Soil Moisture Distribution Status and Wetting Pattern under SDI
Neetha Shaju

Abstract:
This study was carried out for the purpose of determining the influence of soil moisture distribution and wetting pattern in the crop yield under subsurface drip irrigation (SDI). Moisture distribution pattern is one of the basic requirements for efficient design and management of an irrigation system. The knowledge of moisture distribution pattern helps in the effectiveness of drip irrigation. Uniformity in water application is determined by system uniformity and spatial uniformity. Due to increased drainage or pressure difference, water may be non-uniformly distributed in the field. Greater uniformity can be achieved by using pressure compensating emitters. In a condition where pressure compensating emitters cannot maintain the uniformity in moisture distribution, either synthetic soil conditioners or impermeable membrane can be used. The soil moisture increased uniformly from surface layer towards deeper soil depths in higher water application rates. The main problem reported was emitter plugging by root intrusion. Keeping the soil around the dripline sufficiently wet and injecting chemical products to kill those roots are used to alleviate this problem. Subsurface drip irrigation system should overcome mainly two factors. One thing is the high cost associated with installation and maintenance. The other is objection to the tillage practices. If these problems are reduced relative to other irrigation system, the application of SDI will be increased in the near future.

1. INTRODUCTION
Micro irrigation system is introduced for increasing the productivity by economizing the use of water. In this system, water is applied to plant root zone through emitters. Water is applied at frequent intervals in controlled quantities as per the requirements of plant. It is the most advanced irrigation method with the highest application efficiency. The water is delivered continuously in drops at the crop root zone and wets the root zone vertically by gravity and laterally by capillary action. Water is the key factor in the development processes. Therefore it is important to study the feasibility of saving water in various ways. Behrouz, et al. (2007) showed that subsurface irrigation system would reduce the loss of water by evaporation, runoff, and deep percolation than other irrigation systems. Subsurface drip irrigation is defined by ASAE as “application of water below the soil surface through emitters, with discharge rates in the same range as drip irrigation”. It is a low pressure, high efficiency irrigation system that uses buried drip tubes or drip tape to meet crop water needs. Since the water is applied below the soil surface, the effect of surface irrigation characteristics, such as crusting, saturated conditions of ponding water, and potential surface runoff (including soil erosion) are eliminated when using subsurface irrigation (Reich et al., 2014). If the system is well maintained, water application will be highly uniform and efficient (Shaviv and Sinai, 2004).

1.1 ADVANTAGES OF SDI
➢ More efficient water use
➢ Enhanced plant growth, crop yield and quality
➢ Improved plant health
➢ Better weed control
➢ Decreased energy costs
➢ Less pest damage

(Lamm et al., 2012)

1.2 DISADVANTAGES OF SDI
➢ Smaller wetting pattern
➢ Monitoring and evaluating irrigation events
➢ Soil/Application rate interactions
➢ Reduced upward water movement
➢ Less tillage options
➢ Restricted plant root development
➢ Row spacing and crop rotation issues
➢ Poor germination of seed  (Lamm et al., 2012)

2. SOIL MOISTURE DISTRIBUTION AND WETTING PATTERN
Moisture distribution pattern is one of the basic requirements for efficient design and management of an irrigation system. The knowledge of moisture distribution pattern helps in the effectiveness of drip irrigation (Yaragattikar et al., 2003). The extent of soil wetted volume in an irrigation system determines the sufficient amount of water needed to wet the root zone. In a study by Goya (2014), soil water stored in the root zone was determined by the volume of wetted soil.

