station was taken and the values are shown in Table 4 above.

## 2.6 Plant Protection

The pesticides, fertilizers, vitamins, enzymes, and different measures for soil treatment were applied during the research. List of the chemical used during the research is shown in Appendix 4

## 2.7 Interview with IDE-Farmers

A number of structured and unstructured interviews were conducted with IDE farmers in two districts (one in research area .i.e. Lalitpur district and another in nearby district named Kavre). Unstructured interviews were conducted among field staffs (extension workers) of IDE/N. This interview was carried out to understand the farmers' current irrigation practices before the actual research started. This helped me understand the amount of water they were applying and the frequency of irrigation. This helped me formulating a treatment "Farmers' Practice".

A few IDE-farmers were chosen for the interview. Refer to Appendix 5 for a more detailed questionnaire. Interviews with farmers and field observations showed that most of the farmers used drip kit size of 80 $m^2$ with 4 laterals. Based on this drip kit size, I calculated the amount of water applied by the farmers on the crop.

**Figure 14: Interviewing IDE-farmer (Indira Pudasainy) regarding the water allocation.**

## 2.8 Focus Group Discussions (FGDs)

A focus group discussion is a technique to assess the user's needs and feelings before and after the project implementation (Nielsen, 1997).

The FGDs included some members of the women group committee and some male farmers in the village. The group of 4-6 farmers were gathered for the FGD. Two FGD were conducted in two different districts. First FGD was held on 19th of May 2009 at branch office of District Agriculture Development Office (DADO) in Lele, Lalitpur. And Second FGD was held in Panitanki, WN 2, Kavrepalanchowk District in 22nd of May 2009 in the farmers house as shown in Figure 15(a) & 15(b) respectively. The questionnaire for FGDs is presented in Appendix 6

Figure 15(a) Figure 15(b)

**Figure 15 Focus Group Discussion (a) At Lele, Lalitpur District (b) At Panitanki, Dhulikhel, Kavre District**

The rationale of FGD was to understand their knowledge on drip system, situation analysis of before and after introduction of the Drip system. Moreover, FGD was conducted to introduce and to know their view about the Drip Planner Chart at a glimpse.

The purpose of the meeting was to explain the intention of my research to the farmers. Moreover, the meeting helped to introduce the DPC to the farmers and give an abbreviated explanation of its background and its uses. During this introduction, the floor was open to the farmers to raise their queries so as to give better clarity on the chart.

# 3. DATA ANALYSIS AND RESULTS

## 3.1 Crop Measurements:

### Yield:

Figure 16 below provides the information of the maximum total yield, minimum total Yield and average yield for all the treatments. The detail information of the total yield for different treatments in each replication is shown in appendix 7.

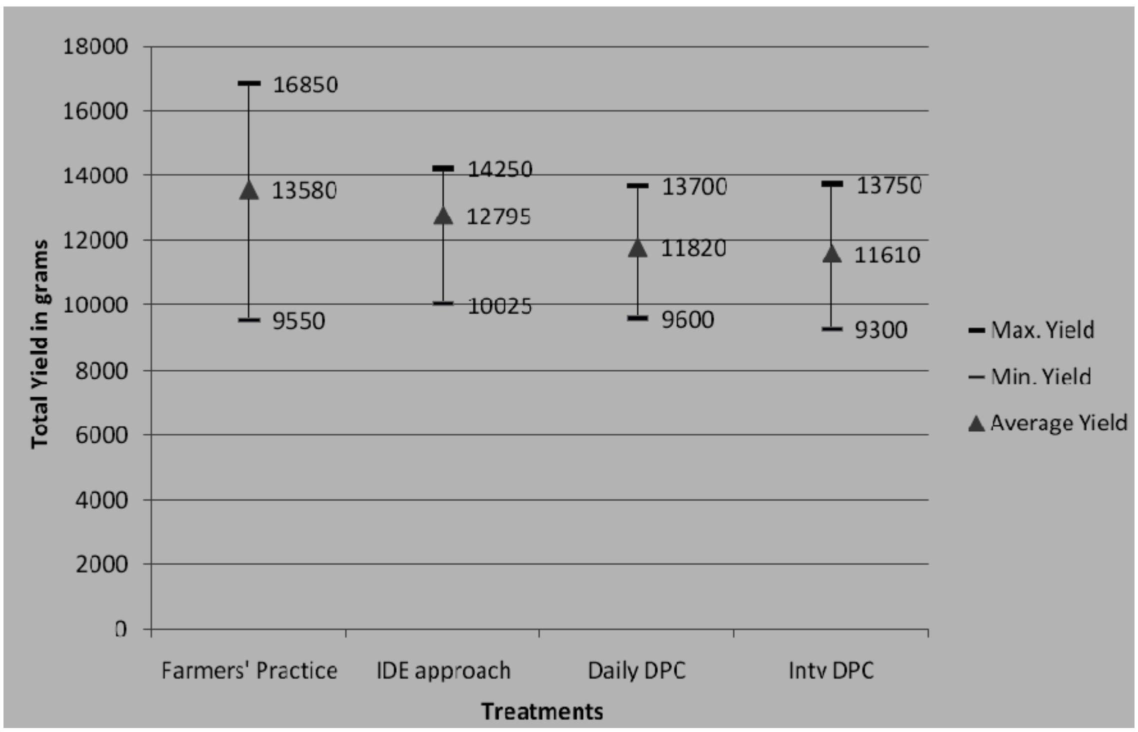



**Figure 16: Maximum, Minimum and Average yield of Cabbage**

The average head weight of the cabbage for different treatments is shown in figure 17 below. It is the average of all the cabbages head for each treatment.

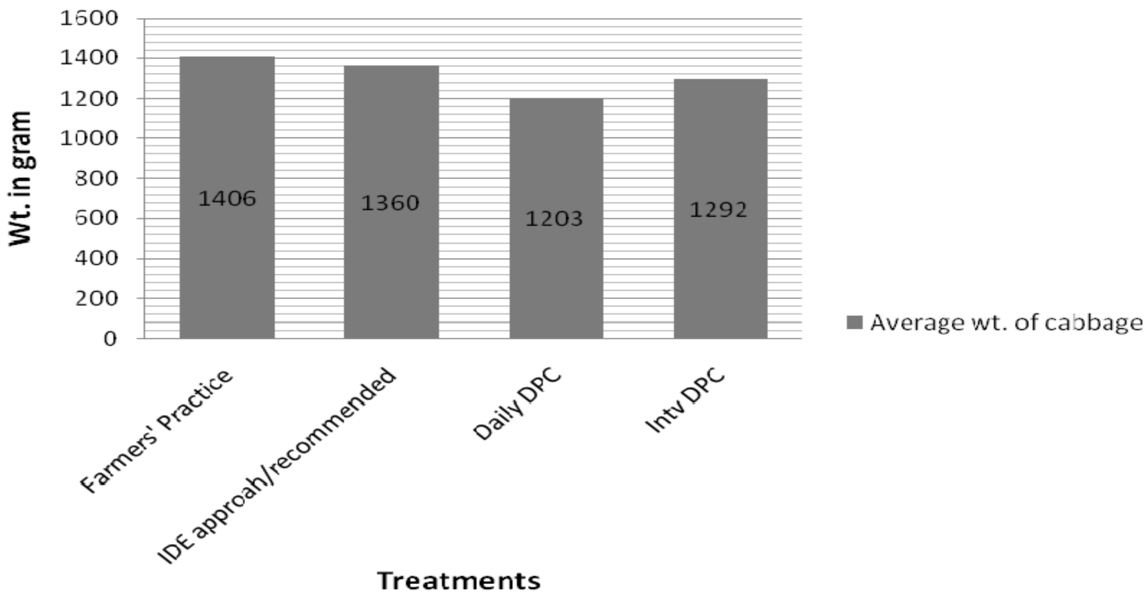



**Figure 17: Average weight of the head for all Treatments**

## 3.2 Statistical Analysis: Analysis of Variance (ANOVA)

An alpha level of 0.05 was used for all statistical tests (i.e. 95 % level of confidence). The one way ANOVA for Average head weight, average total yield and Harvest Index[5] (HI) was preceded using *GenStat*. The result is published in Table 11 below:

[5] It is the ratio of economic yield (i.e. wt. of head) and total plant yield (wt. of head, leaf, stem and root) in case of cabbage (http://www.dawn.com/2007/10/01/ebr6.htm)

**Table 11: Result from one way ANOVA for Avg. head wt., Avg. total yield & HI of cabbage**

| Treatment | Mean | | |
|---|---|---|---|
| | **Avg Head wt. (g)** | **Avg. total yield (g)** | **Harvest Index (HI)** |
| Farmers' Practice | 1406 $^{ns}$ | 13580 $^{ns}$ | 0.568 $^{ns}$ |
| IDE approach/recommended | 1360 $^{ns}$ | 12795 $^{ns}$ | 0.553 $^{ns}$ |
| Daily DPC | 1203 $^{ns}$ | 11820 $^{ns}$ | 0.537 $^{ns}$ |
| Intv DPC | 1292 $^{ns}$ | 11610 $^{ns}$ | 0.557 $^{ns}$ |
| | p = 0.267<br>l.s.d = 219.5<br>cv = 12.4 % | p = 0.469<br>l.s.d = 2904.3<br>cv = 17.4 % | p = 0.466<br>l.s.d = 0.04034<br>cv = 5.4 % |

$^{ns}$*-non-significant*

**Note: Harvest Index for cabbage and other brassica crops have normally range of 40-60 %.**

- The analysis for Average Head weight in all treatments is not significant, $F(3,16) = 1.44$, *p(0.267)>0.05*
- The analysis for Average total yield in all treatments is not significant, $F(3,16) = 0.89$, *p(0.467)>0.05*
- The analysis for harvest index in all treatments is not significant, $F(3,16) = 0.89$, *p(0.466)>0.05*

The result showed the non-significant variation in economic yield of the cabbage in all treatments. The different amount of water application in 4 treatments does not result to the significant difference in yield at 95 % level of confidence. The details of the calculation are shown in Appendix 8

The analysis of the variance (one-way) showed the coefficient of variance (cv) for average head weight, average total yield and harvest index is within the limit for field trial type research in the external environment.

### 3.3 Soil-moisture Measurement:

Figure 18, 19 & 20 shows the soil moisture conditions in Developmental Stage, Mid growth stage and Harvest (late season) stage respectively. The data-logger record the soil matric potential values in centibar (1cb=1kpa) with the help of watermark sensors installed in the soil. The values are the average values from the 5 sensors set in 5 replications of each treatment.

