2.0 RESEARCH OVERVIEW

Agricultural controlled drainage research in Ontario and in nearby northwestern Ohio was initiated on long term plots and at field scale in the early to mid 1990's. This period has been observed to coincide with decreasing summer precipitation trends, more frequent growing season water deficits (droughts) and intensifying summer rainfall storm events. Controlled drainage alone on plots and at field scale produced modest average crop yield improvement, but did not produce year to year stable high crop yields. Furthermore, controlled drainage alone did not provide sufficient opportunity to manage drainage water or nutrient residuals to close tolerances.

There is a decided trend in southwestern Ontario to closer and closer free subsurface drain spacings. Parallel drains installed even in recent decades for cash crops (corn and soybeans) on Brookston soils are now being split from 18 m (60 ft) to 9 or 6 m and from 12 m (40 ft) to 6 m (20 ft). Specialty crop areas drains are being split from 6 m to 3 m or less. Closer drain spacings support improved trafficability, earlier planting, and flexible cropping for extended season harvest machinery utilization. However, closer drain spacing without water table controls reduces the soil moisture available to support crop growth.

Tan et al (2001) quoting various researchers stated that one of the main challenges to agricultural on fine textured soils in Ontario is managing the amount and temporal distribution of soil water in the crop root zone. Too much water may result in insufficient root zone aeration and it may also impede or prevent critical tillage, planting and harvesting operations. Too little soil water on the other hand may cause crop drought stress and subsequent yield reduction.

Using controlled drainage-subirrigation and recycling ponds researchers have shown that farmers can more efficiently conserve moisture and better manage their crops, leading to higher and more consistent yields across several years, while at the same time using resources more efficiently. Estimates from Agriculture and Agri-Foods Canada research plots in Essex County (Harrow, Ontario) have shown dramatic yield increases for common crops such as soybeans, corn and tomatoes. Agricultural Canada reports that in dry years corn yields increased by 90% where soybean and tomato yields increased 50%, all while at the same time ensuring minimal water and nutrient loss from the system.

Increases in crop yields using controlled drainage-subirrigation and storage ponds is further supported by research in Northwestern Ohio where similar systems have shown increases in corn and soybean yields of 48% and 40%, respectively (Fausey, 2005; USDA, 2005).

Controlled drainage-subirrigation systems work on a seasonally closed loop system trapping runoff water in recycling ponds, this maximizes the water use efficiency, increases crop yields, while minimizing runoff of suspended nutrients and chemicals (Melvin and Kanwar, 1995; Allred, 2000). Fausey (2005) estimates that these systems reduce water use by 40% and nitrate loss by 45%. Furthermore, conservation drainage systems also increase the amount of carbon sequestration into soils and vegetation rather than releasing it into the atmosphere as carbon dioxide (Luckeydoo et al., 2002; Allred, 2003).

Design of controlled drainage subirrigation systems in Southern Ontario currently must rely on results published for plots of limited field scale. Technology transfer and scale up to larger field sizes has not been formally documented.

Researchers have often reported using similar fertilizer applications in controlled as in conventionally drained plots. This is likely because of researcher propensity to reduce comparative plot variables by managing conventional and controlled drainage plots in a similar manner. However, year to year variations in precipitation (wet, average and dry) influence nutrient use and residuals especially for non-irrigated free draining unstable yield sites.

In Ohio research sites managed by farmers produced higher yields. Small research plots may have significant edge effects including increased lateral seepage losses compared to a farm scale implementation. Production variations over and between subsurface drains may not be apparent in small plots.

2.1 Climate and Water Deficit Trends

Water deficits and trends in Southern Ontario are described in this section.

