1.0 INTRODUCTION

This Controlled Drainage Sub-irrigation (CDSI) Guide has been prepared as a complement to the Drainage Guide for Ontario, released in October 2007 by Ontario Ministry of Agriculture, Food and Rural Affairs. This is the first version of an Ontario CDSI Guide and attempts to integrate research and practical experience from Ontario and elsewhere to guide farm scale design, installation and management of water table control infrastructure for drainage control and crop subirrigation.

The objective of water table management is to make more effective use of rainfall and improve the soil environment for efficient stable year to year crop yields while minimizing fertilizer and energy inputs. The consequence is optimum uptake of available nutrients by crops and minimal loss through surface and subsurface drainage.

An important complementary reference for detailed design is Chapter 10 'Water Table Control' Part 624 Drainage National Engineering Handbook, Natural Resources Conservation Service, United States Department of Agriculture (2001). The British Columbia Agricultural Drainage Manual also contains CDSI Design information.

This initiative is consistent with Canada- Ontario Water Supply Expansion Program (COWSEP) to position Canada's agri-food community as a world leader.

This project has received continuing project guidance through a Technical Steering Committee composed of representatives from Land Improvement Contractors of Ontario (LICO), Agriculture and Agri-Food Canada, Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) and the Ontario agricultural community.

1.1 Definitions

The following CDSI related definitions are provided in alphabetical order.

1.1.1 Allowable Subirrigation Water Table Sag

The amount of water table sag that may be tolerated midway between the ditches or subsurface drains and still provide the water needed to meet crop evapotranspiration demands. The allowable sag is determined by the drain spacing and saturated lateral and vertical hydraulic conductivity of the soil environment.

1.1.2 Allowable Water Table Drainage Mounding

The amount of water table mounding that may be tolerated between the ditches and subsurface drains. The allowable mounding rise is determined by consideration of the crop sensitivity to root zone saturation, drainage coefficient, effective rooting depth, drain spacing soil capillarity and soil hydraulic conductivity. Mounding takes the form of a water table ellipse between the drains.

1.1.3 Aquifer Vulnerability

Aquifer Vulnerability means an aquifer's intrinsic susceptibility, as a function of the thickness and permeability of overlying layers, to contamination from both human and natural impact on water quality (ORMCP, 2001).

1.1.4 Capillary Fringe

The **capillary fringe** is the subsurface layer or soil immediately above the water table in which groundwater seeps up from a water table by capillary action to fill open soil pores. The size of the diameter of the soil pore defines the capillary rise of the water column.

1.1.5 Carbon Sequestration

Carbon sequestration is the capture of atmospheric carbon (carbon dioxide) and storing it by one of several mechanisms to reduce this greenhouse gas and its contribution to global warming. Carbon may be stored in living (green vegetation and forests) or in non-living reservoirs (soil, geologic formations, oceans, wood products).

1.1.6 Conservation Drainage

Conservation drainage is the term used in this guide to describe seasonally closed loop, controlled drainage subirrigation recycle pond systems and yield management (low-moderate-high) for low nutrient residuals in drainage water.

1.1.7 Controlled Drainage

Controlled Drainage is the regulation of the water table by means of pumps, control dams, check drains, water level control devices or combination to maintain the water table at a depth favourable for crop growth.

1.1.8 Crop Water Deficit

Crop water deficit is generally defined as the difference between the potential and actual evapotranspiration. Production is a maximum when the crop can transpire water at the potential rate. However because of insufficient or poorly timed precipitation actual transpiration is usually significantly below potential evapotranspiration (Tan and Reynolds 2003).

1.1.9 Depth to Impermeable Layer

An impermeable layer at shallow depth (1 to 2 m) facilitates maintenance of water tables and prevents excessive vertical leakage losses. The vertical hydraulic conductivity of the impermeable layer is measured or estimated. By definition the impermeable layer has only about 10% of the vertical hydraulic conductivity of the surface layer.

For most Ontario soils developed on fine textured moraine and lacustrine/marine deposits the impermeable horizon will be the ‘C’ horizon which will require close drain spacing. However there are also are a number of fine textured soils with a coarser surface veneer (less than 1 m depth) of fine sands, silty sands and sandy silts. These soils have seasonally perched water tables (imperfect or poor drainage) and may permit wider drain spacing for subirrigation and watertable control.

Deeper impermeable layers may result in significant shallow lateral seepage and create difficulties for raising the water table.

1.1.10 Depth of Root Zone

The depth of root zone influences how the water table control is designed and managed. In humid climates root zone depths range from about 30 to 75 cm for field crops and to about 90 cm for orchards and vineyards. Root zones may be restricted by dense soil layers or watertables. Depth to the root zone should be determined on site by inspection.

1.1.11 Drainage Coefficient

The drainage coefficient is expressed as depth of water to be removed from an area in 24 hours (mm/day). The depth varies with crop type and sensitivity to root zone flooding. The drainage coefficient is utilized to determine the size of subsurface conduit required to provide adequate drainage of gravitational water from the crop root zone. Controlled drainage with higher water tables may require use of increased drainage coefficients.

1.1.12 Early Planting

Early Planting refers to the practice of crop planting in late April or early May. Early planting allows controlled drainage capture and storage of an additional soil moisture compared to planting in late May or early June.

1.1.13 Effective Root Zone Depth

Normally for most plants about 70% of the moisture is extracted from the upper half of the root zone. This is usually the top 30 cm of the root system on shallow rooted crops (USDA, 1971). Assuming an unrestricted root zone, the upper half of the root zone should be used as the effective zone for the design and management of water control. A factor of safety is added to the effective root depth to determine design water table depths at the ditch or subsurface drain. The minimum factor of safety is 15 cm but up to 30 cm is preferred.

1.1.14 Environmental Benefits

Environmental benefits of closed loop controlled drainage subirrigation systems include reductions in agricultural pesticide and nutrient loading to streams and lakes. Storage ponds provide seasonal waterfowl habitat for resting and staging.

1.1.15 Hydraulic Conductivity (Saturated)

Hydraulic conductivity is the rate at which water moves through a soil and is the most important soil property influencing design of water table control. Both vertical and lateral hydraulic conductivity under saturated conditions should be assessed. Lateral conductivity determines drain spacing and lateral seepage losses and vertical conductivity determines leakage rates to deeper ground water systems. This rate of water movement depends on both the primary characteristics of the soil and secondary management history of the field site including cracks, fissures, worm holes and root tubes.

If the saturated hydraulic conductivity is known for future site conditions and treatments drain spacing may also be estimated from by Dr. S.B. Houghoudt’s ellipse equation for homogeneous soils. (see Appendix B Ontario Drainage Guide (2007)). Chapter 10 Water Table Control Part 624 National Engineering Handbook USDA (2001) provides additional analytical procedures for determination of hydraulic conductivity, water table mounding (ellipse) and sag between drains to estimate drain spacing. This document also includes a description of the preferred soil auger method of determining hydraulic conductivity.

The soil auger method is the preferred field method for determination of lateral hydraulic conductivity. Lateral hydraulic conductivity is determined under saturated soil conditions.