In the case of Intv. DPC, the interval between the irrigation turns was different in different stages. In developmental stage, a 4 days interval irrigation was applied and in Mid stage and late season, a 3 days of interval between the irrigation turns. The matric potential values (from the datalogger) from all the sensors are shown in Appendix 9.

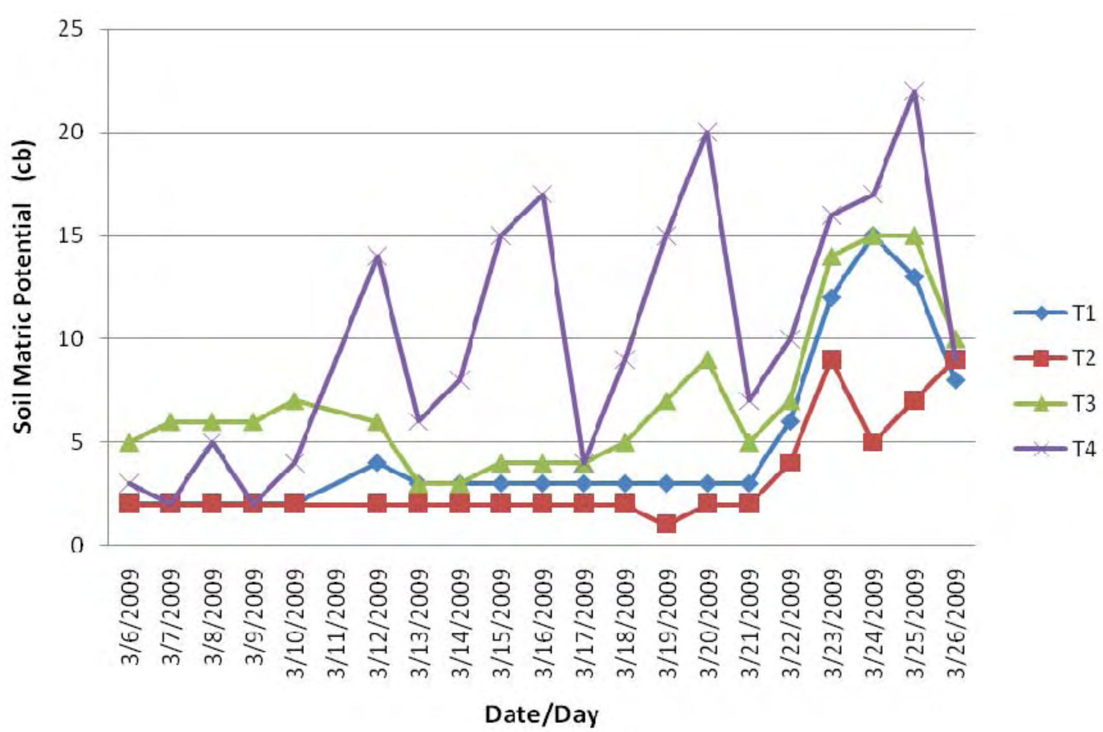



**Figure 18: Average Soil matric potential (cb) for different treatment in developmental Stage. These are the average values from all 5 replications for each treatment.**

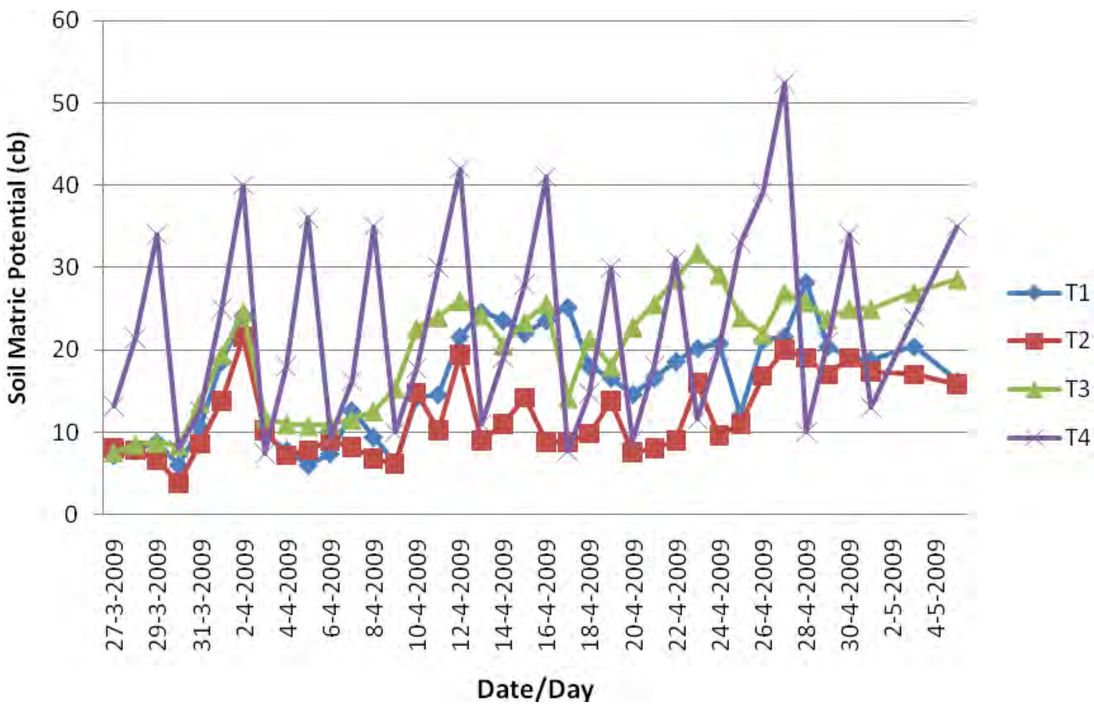



**Figure 19: Average Soil matric potential (cb) for different treatment in Mid-growth Stage. These are the average values from all 5 replications for each treatment.**

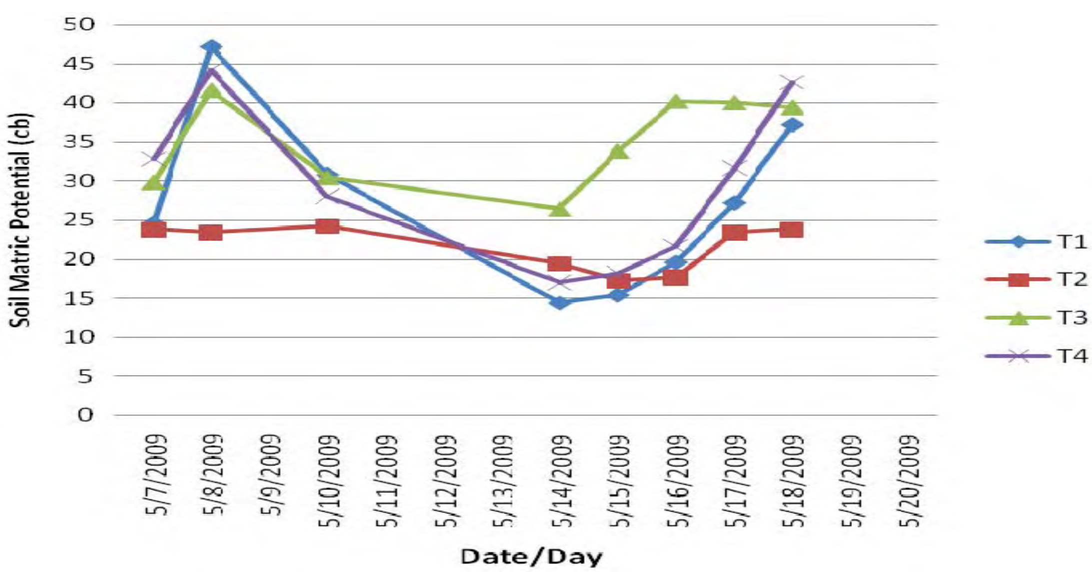



**Figure 20: Chart Average Soil matric potential (cb) for different treatment in Late Season Stage. These are the average values from all 5 replications for each treatment.**

### 3.4 Total amount of Water Applied in whole crop period:

The total amount of water applied during the whole crop season is shown in the Table 12. The table also showed the total amount of water irrigated in four crop growth stages for all the treatments. And it make easier to compare all the treatments at once.

**Table 12: Total amount of water required for 80 $m^2$ drip kits with 80 plants**

| Stages | Amount of water in diff treatments (ltr.) | | | |
|---|---|---|---|---|
| | **Farmers' Practice** | **Daily DPC** | **IDE** | **Intv DPC** |
| **Initial** | 750 | 400 | 1,500 | 400* |
| **Dev** | 1,000 | 900 | 2,000 | 1,000 |
| **Mid** | 3,200 | 3,300 | 10,250 | 4,200 |
| **Late** | 1,200 | 1,275 | 3,750 | 1,500 |
| **Grand Total** | **6,150** | **5,875** | **17,500** | **7,100** |

***The same amount of water as in Daily DPC as the interval seems not feasible in the initial stage (the interval was around 7 days and plant cannot cope such situation)**

### 3.5 Other Parameter:

**i. Leaf**:

Figure 21 shows the graph of number of average leaves in all treatments at certain time interval. Observations or counts of leaves made every two weeks are shown in the graph below. These values obtained for the number of leaves for each treatment are the average numbers of all the randomly selected plant from all the replications.