2.1.1 Controlled Drainage-Subirrigation Influences on Tile Nitrate Losses and Corn Yields on Sandy Loam Soils (Ng et al, 2001)

Ng et al (2001) reported 35 year averages as follows:

For years 1960 to 1993 at the Eugene Whelan Experimental Farm at Woodslee, Ontario (Rochester Township, Essex County)

Table 2.1 Water Deficit 35 Year Averages

	May	**June**	**July**	**August**	**September**	**TOTAL**
Potential Evapotranspiration (mm)	96.4	113.2	126.6	121.0	70.7	527.9
Rainfall (mm)	72.7	97.4	88.6	82.1	80.7	421.5
Difference	23.7	15.8	38	38.9	(10.0)	104.4

The summer (June, July, August) water deficit 1960 to 1993 averaged 92.7 mm and summer potential evapotranspiration 360 mm. Growing season water deficit was 104.4 mm.

2.1.2 Impacts of Recent Climate Trends on Agriculture in Southwestern Ontario (Tan and Reynolds, 2003)

Tan and Reynolds (2003) reported based on 10 year moving averages that precipitation in southwestern Ontario has changed substantially over the last 80 years (Fig 2.1). Precipitation has been declining and water deficits increasing over the last two decades.

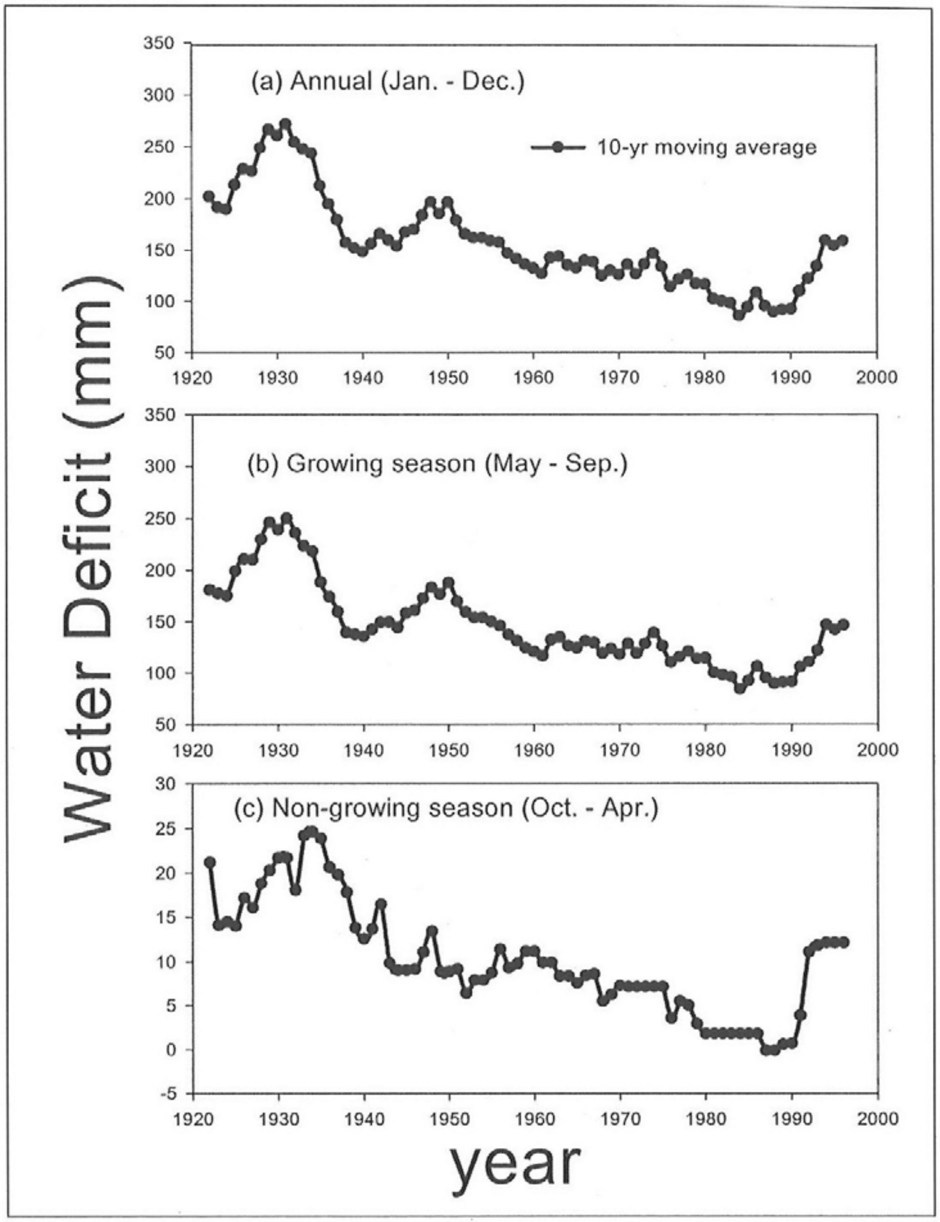


Figure 2.1 Ten Year Moving Average: (a) Annual (b) Growing Season (c) Non-Growing Season Water Deficit Between 1920 and 2000 at Harrow, Southwestern Ontario. (Tan and Reynolds, 2003)

Precipitation:

- Between about 1920 to 1930 precipitation decreased sharply from about 700 mm to 525 mm.
- From about 1930 to 1940 precipitation increased to about 750 mm and remained at that level until 1950.
- After 1950 there was a steady increase of precipitation of about 5 mm/year until the late 1980’s maximum of 975 mm.
- After the late 1980’s precipitation decreased by about 25 mm/year returning to about 750 mm/yr in the late 1990’s.

Air Temperature:

- Annual average air temperatures rose steadily from about 9 ºC to about 10.2 ºC in the early 1950’s and between 1950 and 1960 dropped back to about 9 ºC until the 1980’s, rising again between 1980 and 1990 to about 9.5 ºC and remaining at this level through 2000.
- However despite the distinct warming in annual temperatures between 1980 and 2000 the growing season temperatures showed virtually no warming. Warmer temperatures occurred during the winter.

Water Deficits:

- The annual May to September growing season water deficits have ranged from 250 mm in the late 1920’s to a minimum of 80 mm in the 1980’s.
- **Growing season water deficits rapidly increased to about 150 mm from 1990 to 2000 indicating increasing water stresses over this decade.**