1.1.16 No Tillage

No-Till crop production systems have been shown to reduce production costs, soil erosion, organic matter loss and soil compaction relative to Conventional Tillage. Research indicates that No Till plots contain numerous earthworm casts and about one and one half times the macroporosity. Earth worm channels increase infiltration and reduce surface runoff in long term No Tillage fields and as a consequence increase downward movement of water to subsurface drains.

No Tillage has been shown to result in greater soil wet aggregate stability and hence improved soil structure relative to conventional tillage treatment. However No Till soils in the spring are frequently wetter and colder at the surface due to the crop residue cover and delay planting. It may be difficult to No Till wetter soils.

1.1.17 Nutrient Management

The installation of seasonally closed loop controlled drainage and subirrigation systems with recycle ponds is recognized as a farm best management practice and may form an important component of farm nutrient management plans. The water recycling system may be utilized to recapture nutrients which may seep through soil macro pores and fissures directly into the subsurface drainage system at manure spreading time.

1.1.18 Recycle (Storage) Ponds

Recycle ponds are constructed reservoirs used for collection and storage of surface and subsurface drainage runoff and are utilized as a source of subirrigation water. Together with subirrigation the system may be operated as a seasonal closed loop system most of the time during the growing season.

Controlled drainage and recycle ponds provide a system for interception, capture and reapplication of fertilizer residuals and manure nutrient runoff which would have previously been lost through the conventional subsurface tile systems.

Recycle ponds are a key component of farm nutrient management. Water quality and waterfowl benefits also accrue from the presence of recycling ponds.

1.1.19 Seasonal Priority for Crop Moisture

With respect to corn and soybeans plants, May and June is a period of germination and vegetation growth while July August is a period of flowering and grain filling. For both corn and soybeans, moisture availability is most critical as flowering is initiated. The second most critical time is germination followed by filling stages (Doorenbos et al, FAO, 1979). In southern Ontario moisture reserves are generally abundant at the crop germination stages due to spring snowmelt and early spring rainfalls. Moisture deficits occur mainly through late June, July and August. Rainfall in September will usually have more limited benefit since crop maturity has been reached.

1.1.20 Soil Aeration

Soil drainage is a natural process by which water moves out of the soil under the force of gravity and is replaced by air. This aeration process is vital for plant roots and for many beneficial organisms that live in the soil and require oxygen for respiration. In some soils the natural drainage of water is rapid enough to prevent the death of plant roots and microorganisms from lack of oxygen. In other soils accelerated drainage is needed to remove water from the pores and replace oxygen quickly enough after a heavy rainfall so that plants and organisms can survive.

Soil is comprised of between 30 and 70% solid material. This leaves 30 to 50% of the soil volume that is comprised of void space that can be filled with either air or water. A small amount of the solid phase is organic material. Organic material has a significant positive impact on drainage, aeration and trafficability. Fluids (air and water) tend to move rapidly through sandy soils due to the presence of large uniformly distributed void spaces. Silt soils have smaller void spaces which support slow movement of fluids. Clay soils have very small voids and very slow fluid movement. Silt and clay soils with many small pores experience slow movement of fluids and entrapment of air within pores during rewetting events. Therefore if soils become too dry subirrigation may take an extended period to be effective.

Soils with a range of pore sizes, some macropores, some large pores between aggregates and some smaller pores within aggregates are usually better suited to agricultural use and accelerated drainage installations.

1.1.21 Soil Aggregates

Mixtures of sand, silt and clay soil particles and organic material in the soil become bonded together forming larger units with visible structure. These larger units are called aggregates. Within the aggregates there are small voids. Between the aggregates the void sizes are larger. Water moves rapidly through soils with durable aggregates. Aggregates are dynamic, accelerated drainage tends to reduce the general size of the aggregates but increase their stability. Tillage tends to disrupt aggregates decreasing void size. Addition of organic matter (manure) enhances aggregate development and soil drainage.

1.1.22 Soil Management

Well managed soils with high organic content form stable aggregates with external secondary macropores and improved drainage to the subsurface. Similarly crop rotation with forage crops improves water infiltration to subsurface drains and increases soil water storage and availability. Dry soils also develop shrinkage cracks and fissures which provide direct connections to subsurface drainage. No Tillage soil treatments drain to the subsurface faster than Conventional Tillage. However soil compaction and crop monoculture deterioration of soil aggregates and secondary macropore condition may decrease drain performance. Controlled drainage may also preclude formation of deeper shrinkage cracks and fissures which contribute to secondary hydraulic conductivity and moisture storage.

1.1.23 Subirrigation

Subirrigation is the application of irrigation water below the ground surface by raising the water table to within or near the root zone. Subirrigation distributes water evenly beneath the field, eliminates obstacles in the field, more effectively uses rainfall and drainage water and eliminates water losses by evaporation.

Subsurface irrigation involves pumping water back into the subsurface drains during water deficit periods to provide irrigation water directly to the crop root zone. Water is pumped behind water level control devices installed in the main drain creating a pressure head that forces water back up the drain lines and into the crop root zone. This is a highly efficient low energy form of irrigation and water conservation for field and vegetable crops.

Subirrigation with controlled drainage and yield management achieves more complete use of fertilizer by crops. By comparison, where subsurface horizontal and vertical seepage losses are minimal, subirrigation requires substantially less water than overhead spray irrigation systems, conserves water and takes optimal advantage of rainfall events. Commercial fertilizer and manure nutrient runoff may be recycled back to the crop through the subirrigation system.

1.1.24 Subsurface Drainage

Subsurface drainage is the removal of excess water from the crop root zone by water movement within the soil (below the land surface) to underground conduit or open ditches.

1.1.25 Surface Drainage

Surface drainage is the diversion or orderly removal of water, that cannot infiltrate, from the surface of the land by means of improved natural or constructed channels, supplemented when necessary by shaping and grading of land surfaces to such channels.

1.1.26 Trafficability

Water acts as a lubricant between soil particles, decreases the friction between soil particles and reduces the strength and ability of the soil to carry the weight of machinery. In very wet but not saturated soils trafficability can also be impeded by clay particles sticking to tires of machinery. Organic matter increases soil elasticity and the resistance to deformation and therefore improves trafficability. Closely spaced drains increase trafficability.

The relative amount of air and water in the soils determines the ability of the soil to bear the weight of machines. Cultivation loosens the soil resulting in more voids and a lower bulk density. Heavy machine traffic compacts the soil resulting in fewer voids and a higher bulk density.

1.1.27 Water Table Control

Water table control is the removal of excess water (surface and subsurface) through controlled drainage with the provision to regulate the water table depth within desired parameters for subirrigation.

1.1.28 Water Table Elevation Zones

The partitioning of fields into vertical water table control zones in typical increments of 15 to 30 cm. Water levels are maintained within the individual elevation zones by outlet control devices including weirs, flashboards and valves.

1.1.29 Water Table Management

Water Table Management is the operation of the drainage water conveyance infrastructure so the water table is adequately lowered during wet periods and maintained or raised during dry periods to meet the demands for optimal crop yield during the growing season and for optimum soil management during the non growing season. Generally the water table should not be held within the effective root zone of the crop being irrigated.

Water table management is implemented by controlled drainage, subirrigation and recycle ponds.