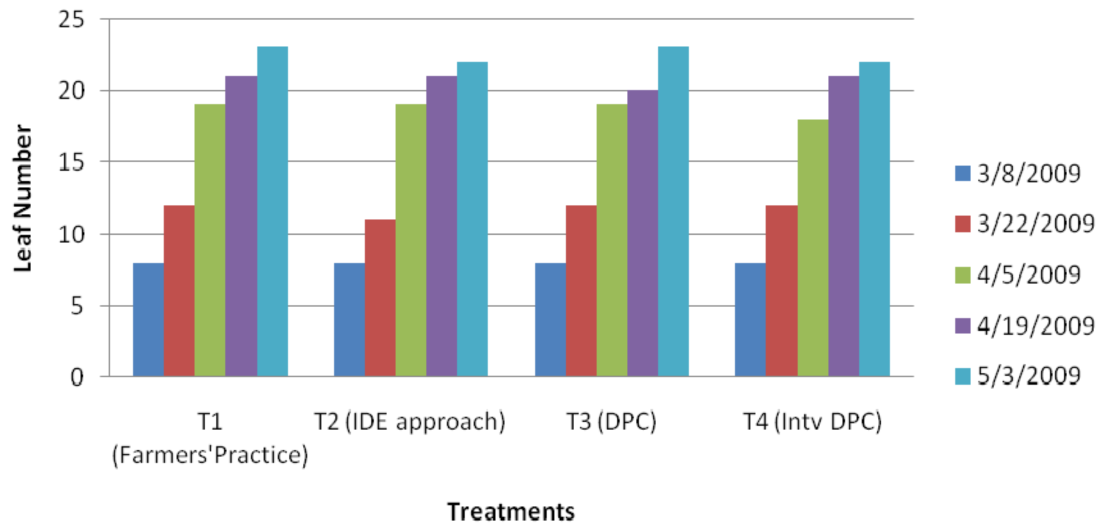



**Figure 21: Biweekly record of Average Number of leaves for all treatments.**

**ii. Plant Height**

Figure 22 shows the chart of plant height of all treatments at certain time intervals. Observations made in every two weeks are shown in the chart below. These values obtained for the Plant Height for all treatments are the average values of all the randomly observed plant from all the replications.

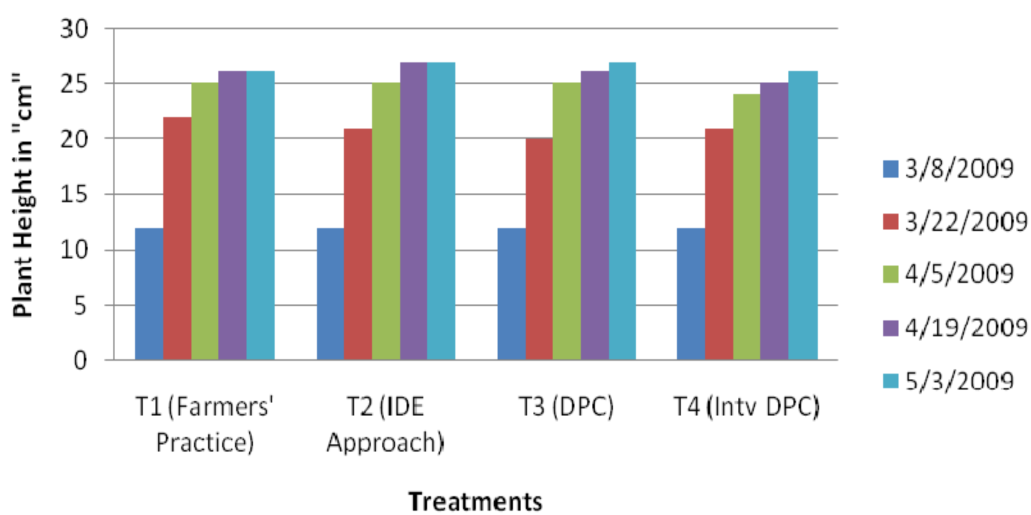



**Figure 22: Biweekly record of Average plant height for all treatments.**

### 3.6 Interview and FGDs’

**Findings from Interviews**

Interview with Jay Ram Basnet, an innovative IDE- farmer, was fruitful. He has an enduring experience with water application. According to him, the only sources of water during dry period are the springs. And he also added there is no possibility of using ground water in the area. In his case, he uses 50 litres (with the drum of 50 litres size available with the smallest drip kits) of water in the evening everyday until the plant reaches its maturity stage. Once the plant is in maturity stage, he applies about 1 litre of water per plant. I was curious to know how he knows about the amount of water he needs to apply per plant a day. Then he said he cannot say that whether each plant is getting exactly the same amount of water (i.e. 1 litre of water each day). But he said it was by his experience. He used to apply water from a drum of a known capacity and this helped him to know the amount of water that is applied to the total number of plants. My analysis was, if they have sufficient water available they will obviously apply more water. Due to scarcity of water in the dry period, they are forced to use less water than their will.

Ghana Shyam Pudasainy, Indira Pudasainy and Nakul Basnet shared a similar idea about the water allocation. According to them, IDE field staff suggested them to irrigate daily. But due to scarcity of water, they irrigates only 3/4 times a week. Sometimes they irrigate daily and sometimes it is not possible. They have no fix schedule for irrigation. They use tap water to irrigate their crop. The source of tap water is the spring. They simply connect the tap to the water drip system tank for about 40/45 minutes for the very small drip kits (i.e. 80 $m^2$ drip kits with 80 plants). The discharge of the tap (at the time of interview) ranged from 2.5 to 3 litre per minute (lpm), making an average of around 2.75 lpm. It came about 55 litres of water for 4 line 80 $m^2$ drip kit. But the discharge is not always the same and it fluctuates frequently. They also highlighted the fact that they change the amount of water once the plant is in the maturity stage. But they could not figure out the duration of irrigation and the amount of water allocation in each irrigation turn.

**Findings from Focus Group Discussion**

The key points that come up in the discussion upon the limitations that farmer faced while irrigating their crops

- Most of the farmers are illiterate. Their remark was how they, as an illiterate people, could understand the chart.
- The DPC allocates a certain amount of water. But farmers have a fixed sized water tank for their drip kits. So, they were confused how it could be possible to measure the water allocated by DPC without graduation of the water tanks.
- Mostly, women are the one who spent most of their time in agriculture and household stuff. So, this was the question arise by the women group of the community. How can this chart/scheduling tool be good for them? How can it save time and labour requirement and women drudgery?

# 4. DISCUSSIONS

## 4.1 Corrections used to adjust present Drip Planner Chart (DPC)

Some of the corrections used in different growth stages of the crop are listed in the table 13 below.

**Table 13 Corrections made in different crop growth stages during the research**

| Correction | Crop Growth Stages | | | | Remarks |
|---|---|---|---|---|---|
| | Initail | Dev. | Mid | Late | |
| **Application Efficiency (AE)** | √ | √ | √ | √ | 80% |
| **Wetted fraction (fw)** | √ | | | | 0.45 |
| **Ground Coverage factor (Kr)** | | √ (0.45) | √ (0.75) | √ (0.75) | * |
| **Percentage correction** | | | √ | √ | 70% |

* The source for Kr values is Boesveld, 2008. If ground cover< 25%, Kr is 0.2; ground cover 25-50%, Kr is 0.45; ground cover 50-75%, Kr is 0.75; ground cover 75-100%, Kr is 1.

## 4.2 Reflection on Soil Matric Potential Values:

During the initial stage, the soil matric potential values were strange. All the readings of the sensors were within the range of 0-3 centibars (cb). Even though correction factor "fw" was used during the initial stage, the soil matric potential values remained low.Seeing this, it was assumed that something had gone wrong and the sensors were reinstalled. After this was done, it was found that there were no mistakes in the previous sensors installation. The values remained the same even after the re-installation. One of the possible causes for the recorded strange values could be the position of the sensors. During the initial stage, the sensors were far below the root of the plants as the sensors were installed at a depth of 20 cm. So these values might not be representative enough.

Even during the developmental stage the values that were recorded were strange. In the developmental stage, a ground coverage factor (Kr) was used. Despite the correction, the average soil matric potential for all the treatments except the Intv. DPC was below 10 cb.

This indicated that the soil was in a saturated state. The same reading went up to the three quarter of the developmental stage. Then after the fourth quarter the value started to increase. However, the average matric potential for treatment “IDE recommended” remained below 10 cb. This implies that more than the required amount of water was applied during the initial and developmental stages.

In the beginning of the mid growth stage, the average soil matric potential values for Daily DPC was below 20 cb. The “Percentage Correction” was made to adjust the average soil matric potential values. During percentage correction, it was assumed that the 70 % of total amount of water calculated by DPC would be enough. Then I decreased the value to 60%. But the plants started showing symptoms of stress with 60% percentage correction. This made me continue with the 70% percentage correction for the rest of the mid and the late season growth stages. This brought improvement in the average soil matric potential as shown in figure 19. The values remained below the limit i.e. 34 cb before next irrigation turn.

The case of Intv. DPC is different. The soil matric potential value for this treatment showed that the plant was water stressed before next irrigation turn.

## 4.3 Logic of Sensors Placement

The sensors were placed further away from the point where water drops from the emitters and were kept in the effective root zone. The logic was to minimize the error that could have occurred by the direct flow of water from the emitter to the sensor. Moreover, this was to create a representative picture of soil water status in the root zone. The surrounding of the sensors that were installed was also checked to make sure that no obstructions would occur with the representative flow of water to the root zone.

The placement of the sensors at 40 cm depth seemed to be unrealistic. By checking the intensity of root in the root zone, it was found that the root intensity was high up to the depth of 25-30 cm and beyond that the only root that was found is the tap root. During the developmental and mid growth stages, the intensity of root was checked in a destruction plot.

### 4.4 Amount of Water Applied in different treatments

Two treatments Daily DPC and Intv DPC were developed from Drip Planner Chart. But the total amount of water allocated in these treatments was different at the end. The reason why more water was allocated in Intv. DPC was made due to the calculation of irrigation interval. Intv. DPC recommend to use the number before decimal only. For Example, if the calculated irrigation interval is 3.5, it recommends the interval of 3 days and ignores the number after the decimal. So, more water allocation was obvious.

The amount of water recommended by IDE is very high compared to other treatments. The amount allocated is about three times than the water allocated in Daily DPC treatment. The water calculation procedure for IDE approach includes all the parameters such as crop coefficient (Kc) values, ground coverage (Kr) factor, & effective rainfall. But when it comes to the ground, due to the customized drip kits, the amount of water that IDE/N recommended appeared to be very high compare to other treatments. The customized drip kits have a lateral spacing of 1.5 m. The same drip kits were used for many cash crops such as cabbage, cauliflower, tomato, cucumber. The row to row and crop to crop distant that should be maintained varies with crop types. For cabbage the lateral spacing of drip kit is large. The row to row and crop to crop distant for cabbage should both be 60 cm. However, with the present drip kit the row to row and crop to crop distant was 60 and 150 cm respectively. Due to this spacing the amount of water calculated was more than the actual requirement.