2.1 Effect of Irrigation Level on Water Distribution Wetting Patterns under SDI System
Abass et al. (2013) conducted a research to study the feasibility of saving water by studying the distribution pattern of soil moisture content in the soil under subsurface irrigation systems. Experiments were designed for two levels of irrigation 4 Liter/h for two hours of application time (Level1 - 100%) and for one hour (Level2 - 50%). In the study the soil moisture content was measured at various depths by soil moisture sensors that did not cause any disturbances to crop root zone while measuring. The moisture contents were measured at different depths both parallel and perpendicular to the lateral line. Two-dimensional version of HYDRUS (Liga and Slack, 2004) or three
dimensional SURfer10 software (Kekkonen, et al., 2010) can be used for evaluating the water flow. Here, SURfer 10 computer software was used for simulating wetting pattern.

The figure showed that the volumetric water content at depth 40 cm was about 32-34%, however at depth 50 cm the moisture content in SDI was 36-38%. The moisture content was increased when applied 100% amount of water at 48 h. The result indicated that there were significant differences between irrigation levels I₅₀, I₁₀₀ at any irrigation systems. In addition, there were significant differences between the elapsed time measurements of 24 and 48 h after irrigation. The best wetting patterns were typically observed in the parallel direction, especially under the emitter, as compared with the perpendicular direction (Badr et al., 2011; Abass et al., 2013). It was clear that the soil moisture was distributed deeper for 48 h irrigation. The data show that after irrigation the soil moisture content increased in both horizontal and vertical directions to be near field capacity all over the soil profile. And also, the contour lines were close together especially perpendicular to the drip line, but the contour lines below the dripper line were more widely separated.

2.2 Effect of emitter spacing

Increasing the emitter spacing allows larger emitter passageways that results in reduced clogging. It also allows longer length of run or increased zone size by decreasing the dripline nominal flow rate per unit of length (Lamm and Camp, 2007). Excessive emitter spacing will cause inadequate distribution of water in the root zone. According to Arbat et al. (2010) the number of dripper emitters needed and the distance between them is determined by the size of the drip zone and the type of soil. Emitter spacing of 0.3 to 0.7 m is generally recommended for SDI. If the plant has a large drip zone, like a tree, it requires more emitters than for a small shrub. Evidently the size of the drip zone will be smaller when the plant is young and will increase in size as the plant grows. Therefore more emitters are necessary to water the drip zone of the plant when it is mature. In sandy soil the emitters will need to be closer together because the water does not move as far horizontally in sandy soil. In clay soil, where the water moves farther sideways, the emitters may be farther apart (Arbat et al., 2010). The figure shows that the volumetric water content in the soil profile was maintained at greater than 0.19 cm³/cm³. There were little or slight differences in volumetric water contents adjacent to the emitter and at the midway point between emitters for emitter spacing ranging from 0.3 to 1.2 m. Arbat et al., (2010) reported that there were no differences in corn grain yield or water productivity and they recommended that under full irrigation this range of emitter spacing (0.3 to 1.2 m) is acceptable.

2.3 Soil Moisture Distribution Patterns under Surface and Subsurface Drip Irrigation Systems

The soil moisture distribution and its uniformity within the soil profile under surface drip were affected by the distance between drippers rather than distance between laterals. Lesser the dripper spacing, more will be the moisture distribution. Under SDI, the allocation of the irrigation system plays an important role in soil moisture trend. The depth of the lateral below soil surface, emitter spacing and system pressure are important for delivering the required amount of water to the plant (Badr et al., 2011). Kheira (2009) reported that the surface drip system resulted in a good distribution of the soil moisture up to 60 cm depth for treatments such as 100%, 80% and 60% of ETₐ. The moisture distribution was found to be more uniform at 48 h after irrigation. This may be due to the high value of uniformity distribution in the surface drip irrigation system. Under subsurface drip, the water available in root zone was enough for plant growth. This is because under subsurface drip, the soil profile below effective soil depth became wetter due to minimum evaporation loss. Mokhtar et al., (2014) conducted an experiment to evaluate the effect of two drip irrigation systems; surface and subsurface system. For that, three levels of irrigation were applied viz. full irrigation (I₁₀₀) and deficit irrigation (I₅₀, I₃₀). Water with an ECₑ of 7.0 dS/m was used for irrigation. The average soil moisture content values under different irrigation treatments for surface drip irrigation (SDI) and subsurface drip irrigation (SSDI) methods at planting, development, mid-season and harvest period of the spring and
autumn potato crop are shown in the figure below. Moisture was directly related to the amount of water applied at full or deficit-irrigated treatments. Moisture in the soil profile initially showed higher moisture content in all the treatments due to the irrigation amount applied before planting to replenish the soil profile to field capacity. Initial soil moisture content in root zone area was about 17.37 and 18.04% in spring season and 17.03 and 18.11% in autumn season, respectively, for SDI and SSDI. They concluded that for all irrigation treatments significant differences were observed between the soil moisture content of the subsurface irrigated plots and those irrigated with the surface drip system. SSDI had higher value of soil moisture content than SDI’s.