1.1.30 Yield Management

Yield management refers to the adoption of realistic crop yield objectives and adjusting the necessary nutrient and management inputs based on the needs of the crop and soil fertility levels. Yield management provides the opportunity to manage the crop for consistent stable yields with improved prediction of fertilizer input requirements and reduction of end of season soil and water nutrient and pesticide residuals. Management may be for high, medium or low yields.

Controlled drainage with subirrigation stabilizes yields and is an effective strategy for risk reduction from having too much or too little water and is much less dependent upon rainfall events, crops grow with higher yields regardless of weather conditions (after Fausey, 2002). Yield increases up to 80 or 90% in dry years and 40 to 50% over the long term for well managed systems may be achieved. However in occasional years of increased and well distributed summer rainfall there may be little or no increase in yield.

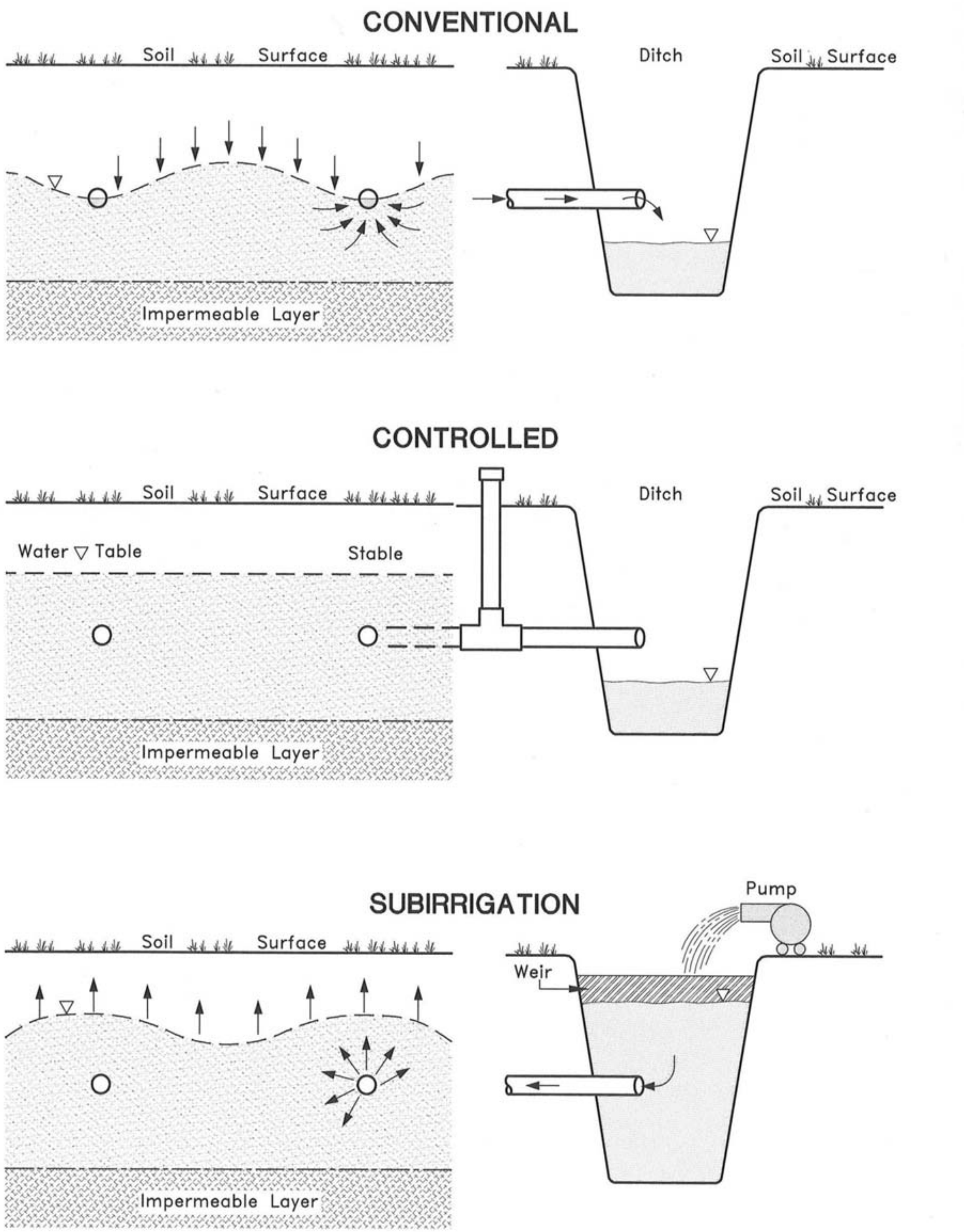


Figure 1.1 Three modes of a drainage system (*B.C. Agricultural Drainage Manual*, 1997)