The grand total water allocation in Farmers' Practice and Daily DPC is almost the same. The water allocation for farmers' practice was made possible by interviewing few farmers using drip systems around the research area. And after focus group discussions with farmers in another district, the question arose of the relevancy of farmers Practice that was created as a treatment for the research. Then a question arose if there is a sole farmers' practice for water allocation or not? After interviews with farmers in another district known as Kavre, I saw diversity of water application by farmers. The mid hill farmers from Kavre district do not face such water scarcity than the farmers from Lalitpur. They do not have any information about how much water they apply for their crops. But they revealed that they irrigate everyday (whereas farmer in Lalitpur district rarely do that). At the same time the irrigation duration was comparatively more than the farmers from Lalitpur district. So, this showed the farmers have intention to irrigate more if they have sufficient water available. I could not measure the water that was discharged from the tap (as farmers use tap water for irrigating their crops using drip system). But the way they irrigate their crops definitely said, Farmers in Kavre district irrigate comparatively more water than the farmers in Lalitpur district.

The statistical analysis showed no significant difference in yield at 95% level of confidence. So looking at the water saving perspective, with DPC recommendation water saving is lot compare to IDE/N recommendation without any significant difference in yield. If we say the water allocated for DPC is 100% then water allocated for IDE/N approach is about 300%.

### 4.5 Accuracy and Simplicity of DPC

There has always been a conflict between in the usage of the terms accuracy and simplicity. The more the accuracy of the technology, higher is the complexity and the cost. There should be a negotiation between these two terms, which will automatically reduce the accuracy of DPC. However, it should meet at some negotiation point.

### 4.6 Selection of Research Site

The selection of the research site is an important issue for this kind of research where one has to use the climate data directly from the weather stations. The local climatic condition of the research area may differ from the climatic condition where the weather station is situated. The case can worsen if the research area is located further away from the weather station. I was confused whether to use the representative data from the nearest weather station or from the IWMI weather site (it gives the weather information based on latitude and longitude). After considering suggestions from many people, I decided to use the information from the nearest weather station. The weather station was about 6-7 km away from the research area. The use of the long term average data lowered the probability of occurrence of big effect in climate data like ETo.

## 4.7 Irrigation Scheduling Tool

Various scientific studies have been conducted on irrigation scheduling tools in different regions of the world. But rarely, the scientific studies have been conducted on drip irrigation scheduling tool for the small holder farmers.

Maisiri, N. *et al*. 2005 carried out drip irrigation scheduling in Zimbabwe and compared it with the conventional irrigation system farmers followed in terms of crop and water productivity. This study does not state whether the amount of water applied in both cases is less, enough or more than the actual crop water requirement.

King, B.A. *et al.* 2001. Stated irrigation support software should assist farmers in deciding how much water to apply and offer simple and easily comprehendible output that farmer can easily use to make decision. The VSWSI (visual soil water status indicators), that use highly visible colours to display current soil water content and was designed for large farms, whereas, the DPC was designed as a drip irrigation scheduling tool for small holder farmers.

# 5. CONCLUSION

The purpose of the research was to evaluate the applicability of the DPC in order to advice the farmer. Moreover, the purpose of the research was to monitor the direct impact of the Chart on the growth and the yield of the crops.

To fulfill the objective of the study, some corrections were used to adjust the present DPC in different growth stages. At the same time, a statistical analysis (i.e. one way ANOVA) was done to show if there were any significant differences in yield with different amount of water application. Lastly, the perception of the farmers on DPC as a manual drip irrigation scheduling tool was examined to understand how it can ease the life of farmers.

**Conclusion drawn from Field Trial**

<u>Effectiveness & Efficiency of DPC</u>

Statistical Analysis (ANOVA using GeneStat) for crop measurements did not show any significant difference in the yield of cabbage for all treatments. This implies that the suggestion by DPC in open field for cabbage has the positive outcome in term of yields (i.e. no reduction in yields). It accepted the null hypothesis (Ho) that said there is no significant difference in yield in all the treatment was accepted. This is a positive outcome for the improvement in DPC.

To realize about the accuracy of DPC, field trial was performed. During the research some correction factors were accommodated for the accuracy of the Chart. In the initial stage a correction factor “fw” was used whereas in the mid and late growth stage a percentage correction was incorporated. Other correction factor used except in initial stage is the crop coverage factor “Kr”. These correction factors seem to be fruitful to adjust in DPC for more accuracy. These corrections are shown in Table 13 above

It is still very difficult to accompany the Drip Planner Chart with the currently available drip kits designed by IDE/Nepal. This may drastically reduce the efficiency of DPC. DPC advises water in term of liter/$m^2$. But when we directly incorporate the adjusted DPC, with the present available drip kits designed by IDE/Nepal, the amount of water recommended to crops will be very high than the actual need. So there should be a provision of some kind of an adjustment mechanism in customized drip kits i.e. provision of incorporating lateral lines as per the crop requirements (adding or removing) to incorporate DPC in IDE Nepal Drip Kits.

**Conclusion from Interviews and Focus Group Discussion**

Interviews and FGDs with farmers, field staff and office staff from IDE and NITP revealed that the Drip Planner Chart is useful hand tool to advice farmers how much water to apply in their crops. But it is still very complex for the farmers to understand and use it for their purpose. And direct observations in the field showed that farmers do not have one particular method of irrigation i.e. no scheduling tool to irrigate their crops. They irrigate their crops either using buckets or connect pipes to the drip kit tank from the tap for unlimited time, or pump water from the water source through the pipes. They also either collect the water in a large tank or directly irrigate it to their crops. So, this may leads to two things, i. Over-application of water; ii. It is not sure that the water applied fully wet the root zone. An interview with farmer also leads to the conclusion that there is difference with and without using drip irrigation system (i.e. more yield in plot using drip irrigation system). But the farmers do not have particular scheduling tool to follow the irrigation turns for the drip irrigation. The field staffs revealed that they suggest famers to irrigate twice a day (one in the morning and one in the evening). But the farmers often irrigate one time in the evening. So, DPC will be a very useful tool to irrigate the right amount of water (which of-course saves water) to the crops without negative effect on the yield (production).

An informal talk with the engineering section of IDE, director of Non-Conventional Irrigation Technology Program (NITP), discussion with farmers and focus group discussions, it was realized that there is a need of further simplify current chart so that the actual users (i.e. the smallholder farmers) can understand it and use it. One of the main problems is that the smallholder farmers are illiterate and they cannot understand the terms and number used in present DPC. So simplifying in term of presenting icons instead of expressing them in number & graduating the water tank in drip kits may be good idea.

# 6. RECOMMENDATIONS

The following recommendations have been formulated based on direct observations from the field trial, discussion and feedback from interactions. So these recommendation can be very useful for the further future improvement in DPC.

*Research Recommendation*

The result from one field trial is not sufficient to draw a conclusion which is why there is a need for more researches in different locations with different climatic condition for further refinements of the Drip Planner Chart. This has also been suggested by the IDE office in Nepal. They are interested to continue similar experiments in different locations in different crops.

It is important to combine further research on the DPC with the drip kits designed by IDE/Nepal. The other option might be making adjustments in the present drip kit according to the need of the crop to incorporate it with DPC (i.e. provision of adding and removing the laterals as per the crop requirements).

For further research in the future, it is recommended to compare the adjusted values in different regions for different crop growth stages. If these values come very close to each other, one adjusted DPC will work for different regions. This will reduce the amount of work needed to develop the tools.

It is recommended that the research area should be near the weather station for this kind of study as it is more practical than setting up equipments to record climate data in new research site.

Many researches on irrigation scheduling tools have been conducted in different region of the world. However, very little work has been done in the area to understand the perception of the farmers on such tools. An integrated approach of research should be emphasized. This will help the farmers better understand the developed tool.

*Management Recommendation*

The thesis showed that the farmers were unaware of the scientific findings on irrigation scheduling in drip irrigation. That is why the recommendation for amount and frequency of water application by the organization and the farmers' practice seemed different. So, the organization who is working on development and dissemination of drip irrigation programme and crop water requirement research should use different means of communication, feedback analysis and post research in evaluating how the outcome is working. By doing this, the effectiveness and success of the outcome from the organization can be established.

Translating the DPC into the Nepali language would make it more accessible for the farmers to incorporate in drip irrigation. As most of the farmers are illiterate, it might be better idea to represent amount of water to apply in icons. For example, IDE Nepal already has different sized water tank (i.e. 50 litres, 100 litres, 200 litres). Graduating these tanks would make the farmers apply the recommended amount of water.

# REFERENCES


B.A. King, R. W. W. and Taberna Jr. J.P., (2001). "Visual soil water status indicator for improved irrigation management." Computers and electronics in agriculture 32 (2001) (2001): 31–43.

Boesveld, H. (2008). "Drip Planner Chart: A simple manual drip irrigation scheduling tool for small farmers". Wageningen University and Research Centre. The Netherlands.

Clyma, W. (1996). Irrigation scheduling revisited: Historical evaluation and reformation of the concept. International Conference on Evapotranspiration and Irrigation scheduling, St Joseph, ASAE.

Cooke, Priscilla A. (May 2000). "Changes in Intra-household labor allocation to environmental goods collection: A case study from rural Nepal, 1982 and 1997, International Food Policy Research Institute". Food Consumption and Nutrition Division FCND Discussion Paper No. 87. (http://www.ifpri.org/DIVS/FCND/dp/papers/fcndp87.pdf).

"District Profile of Nepal 2007/2008: A Socio-Economic Development Data Base of Nepal". pp 274-284; Intensive Study & Research Centre, Putalisadak, Kathmandu

Haile, A. M, Depeweg and H & Stilhardt H., (2003). "Smallholder Drip Irrigation Technology: Potentials and constraints in the Highlands of Eritrea". Volume 23, No 1 (2003): 27-31.

Hodnett, M.G., et al. (1990). "Control of drip irrigation of sugarcane using 'index' tensiometers: some comparisons with control by the water budget method". Agric. Water Management. 17, 189–207.

IAEA. (2008). "Field Estimation of Soil Water Content: A Practical Guide to Methods, Instrumentation and Sensor Technology". Training course series no. 30, 123-129.

Maisiri, N. et al. (2005). “On farm evaluation of the effect of low cost drip irrigation on water and crop productivity compared to conventional surface irrigation system”. Physics and chemistry of the earth 30 (2005): 783–791.

NITP. (2006). “Manual of Drip Irrigation Technology”

Mikhail, M. & Yoder, R. (2008). Multiple Use Water Service Implementation in Nepal and India: Experience and Lessons for Scale-up. IDE,CPWF, IWMI

NIELSEN, J. (1997). “The Use and Misuse of Focus Group”.

Pariyar, D. (2007). “Country Pastures/Forage Resource Profiles: Nepal”. FAO of United Nations.