Figure 4. Soil moisture content (% v/v) under different irrigation treatments (FI\(_{100}\), DI\(_{60}\), and DI\(_{30}\)) for surface (SDI) and subsurface drip irrigation (SSDI) methods during the two cropping periods of potato

2.4 How to improve uniformity in soil moisture distribution

The main problem regarding SDI system is the non-uniformity in moisture distribution. For minimizing non-uniformity of the drip system, it requires: a design which considers the topography of the field, periodic checking of the system (Clark and Phene, 1992), and irrigation scheduling (Burt et al., 1997). Greater irrigation uniformity can be achieved by using pressure-compensating emitters in surface and subsurface drip (Schwankl and Hanson, 2007). Other methods for improving uniformity are as follows:

i) Using synthetic soil conditioner
ii) Providing impermeable membrane
iii) Maintaining water application rate

i) Synthetic soil conditioners

Soil conditioner is a substance that can be added to soil for the purpose of changing the soil properties. It may consist of organic matters either plant or animal remains that are in various stages of decomposition, typically referred to as compost (Bodman et al., 1952). When this compost is added to the soil it begins to decompose immediately which provides an additional rich food source for the microorganisms in the soil. The microorganisms may add themselves to the organic composition of the Soil. The end product of this cycle is Humus. Humus increases the water holding capacity of soil. Soil Conditioner helps to balance out the Cation Exchange Capacity (CEC) within the different types of soil. Synthetic soil conditioners such as polyacrylamide (PAM) may change the properties of soil microbial biomass that helps to maintain the soil nutrients and water holding capacity of soil (Abedin et al., 2006).

Figure 5. Moisture distribution pattern trough two emitters at a dripline 15 cm depth, without polymer (a) and with polymer layer at 30 cm depth (b).

Abedin et al. (2006) found that the deeper the polymer depth was located, the better the water front distribution was progressed upward and downward.

ii) Providing impermeable membrane

To control the downward movement of water, impermeable barrier made of metal foil or polyethylene can be placed below the dripper lines. In soils with extremely high infiltration rates, this physical barrier helps to retain water that increases the crop yields compared to those in its absence in such a highly permeable soil (Elawady et al., 2003; Elnesr, 2012). It also helps to increase the water-use efficiency (WUE) by increasing the benefit from the applied water (Wang et al., 2004). However, in order to place the barrier, it is needed to excavate a deep wide trench, which is a labor intensive and costly. It may cause root rot and shallow root disease. Furthermore, potential hazards of salt accumulation and other toxicity problems are related to the accumulation of fertilizers and other chemicals (Elnesr et al., 2014).
iii) Maintaining water application rate
In general, the soil moisture decreases from surface soil layer (0-15 cm) to deeper soil depth (60-90 cm) in lower water application rate treatments. According to Yaragattikar et al., (2003), the soil moisture increased uniformly from surface layer towards deeper soil depths in higher water application rates (in fig. 5, T4 to T8). At emitter point, the distribution of soil moisture in higher application rates was uniform throughout soil depth (0-90 cm) and it progressively decreased in lower water application rate treatments (Yaragattikar et al., 2003).