- **Water deficits of 210 mm in 2001 and 270 mm in 2002 were observed.**
- These water deficits indicate the productivity of rain fed crops was below maximum as a result of insufficient or poorly timed precipitation.

- Growing season water deficits are expected to continue to increase over the next few decades. It may become necessary to irrigate traditionally rain fed field crops such as corn and soybeans to obtain consistently viable yields.

Tan and Reynolds (2003) suggested that standard field crop recommendations for the rates and timing of crop fertilization and pesticide applications based on longer term historic water deficit averages from the 1960's to the 1980's when the weather was wetter and cooler than now may have to be revised. These recommendations also do not consider possibility of recycling leached nutrients as in CDSI.

2.2 Southwestern Ontario (Essex County)

2.2.1 Drain Spacing on Brookston Clay (Bolton et al, 1980)

Bolton et al (1980) studied the effects of different drain spacings and depths on corn, soybean, and wheat yields on Brookston clay in southwestern Ontario.

- **The closest spacing of 6.1 m produced the highest yields**

- Close drain spacing improved soil condition and tilth in the spring.

2.2.2 Effect of Tillage and Water Table Control on Brookston Soils (after Tan et al, 2002)

Tan et al. (2002) described the effects of two tillage treatments and water table control on **poorly drained Brookston soil plots (15 x 67 m)** in Essex County, Ontario over a three year period from 1992 to 1994. The tillage treatments included soil reduced tillage and moldboard plough. The water table control treatments included controlled drainage-subirrigation and free (conventional) tile drainage.

- Each of the field plots had two 100 mm diameter tile lines at **7.5 m spacing**.
- **The water table was maintained at 30 cm below ground level** in the controlled drainage plots through the use of tile outflow risers and subirrigation during the growing season.
- Summer (June, July, August) precipitation was 314 mm in 1992, 185 mm in 1993 and 225.6 in 1994.
- There was **little evidence of corn root growth below 80 cm** in this poorly drained clayey soil.
- **The saturated hydraulic conductivity below 80 cm was very low, less than 4.6 cm/day, consequently deep drainage and recharge were considered negligible.**

- Subirrigation water was applied during the first week of June to the end of August on an as needed basis and was accurately measured with a water meter.