Pereira *et al.* (1998). “FAO Irrigation and Drainage Paper No. 56: Crop Evapotranspiration (guidelines for computing crop water requirements)”. Rome: FAO-Food and Agriculture Organisation of the United Nations.

Raes, D. *et al.* (2000). „“Charts for guiding irrigation in real time.” Kluwer Academic Publishers. Irrigation and Drainage Systems 14 (2000): 343–352.

Sanders, D.C. (August 1997). North Carolina Cooperative Extension Service (NCSU). Vegetable Crop Irrigation.

Skaggs, K. (2001). “Predicting Drip Irrigation Use and Adoption in a Desert Region”. *Agricultural Water Management 51* , 125-142.

TABONO (2004). “Intervention Skills and Tools: Conducting Focus Group Discussions”.

Upadhyay, B. (2004).” Gender Aspects of Smallholder Irrigation Technology: Insights from Nepal”. *Journal of Applied Irrigation Science, Vol. 39. No 2/2004* , 315-327.

Wiedenfeld, B., (2003). “Scheduling water on drip irrigated sugarcane.” Texas Agricultural experiment Station, Texas A&M University Research and Extension Center, 2415 East Highway 83, Weslaco, TX 78596, USA. (2003).

Yakami S. & Zisengwe L.S. (2008). “Quality Control, Farmer Adoption and Work on Drip Planner Chart: Internship in Ziway, Ethiopia”

**Internet Sources**

Digitemp. (2009). “Digitemp: Temperature Sensor for Linux”, Retrieved April 24, 2009, from http://www.digitemp.com/wetbulb.shtml

APP. (2009). “Government of Nepal: Agricultural Perspective Plan”, Retrived May 10, 2009 from http://www.moac.gov.np/appsp/index.php

Spectrum Technologies .(2009). “Watermark Soil Moisture Sensors: catalog # 6450WD”, Retrieved June 15, 2009, from http://www.specmeters.com/pdf/6450WD.pdf

RCBD. (2009). “Randomized Complete Block Design (RCBD)”, Retrieved November 12, 2008 from http://www.ndsu.nodak.edu/ndsu/horsley/RCBD.pdf

# APPENDIXES

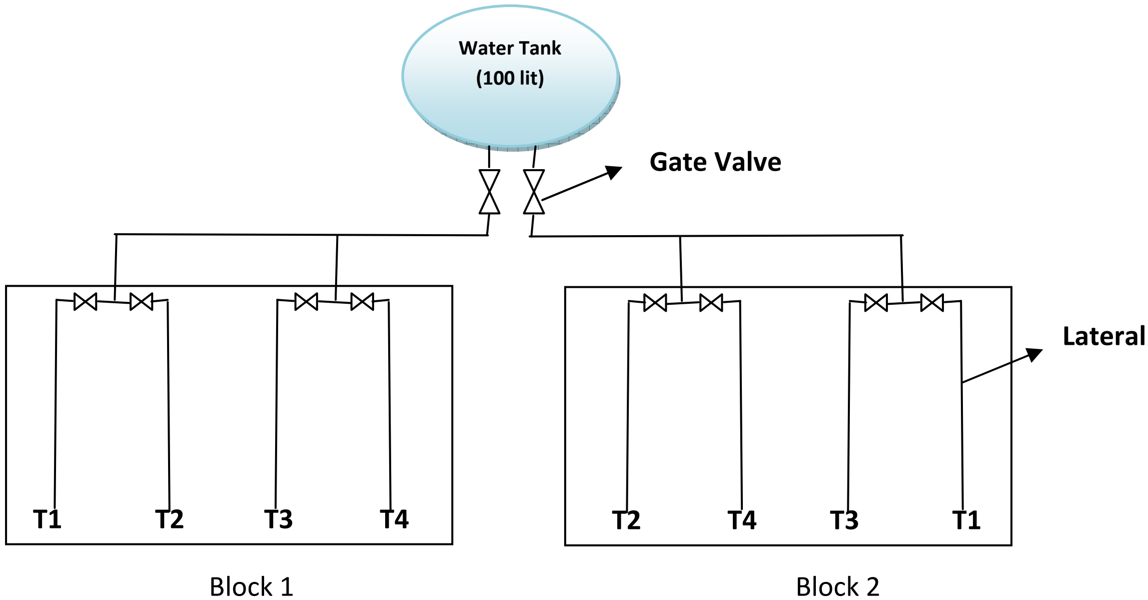
## APPENDIX 1: ORDERING OF AVERAGE MONTHLY RAINFALL DATA TO FIND DEPENDABLE RAINFALL

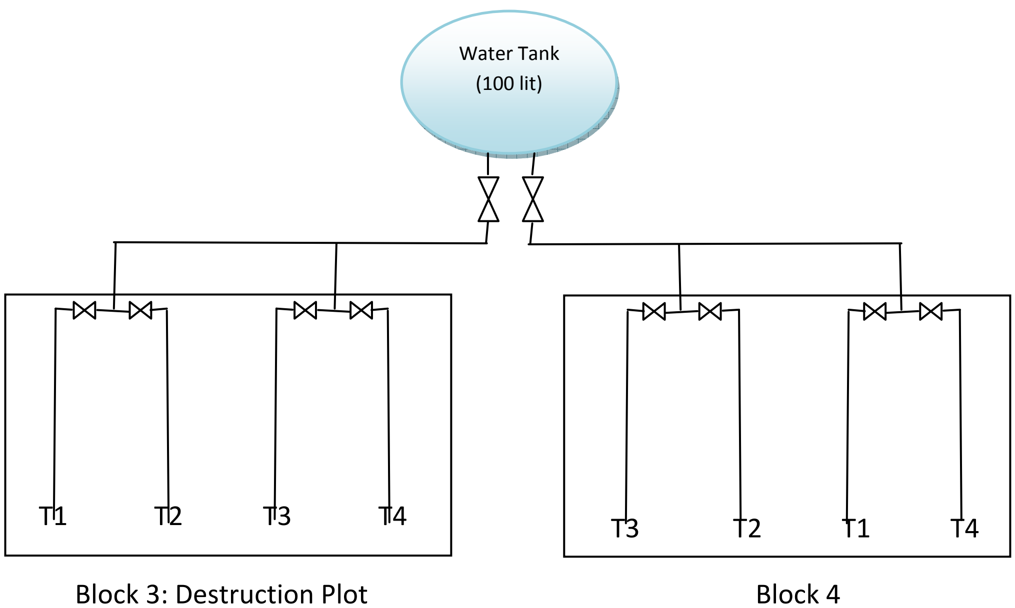
| SN | Jan | Feb | Mar | Apr | May | Jun | July | Aug | Sep | Oct | Nov | Dec | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 0 | 0 | 0 | 0 | 12 | 55 | 137 | 136 | 10 | 0 | 0 | 0 | |
| **2** | 0 | 0 | 0 | 0 | 36 | 62 | 170 | 138 | 36 | 0 | 0 | 0 | |
| **3** | 0 | 1 | 0 | 5 | 40 | 89 | 181 | 143 | 46 | 1 | 0 | 0 | |
| **4** | 0 | 1 | 4 | 6 | 52 | 104 | 235 | 144 | 51 | 2 | 0 | 0 | |
| **5** | 1 | 4 | 4 | 8 | 60 | 108 | 241 | 207 | 54 | 3 | 0 | 0 | |
| **6** | 1 | 6 | 6 | 11 | 60 | 109 | 245 | 210 | 72 | 8 | 0 | 0 | |
| **7** | 1 | 7 | 7 | 13 | 65 | 131 | 246 | 217 | 77 | 9 | 0 | 0 | |
| **8** | 1 | 7 | 7 | 19 | 68 | 136 | 248 | 220 | 82 | 10 | 0 | 0 | Dependable rainfall (80%) |
| **9** | 2 | 7 | 9 | 24 | 73 | 137 | 248 | 232 | 107 | 12 | 0 | 0 | |
| **10** | 2 | 8 | 11 | 28 | 73 | 137 | 248 | 233 | 107 | 15 | 0 | 0 | |
| **11** | 4 | 9 | 12 | 33 | 76 | 150 | 260 | 234 | 109 | 16 | 0 | 0 | |
| **12** | 5 | 10 | 13 | 33 | 81 | 153 | 275 | 235 | 111 | 18 | 0 | 0 | |
| **13** | 5 | 10 | 14 | 35 | 82 | 164 | 277 | 236 | 118 | 22 | 0 | 0 | |
| **14** | 7 | 12 | 15 | 37 | 86 | 176 | 282 | 241 | 120 | 22 | 0 | 0 | |
| **15** | 9 | 12 | 16 | 41 | 89 | 183 | 292 | 242 | 128 | 23 | 0 | 0 | |
| **16** | 12 | 14 | 19 | 43 | 90 | 194 | 299 | 243 | 131 | 26 | 0 | 0 | |
| **17** | 13 | 15 | 24 | 45 | 95 | 197 | 303 | 253 | 141 | 26 | 0 | 0 | |
| **18** | 13 | 15 | 24 | 47 | 95 | 205 | 306 | 260 | 147 | 27 | 0 | 0 | |
| **19** | 13 | 16 | 29 | 48 | 96 | 205 | 310 | 260 | 149 | 28 | 0 | 1 | |
| **20** | 14 | 16 | 30 | 53 | 96 | 207 | 321 | 265 | 149 | 33 | 0 | 1 | |
| **21** | 17 | 17 | 33 | 54 | 102 | 222 | 323 | 265 | 150 | 35 | 1 | 2 | |
| **22** | 18 | 21 | 36 | 54 | 102 | 225 | 350 | 270 | 153 | 45 | 2 | 5 | |
| **23** | 19 | 21 | 37 | 60 | 106 | 227 | 356 | 283 | 153 | 48 | 4 | 7 | |
| **24** | 20 | 26 | 38 | 61 | 107 | 237 | 357 | 292 | 154 | 49 | 5 | 8 | |
| **25** | 20 | 28 | 40 | 61 | 117 | 247 | 397 | 292 | 201 | 60 | 6 | 10 | |
| **26** | 21 | 30 | 40 | 72 | 122 | 263 | 399 | 293 | 204 | 84 | 7 | 14 | |
| **27** | 26 | 31 | 43 | 72 | 131 | 267 | 403 | 296 | 204 | 84 | 7 | 17 | |
| **28** | 29 | 31 | 50 | 81 | 133 | 267 | 409 | 297 | 215 | 107 | 8 | 22 | |
| **29** | 30 | 34 | 53 | 102 | 145 | 288 | 421 | 302 | 238 | 110 | 9 | 22 | |
| **30** | 31 | 35 | 60 | 104 | 148 | 289 | 428 | 303 | 245 | 113 | 10 | 50 | |
| **31** | 36 | 39 | 61 | 106 | 152 | 291 | 430 | 309 | 249 | 141 | 11 | 52 | |
| **32** | 39 | 40 | 67 | 108 | 163 | 302 | 436 | 329 | 251 | 142 | 15 | 68 | |
| **33** | 58 | 41 | 74 | 111 | 177 | 344 | 438 | 347 | 276 | 146 | 19 | 68 | |
| **34** | 59 | 52 | 74 | 124 | 178 | 456 | 503 | 388 | 306 | 183 | 21 | 79 | |
| **35** | 60 | 62 | 74 | 180 | 217 | 462 | 512 | 401 | 327 | 289 | 57 | 106 | |