4. MAINTENANCE OF SDI
A well maintained permanent SDI system should last more than 20 years. Maintenance program includes cleaning the filters, flushing the lines, adding chlorine, and injecting acids. These preventive measures will reduce the need for major repairs and extend the life of the system. The purpose of preventive maintenance is to keep the system more efficient (Juan et al., 2004).

4.1 Maintenance of Filters
Filters are the essential components of an SDI system. They remove suspended solids from the water. There are mainly three types of filters: cyclonic filters (centrifugal separators); screen and disk filters; and media filters. It is common practice to install a combination of filters to remove particles of various sizes and densities effectively (Juan et al., 2004).

i) Centrifugal separators
These filters need little maintenance, but they require regular flushing. The amount of sediment in the incoming irrigation water and the capacity of the collection chamber at the bottom of the filter should be considered while operating. It determines way in which the flushing valve needs to operate. Automated operation of the valve should be checked at least every other day during the season (Juan et al., 2004).

ii) Screen and disk filters
Small screen filters use a nylon strainer or bag that should be removed separately and checked for small holes. The flush valve controls the flushing of the screen filter. This can be operated manually or automatically. Automatic filters use a device called a “pressure differential switch” to detect a pressure drop across the filters. Automated flushing devices should be checked at least every other day on large systems (Juan et al., 2004).

ii) Sand media filters
The most important task is to adjust the back-flush adjustment valve. If the backflow rate is too high, sand filter media will be washed out of the filter container. If the backflow rate is too low, contaminating particles will not be washed out of the filter. Therefore optimum backflow rate should be provided. Bacterial growth and the chemistry of the water can cause the sand media to cement. Cementing of the media causes formation of channels in the sand, which can allow contaminated water to pass unfiltered into the irrigation system. Chlorination can correct or prevent sand media cementing (Juan et al., 2004).

4.2 Flushing lines and manifold
Very fine particles that pass through the filters can cause clogging of emitters. Systems must be designed so that mainlunes, manifolds (submains) and laterals can all be flushed. Mainlunes and manifolds are flushed with a valve installed at the very end of each line. Lines can be flushed manually or automatically. It is important to flush the lines at least every 2 weeks during the growing season (Juan et al., 2004).

Table 1. Water uptake results in three treatments

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average water uptake per plant per week, ml</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative pressure</td>
<td>14.17</td>
</tr>
<tr>
<td>Zero pressure</td>
<td>11.91</td>
</tr>
<tr>
<td>Hand-watered</td>
<td>16.07</td>
</tr>
</tbody>
</table>

The water uptake rate for the negative pressure treatment was approximately 10% less than that of hand-watered, and 18% greater than the zero pressure. The uptake rate for the zero pressure treatment was 34% lower than the hand watered treatment. Thus, the negative pressure treatment had a better water uptake rate compared to the zero pressure treatment.
4.3 Chlorine injection
According to Alam et al., (2012) chlorination is the most common method for treating organic contaminants. Active chlorine is a strong oxidizer as well as useful for the following:

A. Prevent clogging and sedimentation of organic substances
B. Destroy and decompose sulfur and iron bacteria, as well as accumulated bacterial slime in the system.
C. Improve performance of filtration systems while reducing back flush water.
D. Clean systems of organic sediments.

If the micro-irrigation system water source is not chlorinated, it is a good practice to equip the system to inject chlorine to suppress microbial growth. Since bacteria can grow within filters, chlorine injection should occur prior to filtration (Alam et al., 2012).

4.4 Acid injection
Alam et al., (2012) stated that acids should be injected into irrigation water to eliminate plugging caused by calcium carbonate (lime) and magnesium precipitation. They used acids for the following purposes also:

a) To lower the pH of irrigation water
b) To reduce the potential for chemical precipitation and c) To enhance the effectiveness of the chlorine injection.