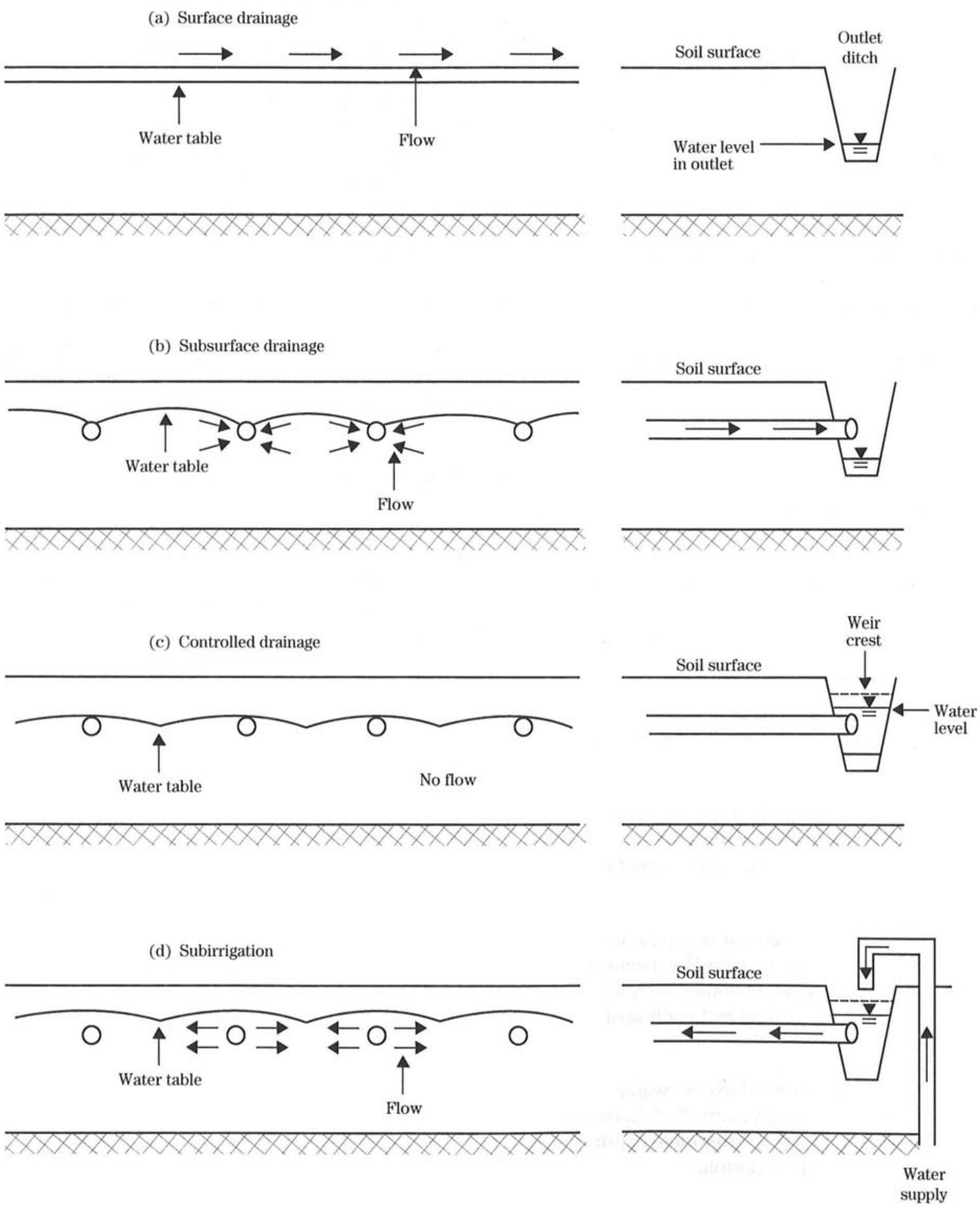


Figure 1.2 Flow direction and water table position in response to different water management alternatives (*National Engineering Handbook Part 624 Chapter 10*, USDA, 2001)

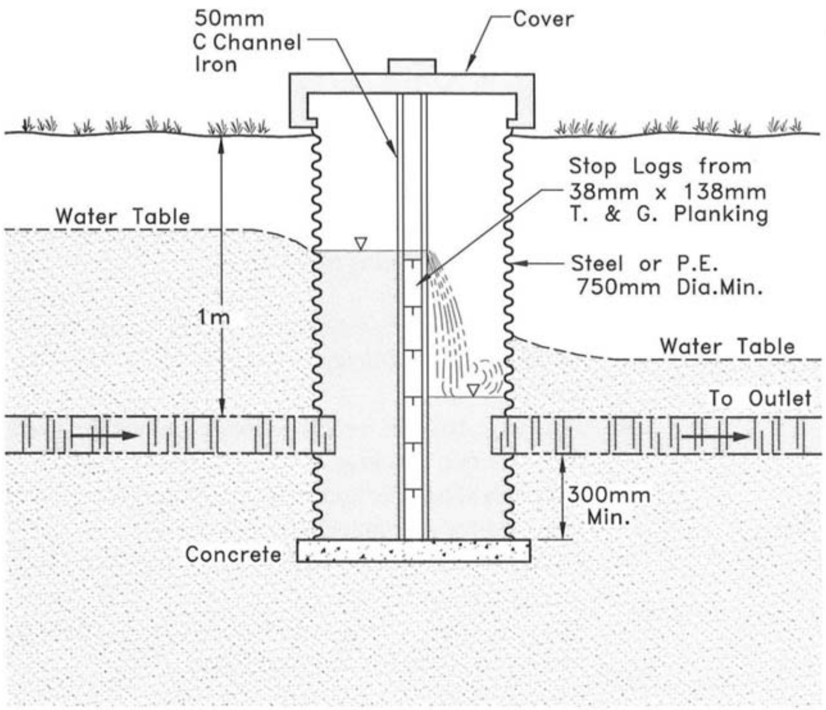


Figure 1.3 Flashboard Type Design (*B.C. Agricultural Drainage Manual*, 1997)

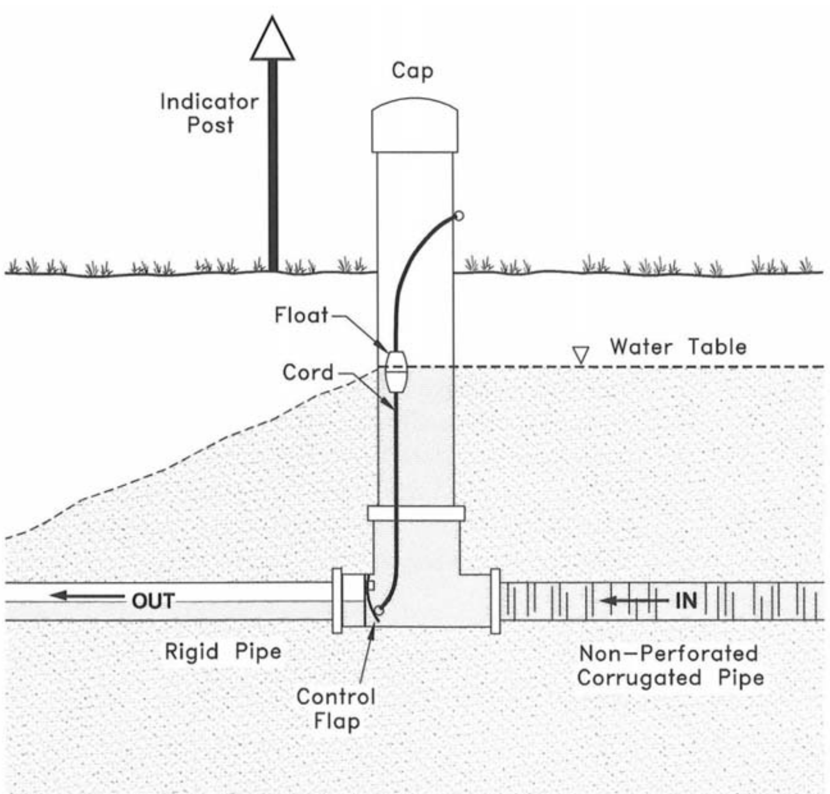
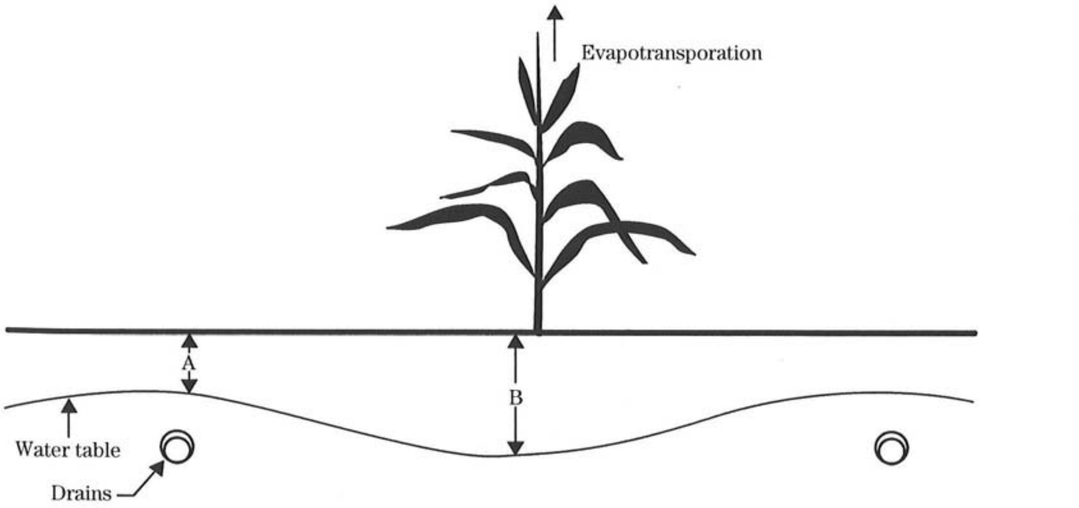


Figure 1.4 Float Type Design (*B.C. Agricultural Drainage Manual*, 1997)



A Tolerable water table elevation above drains or in ditches. This elevation is dependent on the effective root zone.