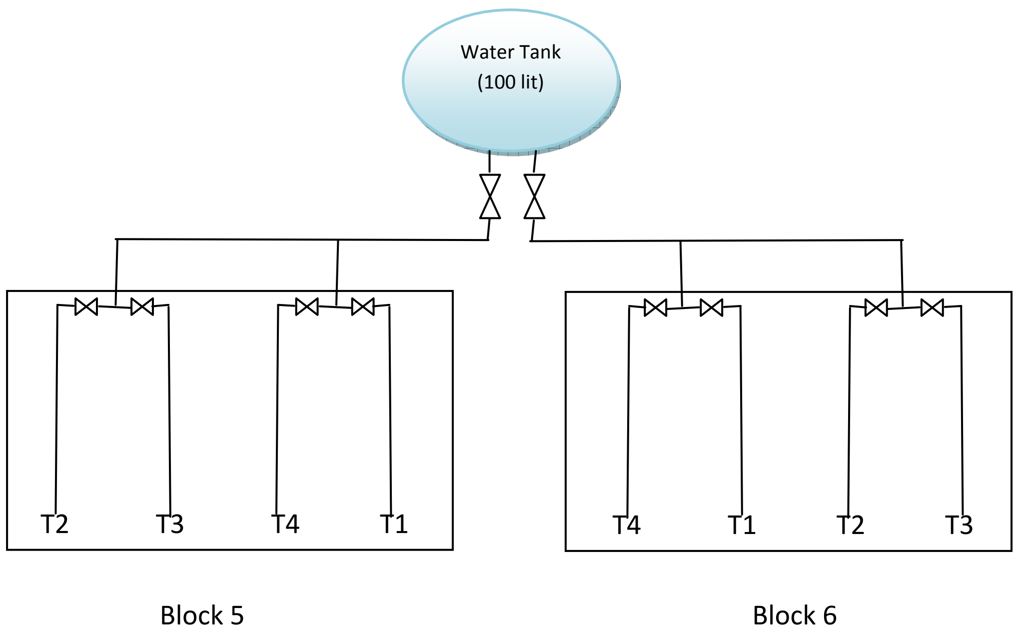
## APPENDIX 2: AVERAGE TOTAL R/F, DEPENDABLE R/F AND EFFECTIVE R/F

| Months | AverageTotal R/F | Dependable R/F | Effective R/F |
|---|---|---|---|
| **Jan** | 17 | 1 | 0.8 |
| **Feb** | 19 | 7 | 5.6 |
| **Mar** | 28 | 7 | 5.6 |
| **Apr** | 54 | 19 | 15.2 |
| **May** | 103 | 68 | 54.4 |
| **Jun** | 205 | 136 | 108.8 |
| **July** | 321 | 248 | 198.4 |
| **Aug** | 252 | 220 | 176 |
| **Sep** | 148 | 82 | 65.6 |
| **Oct** | 55 | 10 | 8 |
| **Nov** | 6 | 0 | 0 |
| **Dec** | 14 | 0 | 0 |

## APPENDIX 3: DESIGN LAYOUT OF THE EXPERIMENTAL PLOT




Water Tank
(100 lit)
T2
T3
T4
T1
T4
T1
T2
T3
Block 5
Block 6

**APPENDIX 4: PLANT PROTECTION MATERIAL USED DURING THE FIELD TRIAL.**

| SN | Description | Remarks |
|---|---|---|
| 1 | Crystal | For Soil Treatment |
| 2 | Charge Greuwal | For Soil Treatment |
| 3 | Jik Chillred | For Soil Treatment |
| 4 | Liberal Boron | For Soil Treatment |
| 5 | Tricho-derma | For Soil Treatment |
| 6 | Biotin Lime | For Soil Treatment |
| 7 | Charge | For Soil Treatment |
| 8 | Servo Agro Spray | Pesticides |
| 9 | Ozoneem | Pesticides |
| 10 | Bio-mytus | Pesticides |
| 11 | Rambaan | Pesticides |
| 12 | Bio-booster | Disease control measure |
| 13 | Emino-boom | Vitamins and Enzymes |
| 14 | Crystal | Vitamins and Enzymes |
| 15 | Charge | Vitamins and Enzymes |
| 16 | Bejod | Vitamins and Enzymes |
| 17 | Liquid Potash | Vitamins and Enzymes |
| 18 | Lib-spray | Vitamins and Enzymes |
| 19 | Classic | Vitamins and Enzymes |

## APPENDIX 5: INTERVIEW WITH INDIVIDUAL FARMERS

**University:** Wageningen University and Research Centre
**Organization:** International Development Enterprises/Nepal
**Research:** Crop Water Requirement
**Research Crew:** Harm Boesveld**,** Luke Colavito; Kailash Sharma; Binod Mishra; Ram Chandra Bhushal, Bal Krishna Thapa; Saroj Yakami

**Questionnaire to know about the farmers' practice in drip system in the research site.**

**Interview Location:** ……………………………………..  **Date:** ………….. - …….. - ……….

**Name of the Farmer/Interviewee:** ……………………………….

**Interviewer:** ……………………………….

1. Family size/number

| SN | Gender | Number | Remarks |
|---|---|---|---|
| **1** | Male | | |
| **2** | Female | | |
| **3** | Kids | | |

2. Other occupation if any in addition to Agriculture

3. What is drip system?

4. No. of years of use (if possible the year of start i.e. date)

5. Responsible person for drip irrigation (Gender Perspective)
And who is responsible for what if it exists?

| SN | Gender | Responsibility | Remarks |
|---|---|---|---|
| **1** | Husband | | |
| **2** | Wife | | |
| **3** | Kids | | |

Responsibility in terms of decision making (when and how much to irrigate), operation, repair and maintenance

6. Total Land holding size and total land cover by drip in water scarce time (for vegetables only)

| SN | Land Use | Area (in………) | Remarks (size of drip kits) |
|---|---|---|---|
| **1** | Total land size | | |
| **2** | Land with Drip | | |
| **3** | Land with no Drip | | |

7. Type of crop in practices: in drip and no drip case

| SN | Irrigation Practice | Crops | Remarks |
|---|---|---|---|
| **1** | Drip | | |
| **2** | No Drip | | |
| | | | |

8. Source of water

| SN | Type of sources | Time in months (range of time) | Remarks |
|---|---|---|---|
| **1** | Rain Water | | |
| **2** | Ground Water | | |
| **3** | Others (mention) | | |
| | | | |

9. Water Availability: when (the time of water availability):season

10. What do you do in Water scarce time?

11. What are the scheduling tools (or source of information) that the farmer is currently practicing?

12. What kind of tool (for irrigation) he/she admire if there exists?

13. Means to bring/convey/carry water to the drip system.

**Water Application**

1. Types of water application method the farmer is employing in their field for the vegetables production.
2. Amount of water applied in different crop in different stage: either per day/per week

3.

| SN | Stages | Amount of water for different crops in different stages | | | | | | Remarks (Also mention diff stage in local description) |
|---|---|---|---|---|---|---|---|---|
| | | Different Crops/Amount of water | | | | | | |
| | | | | | | | | |
| 1 | Initial | | | | | | | |
| 2 | Dev | | | | | | | |
| 3 | Mid | | | | | | | |
| 4 | Mature | | | | | | | |
| | Other if any | | | | | | | |
| | | | | | | | | |

4. Frequency of water application

5. Farmers' Perception on Drip System

a. What are benefits of using drip? (in term of income, time consumption et cetera)

b. In the past before having drip system what was in practice in their field? (i.e. either you put your land fallow or grow something? And what do you find the difference before and after using drip system?)

c. The Problem using drip system. (in its performance, availability, usability, simplicity, productivity in terms of water and yield et cetera).

**OBSERVATION SHEET:**

Equipment Used

State/condition of Equipment (should see how long they have been using, performance, )

State of Crops during the interview (its stand, other description like the plant to plant distant, row to row distant, type of crops, et cetera)

## APPENDIX 6: FOCUS GROUP DISCUSSION

### Focus Group Discussion (FGD)

**Location:** **Date:**

**Interviewer:** **Reporter:**

1. **Drip Irrigation System**
2. **Merit/Demerit of Drip**
3. **Factors that influences to use Drip System.**
4. **Selection criteria of Kit Size**
5. **Water Application (frequency, Amount)**
6. **Decision Maker: Water application and how (u use any tool or suggestion from the field staff or other if any)?**
7. **Responsibility of Women/Women Participation**
8. **Responsibility of Male**
9. **Source of Water for irrigation in different season**
10. **Situation Analysis Before and After Intervention of MIT**
11. **Marketing (how, Access to Market, which crop to grow etc)**
12. **Health**
13. **Drip Planner Chart**

## APPENDIX 7: TOTAL YIELD OF CABBAGE FOR DIFFERENT TREATMENTS IN EACH REPLICATION

| Replications | Total Yield in different Treatments (in grams) | | | |
|---|---|---|---|---|
| | Farmers' Practice | IDE approach | Daily DPC | Intv DPC |
| 1 | **9550*** | 13400 | 11350 | 11900 |
| 2 | 10400 | 12700 | **9600**** | 11700 |
| 3 | 15250 | **14250**** | 11900 | **9300*** |
| 4 | **16850**** | 13600 | 12550 | 11400 |
| 5 | 15850 | **10025*** | **13700**** | **13750**** |