From their study, it is clear that sulfuric, hydrochloric and phosphoric acid can be used. Acid is usually injected after the filter so that it does not corrode the filter. If the filter is made of polyethylene, which resists corrosion, acid can be injected before the filter. Acid can be injected in much the same way as fertilizer; however, extreme caution is required (Alam et al., 2012).

5. CHALLENGES IN SDI

i) Emitter clogging
The major cause of failure of SDI systems is clogging of the emitters. Proper maintenance is necessary for an efficient SDI system. Emitters can be easily clogged by small particles, since they have very small diameter. If the emitters are clogged, it may difficult to unclog them. Therefore it is necessary to avoid those particles that cause clogging. Clogging by soil particles can be prevented by proper filtration and flushing. Chemical precipitates are removed by injecting acids to the irrigation water. To eliminate biological precipitates, chlorine is usually injected (Sinobas et al., 2012). Crop roots that grow around the driplines also can plug emitters, especially when the soil around the dripline is dry. The phenomenon is known as root intrusion. Keeping the soil around the dripline sufficiently wet and injecting chemical products to kill those roots are used to alleviate this problem. Non-pressure compensating emitters are also used for preventing root intrusion (Marais et al., 2000).

ii) Rodents
Some rodents like field mice can cause severe damage to driplines. Evidence of leak can be detected by periodic inspection and by measuring pressure drops and high flow rates in the system. Since locating and fixing leaks created by rodents is a difficult task, the potential for rodent attack in the area should be evaluated prior to installation. Rodent control and prevention program can be implemented, if needed (Marais et al., 2000).

iii) Seed germination
Since the driplines are below the ground surface, it keeps the surface dry. It creates a problem on seed germination, especially in sandy soil. This can be minimized by providing optimum depth of installation of driplines.

iv) Soil salinity
In arid regions, the growth may be affected due to salinity. It may take relatively long time to solve. The main factor when considering salinity problem is the quality of water used for irrigation.

v) Surfacing or chimney effect
If water is applied at a rate greater than the infiltration rate of soil, a saturated zone will develop around the dripline. The water under pressure may take the path of least resistance. If the dripline is sufficiently close to the surface, water and soil particles could pop up to the surface, creating a wetted area above each emitter. This is known as surfacing or chimney effect. It can sometimes be avoided by deeply placed driplines. The choice of emitter discharge must be considered to avoid surfacing (Lamm et al., 2009).

vi) Aerogation
Subsurface drip irrigation system provides water directly to the crop root zone. Long duration irrigation events result in root development concentrated around the emitters resulting in lack of air, which prevents the proper root functioning and it directly influences the crop growth. This can be minimized by applying air in the root zone. Continuous application of air can improve the distribution of soil moisture in the root zone that provides high crop yield (Vyrhas et al., 2014).

6. CONCLUSION
All things considered, SDI is a highly efficient irrigation system which can improve the management of both irrigation water and crop nutrients. The interest in SDI has increased rapidly for the last 30 years, because of the improved commercial products, use of the system for multiple years and the need of water conservation. Subsurface drip irrigation has a number of potential advantages over conventional surface irrigation; it curtails weed growth and reduces water loss due to high irrigation uniformity. It increases water application efficiency. Since the soil surface remains dry, weed problem is also negligible. However, SDI may have significant problems like seed germination, non-uniformity of water application, emitter plugging etc. By providing adequate depth to driplines, seed germination can be enhanced. Impermeable membrane helps to improve uniformity in water application. Also, emitter plugging can be minimized by injecting acid or chlorine. Switching from furrow irrigation to SDI can result in significant water savings. The future of SDI appears to be good. As limiting the number of water resources and need of water conservation increases, application of SDI should also increase. This advanced technology offers more efficient delivery system and low wastage of water than other conventional irrigation systems.
7. REFERENCE