B Allowable sag in the water table midway between the drains or ditches. The allowable sag is dependent upon the soil's ability to transport water from the water table to the effective root zone at the rate that water is being used by the plant during periods of peak evapotranspiration.

Figure 1.5 Allowable sag of the water table midway between drains or ditches and the tolerable water table elevation above drains or in ditches during subirrigation (*National Engineering Handbook Part 624 Chapter 10,* USDA, 2001)

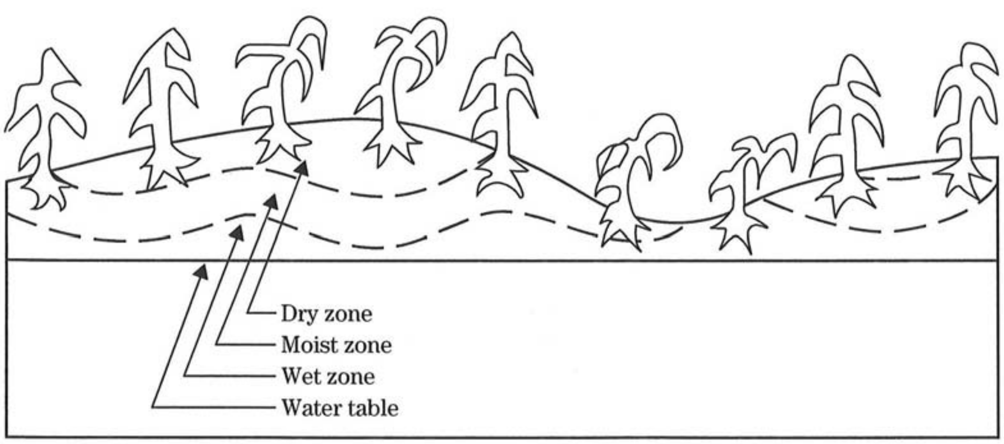


Figure 1.6 Uneven moisture distribution occurs with subirrigation when the surface is not uniform (*National Engineering Handbook Part 624 Chapter 10,* USDA, 2001)

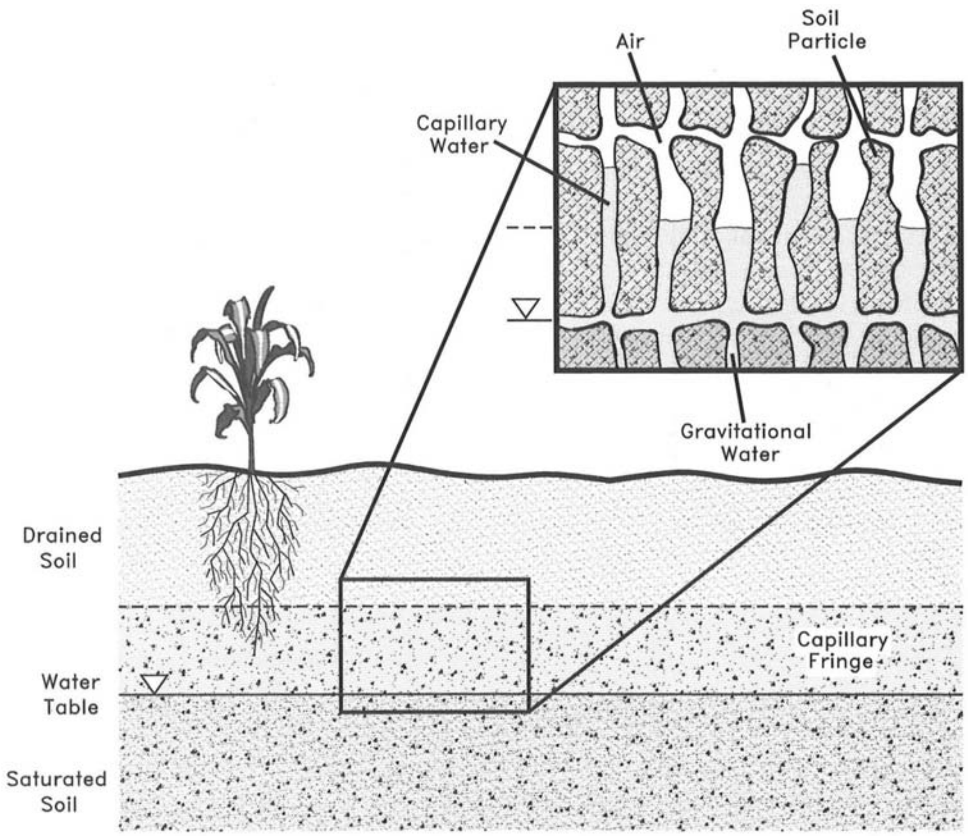


Figure 1.7 Capillary Fringe
(*B.C. Agricultural Drainage Manual*, 1997)

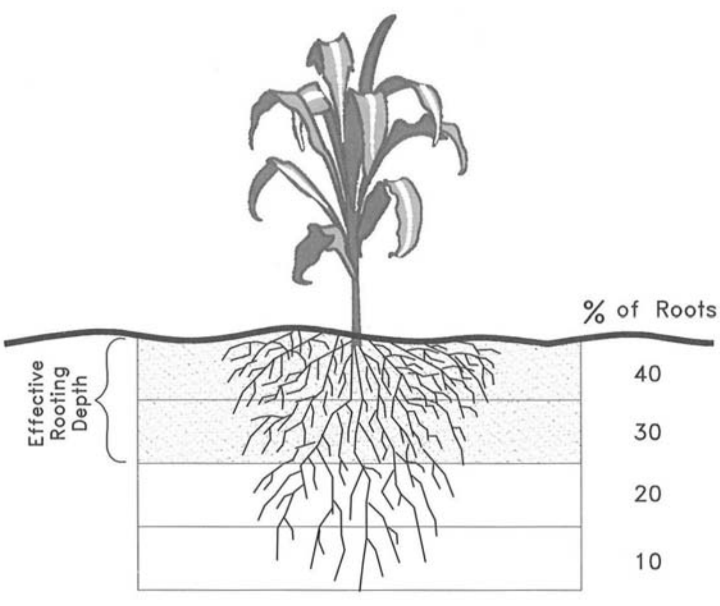


Figure 1.8 Effective Rooting Depth
(*B.C. Agricultural Drainage Manual*, 1997)