- The 1992 cropping season was wet and only **5.7 mm of subirrigation** was required.

- The 1993 and 1994 seasons had low growing season rainfall and **subirrigation of 126 and 115 mm was required**.

2.2.3 Effect of Controlled Drainage and Tillage on Soil Structure and Nitrate Loss on Brookston Soils (after Tan et al, 1998)

Tan et al. (1998) observed that conservation tillage has become an attractive form of agricultural management for corn and soybean production on heavy textured soils in Southern Ontario. Field scale on farm demonstration sites were set up on Brookston clay loam soils to compare the effects of No Tillage vs Conventional Tillage systems on soil structure and water quality. The sites included controlled drainage and free drainage systems to monitor their effects on nitrate loss in the drainage water. Measurements were undertaken from May 1995 to April 30, 1997.

- Two field sites of 4 ha each and 0.5 km apart were selected on Brookston clay loam soils. Each site consisted of two plots one with controlled drainage and one with free drainage. **Each plot was 45 m by 494 m with average tile drain spacing of 9.3 m and average drain depth of 0.65 m.**

- The 1995 and 1996 growing seasons were very dry with total precipitation from May to August of 80 mm and 136 mm respectively.

- Precipitation at both sites were similar except for during September 1996 when 198 mm fell at the Conventional Tillage site and only 75 mm fell at the No Tillage site.

- **Soil structure, organic matter content and water storage in the soil profile were observed to be improved with No Tillage compared to Conventional Tillage.** No Tillage also increased earthworm populations

- No Tillage was found to have higher tile drainage volume and nitrate losses. This was attributed to an increase in macropores due to earth worm activity.

- **The No Tillage site had 45% more tile drainage volume than the conventional drained site. These increased volumes were evident throughout the year.**

- Controlled drainage treatments reduced nitrate losses by 25% on the No Tillage site and by 14% in the Conventional Tillage site compared to traditional drainage. These differences were mainly due to the higher volume drainage losses from the No Tillage sites.

- **No Tillage increased mean weight diameter of soil aggregates, improved wet aggregate stability and soil water storage compared to Conventional Tillage.**

2.2.4 *Effects of Long Term Conventional Tillage and No Tillage on Soil and Water Quality in Brookston Soils (after Tan et al, 2002)*

This research study conducted over the 1995 to 1999 field seasons used two 2 ha field sites located within 0.5 km of each other on a **Brookston clay loam soil** (see also Sec. 2.2.3). In 1995 at the commencement of the study, one site had been under conventional moldboard plow tillage for 4 years and the other site under no tillage for six years. **Each plot was 46 m by 494 m with 9.3 m drain spacing and 0.65 m average depth.**

- The growing season (May to August) precipitation from 1995 to 1999 was dry and precipitation was well below the long term average.

- The precipitation at the No Tillage site was slightly below that for the Conventional Tillage site except for Sept 1996 when 198 mm fell on the Conventional Tillage site and only 75 mm at the No Tillage site.

- Soybeans were planted in 1995, 1996, 1998 and 1999 on both sites. The 4 year average soybean yields where not significantly different between sites.

- The corn yields in 1997 were also similar between tillages.

- The saturated conductivity from intact cores under the No Till site at 1 to10 cm was 9.83×10^{-2} cm/s and from 20 to 30 cm depth was 8.76×10^{-3} cm/s. The saturated hydraulic conductivity in the Conventional Tillage site was 2.46×10^{-2} and 1.28×10^{-2} cm/s.

- **The No Tillage site allowed more extensive infiltration of precipitation before surface ponding and runoff occurred.**

- The No Tillage site produced consistently greater tile drainage volume (45% more) than the Conventional Tillage site as a result of greater surface hydraulic conductivity and more numerous soil macropores due to abundance of earthworms.