*** Minimum total Yield**

**** Maximum Total Yield**

## APPENDIX 8: CALCULATION STEPS FOR ANALYSIS OF VARIANCE

### 1. Variate: Avg. Head wt.

| Source of variation | d.f. | s.s. | m.s. | F | p. |
|---|---|---|---|---|---|
| Treatment | 3 | 116112. | 38704. | 1.44 | 0.267 |
| Residual | 16 | 428667. | 26792. | | |
| Total | 19 | 544779. | | | |

### Least significant differences of means (5% level)

| Table | Treatment |
|---|---|
| rep. | 5 |
| d.f. | 16 |
| l.s.d. | 219.5 |

### Stratum standard errors and coefficients of variation

Variate: Head

| d.f. | s.e. | cv% |
|---|---|---|
| 16 | 163.7 | 12.4 |

### 2. Variate: Harvest_Index

| Source of variation | d.f. | s.s. | m.s. | F | p |
|---|---|---|---|---|---|
| Treatment | 3 | 0.0024258 | 0.0008086 | 0.89 | 0.466 |
| Residual | 16 | 0.0144846 | 0.0009053 | | |
| Total | 19 | 0.0169104 | | | |

### Least significant differences of means (5% level)

| Table | Treatment |
|---|---|
| rep. | 5 |
| d.f. | 16 |
| l.s.d. | 0.04034 |

### Stratum standard errors and coefficients of variation

| d.f. | s.e. | cv% |
|---|---|---|
| 16 | 0.03009 | 5.4 |

### 3. Variate: Average Total Yield

| Source of variation | d.f. | s.s. | m.s. | F | p |
|---|---|---|---|---|---|
| Treatmet | 3 | 12492094. | 4164031. | 0.89 | 0.469 |
| Residual | 16 | 75076000. | 4692250. | | |
| Total | 19 | 87568094. | | | |

### Least significant differences of means (5% level)

| Table | Treatmet |
|---|---|
| rep. | 5 |
| d.f. | 16 |
| l.s.d. | 2904.3 |

### Stratum standard errors and coefficients of variation

Variate: Yield

| d.f. | s.e. | cv% |
|---|---|---|
| 16 | 2166.2 | 17.4 |

## APPENDIX 9: SOIL MATRIC POTENTIAL VALUES

a. Initial Stage

| Date | Data-logger 1 (DL 1) | | | | | DL 2 | | | DL 3 | | | | | | DL 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T1** | **T2** | **T3** | **T4** | **T2** | **T4** | **T3** | **T1** | **T2** | **T3** | **T4** | **T1** | **T4** | **T1** | **T2** | **T3** | **T3** | **T2** | **T1** | **T4** |
| 2/21/2009 | 1 | 0 | 1 | 2 | 2 | 3 | 1 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 1 | 0 | 2 | 1 | 1 | 0 |
| 2/22/2009 | 1 | 0 | 2 | 2 | 3 | 3 | 1 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 1 | 0 | 2 | 2 | 1 | 0 |
| 2/23/2009 | 2 | 0 | 1 | 2 | 3 | 3 | 1 | 2 | 2 | 3 | 3 | 2 | 1 | 3 | 1 | 0 | 2 | 2 | 1 | 1 |
| 2/24/2009 | 2 | 0 | 1 | 2 | 4 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 2 | 0 | 2 | 3 | 1 | 2 |
| 2/25/2009 | 2 | 0 | 1 | 2 | 4 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 2 | 0 | 2 | 3 | 1 | 2 |
| 2/26/2009 | 2 | 0 | 1 | 2 | 4 | 3 | 2 | 2 | 2 | 4 | 2 | 3 | 2 | 3 | 1 | 1 | 2 | 3 | 2 | 2 |
| 2/27/2009 | 2 | 0 | 1 | 2 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 1 | 3 | 3 | 2 | 2 |
| 2/28/2009 | 2 | 1 | 1 | 3 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 1 | 3 | 2 | 1 | 3 | 3 | 2 | 2 |
| 3/1/2009 | 2 | 4 | 1 | 3 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 0 | 3 | 3 | 2 | 2 |
| 3/2/2009 | 2 | 6 | 2 | 3 | 4 | 3 | 4 | 2 | 3 | 3 | 3 | 3 | 1 | 3 | 2 | 1 | 3 | 3 | 2 | 7 |
| 3/3/2009 | 2 | 5 | 2 | 3 | 4 | 3 | 3 | 2 | 2 | 3 | 2 | 3 | 1 | 3 | 2 | 0 | 3 | 3 | 2 | 3 |
| 3/4/2009 | 2 | 4 | 2 | 3 | 4 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 2 | 0 | 3 | 3 | 2 | 9 |
| 3/5/2009 | 2 | 3 | 2 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 3 | 2 | 0 | 2 | 3 | 2 | 3 |

b. Developmental Stage

| Date | Data-logger 1 (DL 1) | | | | | DL 2 | | | DL 3 | | | | | | DL 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T1** | **T2** | **T3** | **T4** | **T2** | **T4** | **T3** | **T1** | **T2** | **T3** | **T4** | **T1** | **T4** | **T1** | **T2** | **T3** | **T3** | **T2** | **T1** | **T4** |
| 3/6/2009 | 2 | 3 | 1 | 2 | 2 | 2 | 13 | 2 | 2 | 2 | 4 | 2 | 1 | 3 | 1 | 0 | 2 | 2 | 2 | 6 |
| 3/7/2009 | 2 | 1 | 1 | 2 | 3 | 2 | 18 | 2 | 2 | 1 | 2 | 1 | 1 | 3 | 1 | 0 | 2 | 2 | 1 | 3 |
| 3/8/2009 | 2 | 0 | 1 | 2 | 3 | 2 | 19 | 2 | 2 | 2 | 10 | 1 | 1 | 3 | 1 | 0 | 2 | 2 | 2 | 10 |
| 3/9/2009 | 2 | 1 | 1 | 2 | 3 | 2 | 20 | 2 | 2 | 2 | 4 | 1 | 1 | 3 | 1 | 0 | 2 | 2 | 2 | 3 |
| 3/10/2009 | 2 | 1 | 1 | 2 | 2 | 2 | 20 | 2 | 2 | 3 | 8 | 1 | 1 | 3 | 1 | 0 | 2 | 2 | 3 | 8 |
| 3/11/2009 | | | | | | | | | | | | | | | | | | | | |
| 3/12/2009 | 2 | 0 | 1 | 16 | 5 | 9 | 19 | 2 | 2 | 3 | 20 | 1 | 9 | 3 | 1 | 0 | 1 | 2 | 11 | 18 |
| 3/13/2009 | 3 | 1 | 2 | 6 | 3 | 3 | 8 | 3 | 3 | 2 | 11 | 1 | 3 | 3 | 2 | 0 | 1 | 3 | 5 | 9 |
| 3/14/2009 | 3 | 0 | 1 | 10 | 4 | 2 | 5 | 2 | 2 | 3 | 16 | 1 | 3 | 3 | 1 | 0 | 1 | 2 | 4 | 11 |
| 3/15/2009 | 3 | 1 | 2 | 17 | 2 | 3 | 8 | 2 | 3 | 3 | 23 | 1 | 11 | 3 | 1 | 0 | 1 | 2 | 4 | 19 |
| 3/16/2009 | 3 | 0 | 1 | 21 | 5 | 2 | 8 | 3 | 2 | 6 | 26 | 1 | 14 | 3 | 1 | 0 | 1 | 1 | 4 | 21 |
| 3/17/2009 | 2 | 0 | 1 | 5 | 5 | 2 | 9 | 3 | 2 | 4 | 6 | 1 | 4 | 3 | 1 | 0 | 1 | 1 | 4 | 5 |
| 3/18/2009 | 3 | 1 | 1 | 10 | 5 | 2 | 13 | 3 | 2 | 4 | 17 | 2 | 4 | 3 | 2 | 0 | 2 | 1 | 4 | 12 |
| 3/19/2009 | 3 | 1 | 1 | 18 | 2 | 2 | 20 | 4 | 2 | 6 | 24 | 3 | 11 | 3 | 1 | 0 | 2 | 1 | 4 | 19 |
| 3/20/2009 | 3 | 5 | 2 | 24 | 1 | 6 | 20 | 4 | 2 | 12 | 30 | 2 | 16 | 3 | 1 | 0 | 2 | 3 | 4 | 24 |
| 3/21/2009 | 3 | 7 | 1 | 6 | 2 | 3 | 13 | 4 | 2 | 5 | 14 | 2 | 5 | 3 | 1 | 0 | 2 | 0 | 4 | 8 |
| 3/22/2009 | 3 | 10 | 2 | 6 | 1 | 3 | 20 | 10 | 6 | 2 | 23 | 7 | 5 | 3 | 1 | 0 | 2 | 1 | 5 | 13 |
| 3/23/2009 | 3 | 13 | 12 | 15 | 1 | 13 | 24 | 17 | 14 | 1 | 32 | 14 | 1 | 5 | 2 | 9 | 11 | 14 | 19 | 20 |
| 3/24/2009 | 8 | 16 | 19 | 23 | 0 | 18 | 27 | 20 | 7 | 5 | 12 | 20 | 6 | 13 | 1 | 14 | 17 | 1 | **15** | **24** |
| 3/25/2009 | 5 | 18 | 12 | 29 | 0 | 23 | 30 | 23 | 7 | 7 | 22 | 19 | 5 | 7 | 2 | 2 | 7 | 10 | 11 | 29 |
| 3/26/2009 | 4 | 20 | 6 | 8 | 1 | 6 | 21 | 15 | 9 | 4 | 18 | 8 | 5 | 7 | 5 | 4 | 6 | 10 | 6 | 8 |