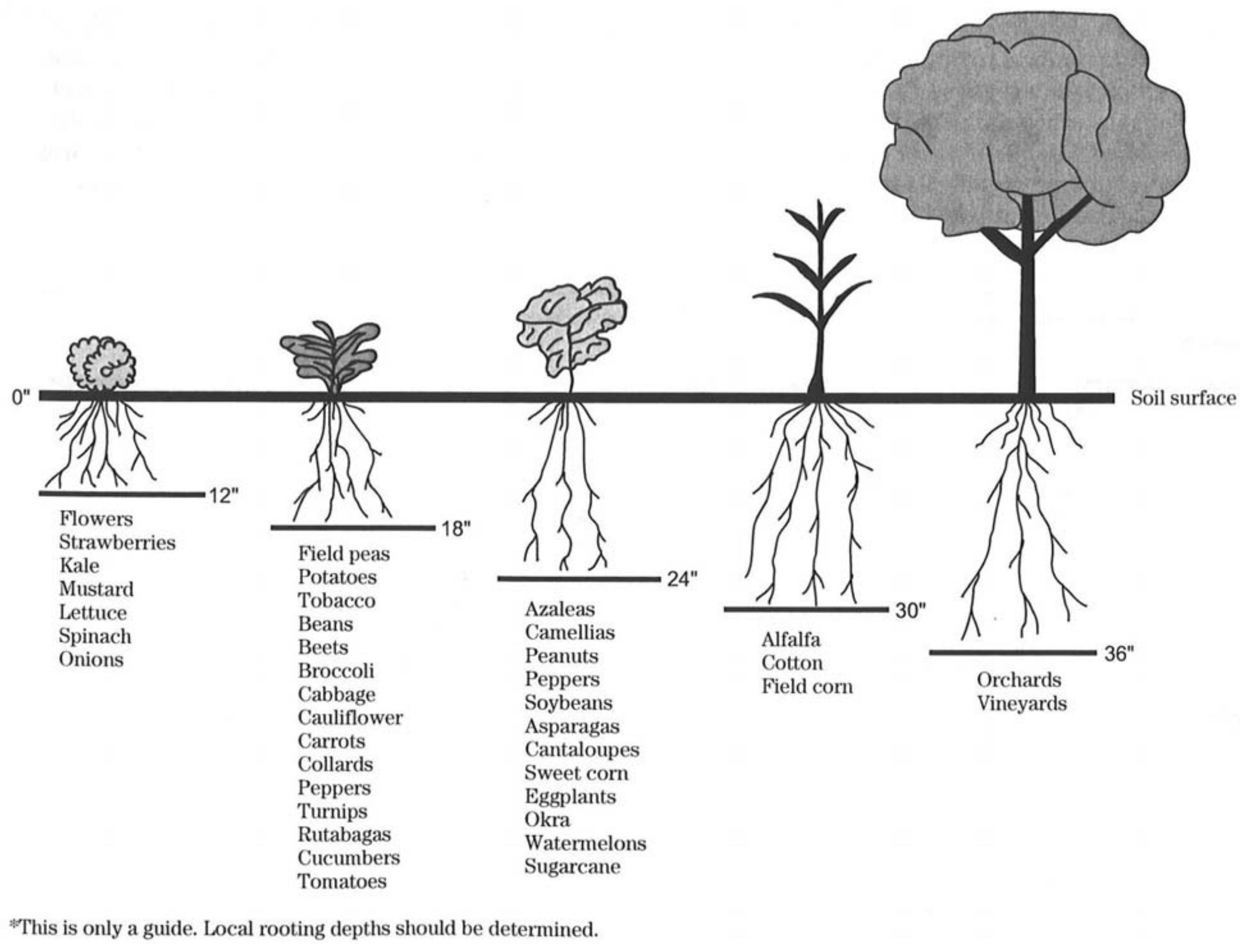


Figure 1.9 Typical rooting depths for crops in humid areas (*National Engineering Handbook Part 624 Chapter 10,* USDA, 2001)

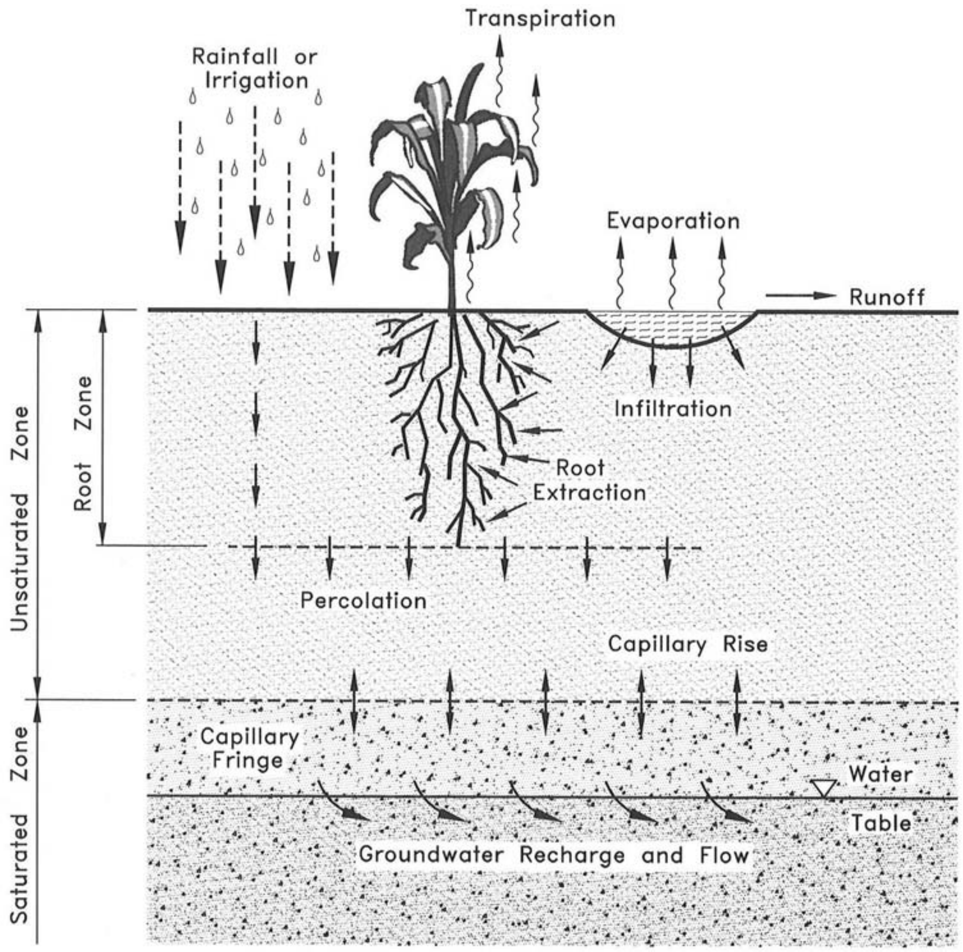


Figure 1.10 The Soil Water Balance in the Root Zone (*B.C. Agricultural Drainage Manual*, 1997)