- Over the 5 year period the No Tillage site had flow weighted Nitrate – Nitrogen concentration of 11.8 mg/L compared to the conventional tillage site at 13.5 mg/L. The Canada Water Quality Guidelines for Drinking Water for Nitrate-Nitrogen (10 mg/L) value was exceeded in 70% of the tile drainage events from the Conventional Tillage site but for only 57% of the events from the No Tillage site.

2.2.5 Effect of Controlled Drainage-Subirrigation on Nitrate Losses on Sandy Loam Soils on Sandy Loam Soils (after Tan et al, 1999)

A 4 ha field scale experiment on **sandy loam soils (Colwood?)** was conducted for the years 1995 to 1996 at Bicrel Farm. **There was a shallow impermeable layer at 2.5 m and an abundant supply of water from the lake. Drain spacing was 6 m.**

- In 1995 between May and August there was 282 mm of precipitation, 59 mm below the 30 year average. **Subirrigation was initiated on June 15 and terminated on September 13 with 78.5 mm of water applied.**

- In 1996 between May and August there was 203 mm of precipitation, 137 mm below the long term average. **Subirrigation was initiated on July 8 and terminated on September 6 with 183.9 mm of water added.**

- Both 1995 and 1996 growing seasons were very dry until September 1996.

- In the fall of 1996 there was greater tile drainage volume from the controlled drainage-subirrigation system attributed to higher antecedent soil moisture, higher water tables and heavy precipitation (239 mm) in September. Soils in the traditional drained tile areas were much drier prior to this wet period and were able to **store 120 mm (4.7 inches) more water in the soil profile compared to the controlled drainage subirrigated soils.**

- For the period May 1995 to April 1997 the controlled drainage system reduced flow weighted mean nitrate concentration in tile drainage water by 38% and total nitrate loss by 37% compared to traditional tile drainage systems.

- During the non cropping period, 42% of nitrate losses for controlled drainage-subirrigation and 68% for regular tile drainage occurred through the subsurface tile system.

- With water table management nitrate losses by nitrification may have contributed to some of the nitrate removal observed.

- **Marketable processing tomato yields were increased by 11% in 1995 and corn yields by 64% in 1996 with controlled drainage-subirrigation on these sandy loam soils.**

2.2.6 Controlled Drainage-Subirrigation Influences on Tile Nitrate Losses and Corn Yields on Sandy Loam Soils (after Ng et al, 2001)

Ng et al (2001) conducted an on farm study (Bicrel Farm) from May 1, 1996 to April 30, 1997 on **a sandy loam soil (Colwood?)** with two (2) plots each 67 by 284 m (See also Sec. 2.2.5). One plot was a free draining traditional tile system, the other a controlled drainage-subirrigation plot. **Each plot contained 100 mm diameter drains at an average depth of 0.6 m spaced at 6.1 m (20 ft) between the tiles.**

- The rainfall from June to October was 414 mm, similar to the long term average, however the rainfall was not evenly distributed during the growing season with very dry months from June to August and three times normal rainfall in September.
- **Subsurface irrigation was initiated July 8 and continued until September 6 with a total of 184 mm water applied.**
- The cumulative tile drainage volume was 24 mm more from the controlled drainage-subirrigation treatment (325 mm) compared with the regular tile drainage plot (301 mm).
- Controlled drainage-subirrigation reduced nitrate concentration by 70% and total nitrate loss by 58%.
- Soil moisture content was 15% greater in the top 120 cm of the soil than in traditional tile drainage. Water Table depth was 49 cm deeper in the traditional tile drainage area.
- Controlled drainage-subirrigation system also increased rates of corn leaf transpiration (by 50%), stomatal conductance (by 12%) and water use efficiency.
- **Corn yields were increased by 64% in 1996 compared to regular tile drainage.**

2.2.7 Wetland Reservoir System (Tan et al, 2007)

Tan et al. (2007) described a wetland reservoir system on an experimental site on the Essex Region Conservation Authority demonstration farm at Holiday Beach, west of Harrow Ontario. At the experimental site tile drainage water and surface runoff water was routed into a wetland reservoir rather than into drainage ditches and streams. The collected water was reclaimed and recycled back through a controlled subsurface drainage system to provide subsurface irrigation during times of crop water deficit. **This site is mapped as Perth clay loam soils.**

The experimental site included controlled drainage-subirrigation and traditionally tile drained **plots each 25 by 131 m with 100 mm diameter subsurface drains at 4.6 m (15 ft) spacing and 0.6 m average depth.** Precisely measured observational data over five (5) growing seasons from June 1, 2000 to Dec 31, 2004 resulted in the following observations and conclusions:

- Subirrigation was initiated when the crop height was approximately 60 cm usually around the first week of July.