c. Mid Growth Stage

| Date | Data-logger 1 (DL 1) | | | | | DL 2 | | | DL 3 | | | | | | DL 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | T1 | T2 | T3 | T4 | T2 | T4 | T3 | T1 | T2 | T3 | T4 | T1 | T4 | T1 | T2 | T3 | T3 | T2 | T1 | T4 |
| 3/27/2009 | 3 | 20 | 5 | 13 | 4 | 5 | 15 | 14 | 6 | 4 | 29 | 8 | 5 | 6 | 3 | 4 | 10 | 7 | 5 | 14 |
| 3/28/2009 | 3 | 20 | 5 | 24 | 5 | 17 | 13 | 18 | 6 | 10 | 26 | 7 | 17 | 6 | 2 | 4 | 11 | 6 | 5 | 23 |
| 3/29/2009 | 3 | 21 | 5 | 32 | 2 | 25 | 20 | 22 | 6 | 4 | 43 | 9 | 20 | 6 | 2 | 4 | 11 | 2 | 4 | 31 |
| 3/30/2009 | 3 | 6 | 7 | 6 | 3 | 9 | 20 | 12 | 6 | 5 | 14 | 7 | 7 | 6 | 2 | 4 | 6 | 2 | 2 | 4 |
| 3/31/2009 | 3 | 11 | 17 | 11 | 1 | 9 | 25 | 23 | 12 | 2 | 23 | 14 | 6 | 8 | 9 | 12 | 12 | 10 | 5 | 14 |
| 4/1/2009 | 12 | 17 | 26 | 20 | 0 | 25 | 32 | 29 | 20 | 1 | 33 | 24 | 20 | 15 | 17 | 18 | 20 | 15 | 13 | 17 |
| 4/2/2009 | 19 | 23 | 31 | 31 | 12 | 40 | 35 | 33 | 27 | 12 | 44 | 31 | 8 | 19 | 26 | 21 | 24 | 20 | 19 | 20 |
| 4/3/2009 | 2 | 21 | 4 | 4 | 2 | 7 | 36 | 25 | 10 | 9 | 13 | 7 | 8 | 7 | 5 | 5 | 5 | 13 | 7 | 5 |
| 4/4/2009 | 2 | 17 | 4 | 10 | 4 | 10 | 33 | 19 | 7 | 9 | 24 | 7 | 6 | 6 | 4 | 5 | 4 | 4 | 5 | 14 |
| 4/5/2009 | 1 | 12 | 3 | 18 | 3 | 14 | 34 | 12 | 11 | 9 | 34 | 6 | 12 | 6 | 4 | 4 | 4 | 9 | 5 | 22 |
| 4/6/2009 | 1 | 7 | 3 | 5 | 2 | 9 | 34 | 16 | 15 | 8 | 15 | 10 | 8 | 6 | 10 | 6 | 4 | 11 | 4 | 10 |
| 4/7/2009 | 1 | 5 | 3 | 13 | 4 | 12 | 35 | 26 | 9 | 8 | 27 | 25 | 11 | 6 | 6 | 5 | 7 | 17 | 5 | 18 |
| 4/8/2009 | 1 | 3 | 2 | 26 | 6 | 20 | 38 | 18 | 9 | 8 | 42 | 17 | 18 | 6 | 6 | 9 | 6 | 10 | 5 | 29 |
| 4/9/2009 | 1 | 3 | 2 | 6 | 5 | 9 | 45 | 9 | 7 | 11 | 16 | 11 | 8 | 5 | 5 | 6 | 13 | 11 | 5 | 11 |
| 4/10/2009 | 5 | 8 | 3 | 15 | 2 | 14 | 48 | 19 | 24 | 27 | 28 | 23 | 12 | 14 | 19 | 17 | 18 | 21 | 10 | 20 |
| 4/11/2009 | 12 | 8 | 11 | 30 | 7 | 24 | 54 | 27 | 23 | 21 | 38 | 16 | 22 | 11 | 2 | 21 | 13 | 11 | 7 | 32 |
| 4/12/2009 | 21 | 15 | 27 | 44 | 30 | 36 | 61 | 41 | 20 | 21 | 52 | 30 | 28 | 10 | 17 | 11 | 10 | 15 | 6 | 42 |
| 4/13/2009 | 11 | 7 | 10 | 9 | 9 | 10 | 66 | 50 | 7 | 24 | 16 | 46 | 9 | 10 | 7 | 11 | 10 | 15 | 6 | 11 |
| 4/14/2009 | 10 | 4 | 5 | 14 | 11 | 18 | 68 | 39 | 14 | 12 | | 57 | 12 | 7 | 8 | 8 | 10 | 18 | 5 | 16 |
| 4/15/2009 | 11 | 9 | 5 | 23 | 4 | 28 | 69 | 18 | 21 | 20 | | 65 | 14 | 11 | 17 | 11 | 12 | 20 | 5 | 23 |
| 4/16/2009 | 11 | 5 | 10 | 31 | 5 | 40 | 69 | 19 | 7 | 23 | | 70 | 20 | 13 | 7 | 12 | 14 | 20 | 5 | 32 |
| 4/17/2009 | 11 | 4 | 16 | 6 | 8 | 10 | 12 | 14 | 9 | 22 | | 75 | 9 | 11 | 9 | 10 | 11 | 14 | 15 | 6 |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/18/2009 | 15 | 5 | 16 | 13 | 5 | 23 | 13 | 22 | 12 | 48 | | 15 | 11 | 18 | 11 | 14 | 16 | 16 | 20 | 12 |
| 4/19/2009 | 13 | 9 | 13 | 21 | 3 | 36 | 12 | 16 | 20 | 38 | | 17 | 16 | 14 | 18 | 12 | 15 | 19 | 23 | 18 |
| 4/20/2009 | 18 | 5 | 18 | 10 | 3 | 9 | 13 | 19 | 14 | 54 | 7 | 10 | 9 | 17 | 12 | 13 | 16 | 4 | 9 | 10 |
| 4/21/2009 | 18 | 5 | 23 | 18 | 5 | 21 | 22 | 18 | 14 | 51 | 11 | 17 | 8 | 20 | 12 | 14 | 18 | 4 | 10 | 16 |
| 4/22/2009 | 20 | 5 | 23 | 31 | 4 | 34 | 10 | 19 | 17 | 74 | 19 | 19 | 13 | 24 | 15 | 16 | 20 | 4 | 11 | 24 |
| 4/23/2009 | 23 | 14 | 24 | 13 | 20 | 13 | 13 | 21 | 16 | 83 | 14 | 20 | 8 | 25 | 15 | 18 | 21 | 15 | 12 | 10 |
| 4/24/2009 | 24 | 6 | 30 | 26 | 13 | 13 | 13 | 23 | 11 | 62 | 13 | 20 | 10 | 24 | 10 | 18 | 23 | 8 | 13 | 18 |
| 4/25/2009 | 13 | 10 | 19 | 39 | 12 | 37 | 14 | 18 | 14 | 30 | 23 | 12 | 17 | 10 | 11 | 17 | 40 | 8 | 8 | 10 |
| 4/26/2009 | 24 | 11 | 27 | 50 | 14 | 58 | 13 | 24 | 32 | 32 | 38 | 22 | 31 | 24 | 19 | 18 | 20 | 8 | 12 | 19 |
| 4/27/2009 | 24 | 18 | 29 | 56 | 34 | 64 | 14 | 29 | 33 | 56 | 60 | 21 | 46 | 23 | 30 | 17 | 19 | 17 | 11 | 36 |
| 4/28/2009 | 18 | 13 | 24 | 7 | 26 | 24 | 12 | 28 | 57 | 52 | 6 | 41 | 9 | 44 | 49 | 26 | 15 | 13 | 10 | 4 |
| 4/29/2009 | 21 | 15 | 23 | 13 | 29 | 49 | 12 | 23 | 28 | 51 | 13 | 22 | 9 | 24 | 24 | 17 | 16 | 14 | 12 | 12 |
| 4/30/2009 | 43 | 30 | 49 | 19 | 39 | 61 | 22 | 47 | 27 | 48 | 21 | 47 | 16 | 48 | 24 | 27 | 32 | 15 | 24 | 19 |
| 5/1/2009 | 18 | 12 | 40 | 31 | 21 | 68 | 13 | 23 | 24 | 44 | 32 | 20 | 24 | 20 | 18 | 14 | 14 | 12 | 13 | 31 |
| 5/2/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/3/2009 | 23 | 18 | 25 | 12 | 37 | 19 | 15 | 19 | 28 | 62 | 12 | 23 | 11 | 23 | 24 | 16 | 17 | 17 | 14 | 12 |
| 5/4/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/5/2009 | 23 | 17 | 25 | 13 | 21 | 23 | 16 | 23 | 16 | 42 | 10 | 15 | 9 | 10 | 15 | 30 | 30 | 10 | 10 | 11 |

d. Late season stage/ Harvest Stage

| Date | Data-logger 1 (DL 1) | | | | | DL 2 | | | DL 3 | | | | | | DL 4 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **T1** | **T2** | **T3** | **T4** | **T2** | **T4** | **T3** | **T1** | **T2** | **T3** | **T4** | **T1** | **T4** | **T1** | **T2** | **T3** | **T3** | **T2** | **T1** | **T4** |
| 5/6/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/7/2009 | 29 | 23 | 38 | 35 | 25 | 40 | 20 | 20 | 22 | 49 | 29 | 30 | 25 | 25 | 28 | 21 | 21 | 21 | 19 | 35 |
| 5/8/2009 | 30 | 26 | 40 | 44 | 24 | 50 | 42 | 45 | 27 | 45 | 45 | 67 | 40 | 53 | 25 | 42 | 39 | 15 | 41 | 42 |
| 5/9/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/10/2009 | 31 | 19 | 35 | 17 | 17 | | 37 | 28 | 30 | 33 | | 38 | 49 | 34 | 32 | 28 | 19 | 23 | 23 | 18 |
| 5/11/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/12/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/13/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/14/2009 | 16 | 17 | 35 | 13 | 17 | 23 | 30 | 10 | 16 | 30 | 19 | 24 | 13 | 13 | 34 | 18 | 19 | 13 | 9 | 17 |
| 5/15/2009 | 8 | 7 | 46 | 13 | 13 | 33 | 28 | 13 | 23 | 54 | 11 | 37 | 11 | 9 | 32 | 21 | 20 | 11 | 10 | 23 |
| 5/16/2009 | 13 | 15 | 48 | 10 | 10 | 40 | 36 | 16 | 27 | 78 | 20 | 50 | 10 | 9 | 26 | 26 | 13 | 10 | 10 | 28 |
| 5/17/2009 | 22 | 15 | 55 | 24 | 24 | 51 | 49 | 19 | 36 | | 35 | 66 | 14 | 18 | 25 | 36 | 20 | 17 | 11 | 34 |
| 5/18/2009 | 41 | 25 | 40 | 37 | 28 | 62 | 35 | 21 | 23 | 45 | 59 | 78 | 21 | 34 | 25 | 40 | 37 | 18 | 12 | 34 |
| 5/19/2009 | | | | | | | | | | | | | | | | | | | | |
| 5/20/2009 | | | | | | | | | | | | | | | | | | | | |