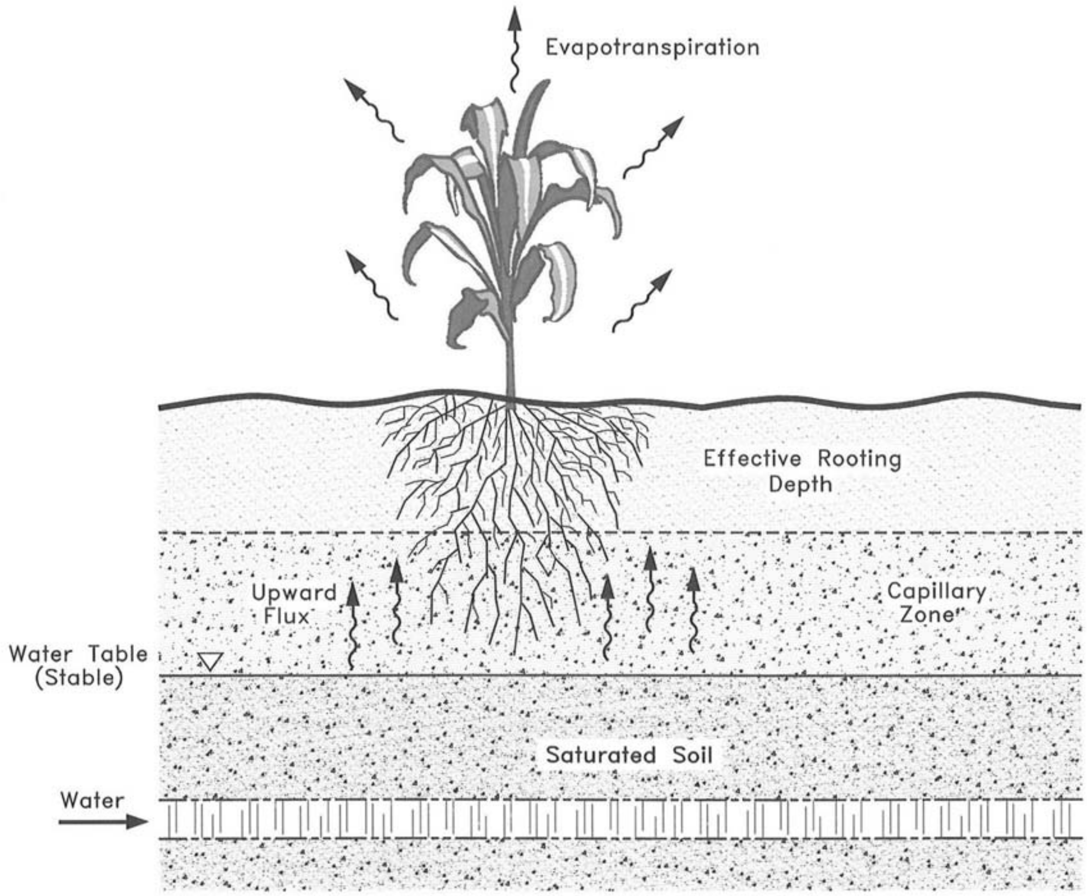


Figure 1.11 Water Table Design Depth
(*B.C. Agricultural Drainage Manual*, 1997)

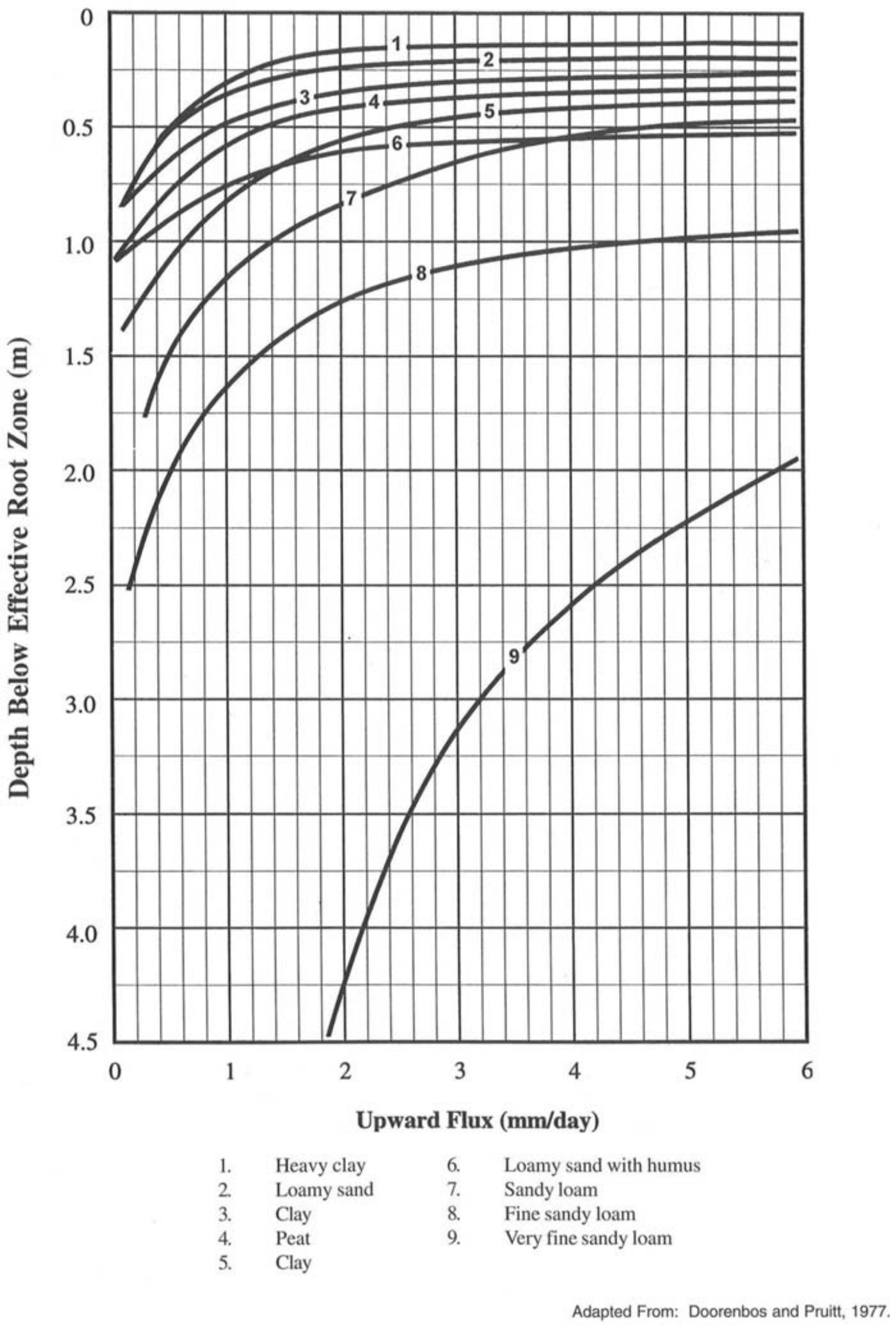


Figure 1.12 Upward Flux vs. Water Depth for Different Soils
(*B.C. Agricultural Drainage Manual*, 1997)