- In 2001 subirrigation was initiated July 3 and terminated August 14 with **a total of 287 mm of subirrigation water applied.**

- In 2002 subirrigation was initiated on July 15 and terminated on August 14 with **a total of 203 mm water applied.**

- In 2003 subirrigation was only required July 6 to 30 with **153 mm water applied.**

- **Subirrigation was not required in 2000 and 2004.**

- **The controlled drainage-subirrigation system reduced total nitrate loss by 41% compared to traditional tile drainage despite that the flow rated mean concentrations were similar.** This was due primarily to the reduced tile drainage volume and increased crop yields under controlled drainage-subirrigation.

- The controlled drainage-subirrigation system reduced losses of dissolved inorganic phosphorous by 18%, dissolved organic phosphorous by 47% and total dissolved phosphorous by 36% compared to traditional tile drainage.

- Tile drainage accounted for 91% of the total phosphorous loss from traditional tile drainage and 62% of the total phosphorous loss from the controlled drainage-subirrigation plot.

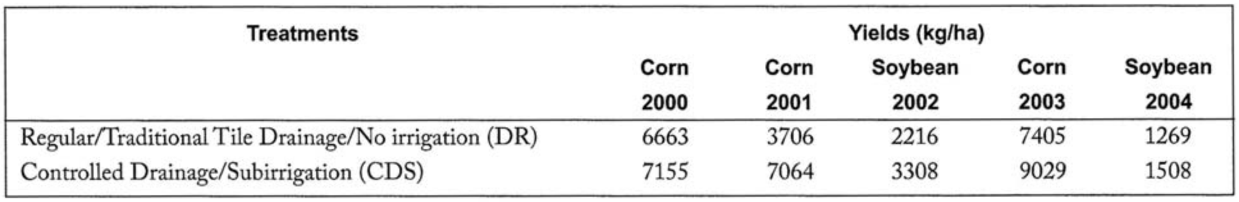
- Phosphorous losses were observed to occur primarily through the tile drainage system rather than by surface runoff. This is likely the result of preferential flow through the abundance of worm holes, root channels and cracks within the fine textured soils.

- The wetland reservoir had substantially lower nitrate and phosphorous concentrations relative to the tile drainage water. This was attributed to nutrient uptake by aquatic plants and algae.

- **During the low rainfall growing seasons of 2001 and 2002 the controlled drainage subirrigation system increased corn yield by 91% (2001) and soybean yield by 49% (2002) compared to traditional tile drainage.**

- Table 2.2 below from Tan et al (2007) provides a summary of corn soybean yields for the growing seasons of 2000 to 2004 for traditional vs controlled drainage-subirrigation plots.

Table 2.2 Effect of controlled subirrigation/drainage (CDS) and regular/traditional tile drainage (DR) on corn yields in 2000, 2001 and 2003, and on soybean yields in 2002 and 2004.



Treatments	Yields (kg/ha)				
	Corn	Corn	Soybean	Corn	Soybean
	2000	2001	2002	2003	2004
Regular/Traditional Tile Drainage/No irrigation (DR)	6663	3706	2216	7405	1269
Controlled Drainage/Subirrigation (CDS)	7155	7064	3308	9029	1508

2.2.8 Controlled Drainage/Subirrigation, Chatham Kent, Bert Rammelaera Farm (2007 pers. comm.)

Mr. Rammelaera has installed CDSI on 160 acres of Brookston (soils) farm land. Water is pumped from a creek into a drainage ditch and then directly to an 8 inch header **discharging to the lateral drains.**

- **Drains are spaced at 5 m**.
- **Laterals are installed at 0.08% grade**
- **Estimated 40 bu/acre yield advantage over conventional drainage**

2.3 Eastern Ontario and Quebec

2.3.1 Drain Spacing Modelling Study Ste. Rosalie Clay, Quebec (Madramootoo, 1990)

Madramootoo undertook a modelling study with 24 years of climate data to quantify the yield and water management benefits associated with **four drain spacings (5, 10, 15 and 20 m) for grain corn** on a Ste. Rosalie clay in Quebec.