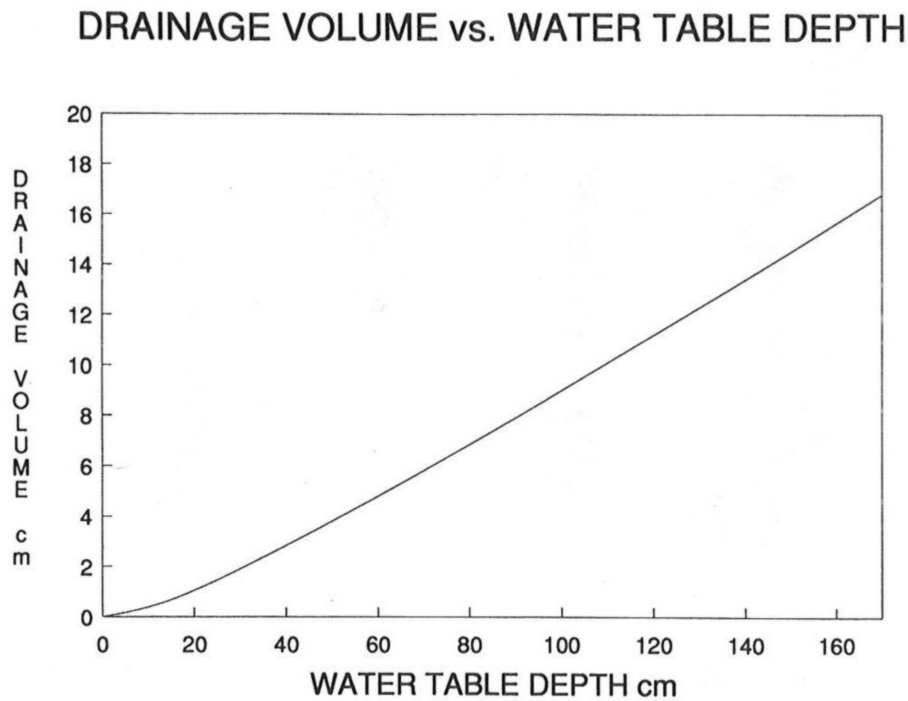


Figure 1.13 Drainage volume curve for a Ste. Rosalie clay (Madramootoo, 1990)

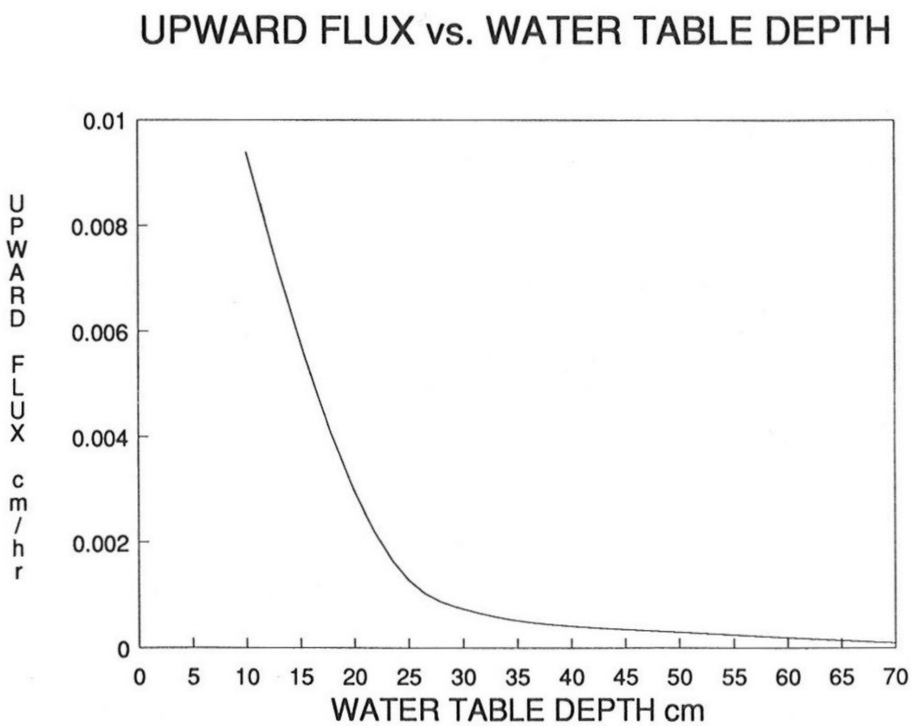


Figure 1.14 Upward flux curve for a Ste. Rosalie clay (Madramootoo, 1990)

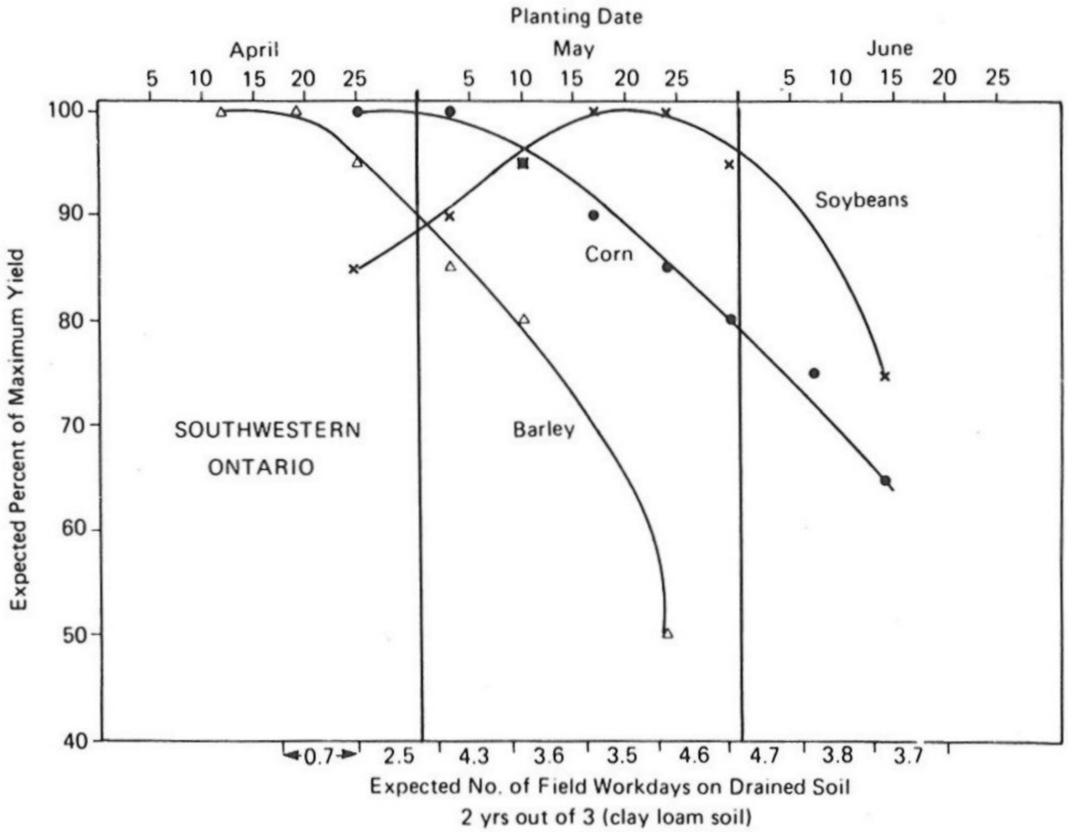


Figure 1.15 Effect of planting date on crop yield
(Irwin, 1994)