- The soils were primarily heavy clays with some fine sands and silts overlying clay subsoil.
- Saturated hydraulic conductivities of these clays averaged from 0.0003 to 1.03 m/day.
- Drainage contractors have encountered problems installing drains in sensitive saturated clays. The drain plow smears and seals the soil around the pipes, thus reducing water entry.
- Heavy clay soils should be subsurface drained in order to improve machine trafficability and reduce damage to soil structure (Steinhardt and Trafford, 1974).

- The maximum corn rooting depth was taken as 50 cm, drain depth 1 m, depth to impermeable layer 3 m, saturated hydraulic conductivity from 0-30 cm at 0.4 cm/hr.

- The water table with 20 m spacing was on average nearly 15 cm higher than the 15 m spacing. In the spring the 20 m spacing water table was 30 cm and closer to the surface on several occasions.

- The widest spacing (20 m) was unable to provide sufficient moisture by capillary rise to significantly increase yields. The low saturated and unsaturated hydraulic conductivities of the Ste. Rosalie clay restrict the upward flux of soil water to the effective root zone.

- More rainfall infiltrates in a 5 m spacing field than with 20 m spacing. The average annual increase over the 20 year period is 66 mm.

- There was 58.1 mm of surface runoff in a 5 m spacing field and 112.7 mm in a field with 20 m spacing in the wettest growing season.

- However, in the same year, in the 5 m spacing field the subsurface drains removed 340 mm of water compared to 248.3 mm of water on the field with 20 m spacing.

- **A 15 m lateral drain spacing provided adequate drainage and there was no reduction in yields due to excess soil water during the wettest growing season.**

- **However, in years of average growing season rainfall, drought stress were shown to reduce yields by nearly 12% for all spacings ranging from 5 to 20 m.**

- **There were significant yield reductions (38 to 40%) during drought years for all spacings ranging from 5 to 20 m.**

- **Approximately 15 additional trafficable days per year may be obtained with 5 m drain spacing compared to 20 m.**

2.3.2 Controlled Drainage Subirrigation – Bainsville (after Mejia et al, 1999)

McGill University (Mejia, Madramootoo and Broughton 1999) undertook a two year (1995 and 1996) field study of strip cropped corn and soybeans on a 3.5 ha field site on the McCrae Farm near Bainsville in Eastern Ontario. The soil was described as a stone free **Bainsville silt loam underlain by an impermeable (clay) layer at 1 m depth.** The subsurface drainage system constructed in 1991 consisted of 125 m long laterals installed parallel to the slope **at 100 cm depth, 0.1% grade and 18.3 m spacing** discharging into a ditch. The field slope across the laterals was 0.06%. The first 10 m of the drains at the ditch outfalls were non perforated tubing to minimize water table drawdown near the ditch. The perforated drainage tubing was 100 mm in diameter and **equipped with a filter sock.**

Water for subirrigation was pumped from a ditch that was connected to nearby Lake St Francis on the St Lawrence River. **The subirrigation system had a peak delivery rate of 0.95 L/s or 3.7 mm/day.** Water table control chambers were installed on the drain outlets with irrigation lines feeding into the risers. Water tables were maintained above the drains by control structures. Observation wells were placed in the field. **An equivalent irrigation water depth of 223 mm was applied in 1995 and 248 mm in 1996.**

For both 1995 and 1996 precipitation in May and June period was below the long term average and for July August above the long term average. However there was not sufficient rainfall in June, July and August to meet the corn and soybean crop requirements for any of the treatment plots. Water deficits for these months were much higher in the non irrigated plots compared to the subirrigated plots. The shallow water tables in the subirrigated plots substantially increased soil moisture levels both years.

Water table treatments included free drainage to the 100 cm deep laterals and controlled water tables of 75 and 50 cm below the ground surface as set at the drain outlets. However the moisture losses due to evapotranspiration, horizontal seepage and vertical leakage prevented static equilibrium at the control levels set. The average water levels for the three treatments in 1995 was 130, 103 and 91 cm and in 1996 121, 85 and 75 cm respectively.

In 1995 corn yield was increased over free drainage by 13.8% on the 50 cm and 3.8% on the 75 cm treatments and soybeans by 8.5 and 12.9%. In 1996 despite late planting, corn yields were increased by 6.6 and 6.9% for the 50 and 75 cm treatments. Soybean yields were increased by 37.3 and 32.2% respectively over free drainage. Yield increases were reflected in larger grains and kernel sizes. Higher increases were expected in drier years.

For similar soils (Bainsville) and climate conditions the researchers **recommended a water table level of 75 cm** for corn and soybean production. This recommended water table level is deeper than on the fine textured soils at other research sites. It appears to represent an upward flux typically of a fine sandy loam soil (See Fig 1.12 this report).

2.4 Northwestern Ohio

2.4.1 Water Table Management to Enhance Crop Yields in Wetland Reservoir Subirrigation Systems, Northwestern Ohio (Allred et al, 2003)

Allred et al (2003) described an agricultural water storage and routing system for capture, treatment, storage and reuse of runoff and subsurface drainage water from cropland and in turn providing both environmental and agriculture production benefits. The environmental benefits include reduction in offsite release of nutrients, pesticides and sediments, decreased flooding potential downstream and more carbon sequestration in soil. **However these benefits can not be achieved at a regional scale without demonstrating to farmers that these systems are capable of increasing crop yields significantly over time and that a proper water table management approach will result in significant crop yield increases.**

The Wetland Reservoir Subirrigation System (WRSIS) is comprised of a wetland and a water storage reservoir linked to a network of subsurface pipes used at different times to either drain or subirrigate crops through the root zone. This system was developed and continues to be tested at field scale at three northwestern Ohio locations in the Lake Erie Maumee River Basin. These three sites are located in Fulton, Defiance and Van Wert Counties.

Model simulations of subirrigation requirements using the computer program DRAINMOD were used to **size the reservoir to meet crop irrigation needs for 8 out of 10 years.** It was considered too costly and take too much land out of production to design for the most severe drought conditions.

The WRSIS agricultural production goal is to consistently achieve crop yields near 12,600 kg/ha **(200 bu/acre)** for corn and 4,700 kg/ha **(70 bu/acre) for soybeans** regardless of rainfall amounts. This goal is being approached at the Fulton County site.

Subsurface drain pipes (100 mm diameter) were installed at a nominal depth of 0.76 to 0.91 m at all three sites.

2.4.2 Defiance County

- The Defiance County, Ohio site has **two 1.4 ha subirrigated fields** as well as 8.1 ha of cropland with various conventional drainage treatments.

- **Soil types are Paulding clay with some Roselms silty clay.**

- The wetland had 700 m^3 and the reservoir 2,950 m^3 of storage or the equivalent of **130 mm** storage over the 2.8 ha irrigated area.

- **Saturated horizontal hydraulic conductivities measured within the soil profile ranged from 7 x 10^{-6} cm/sec to 2 x 10^{-5} cm/sec** at the Defiance County site. **These dense low permeability clayey materials hinder water transfer from the drain pipe to the soil during subirrigation in turn making it difficult to maintain the target range of water table depths.**

- **Target water table depths were 25 cm (10 inches) at the drains and 46 to 51 cm at the sags midway between the drains.**

- **Both 4.9 m (16 ft) and 2.4 m (8 ft) drain spacings were used. The narrower spacing was better adapted for consistently keeping sag water tables in the desired range.**

2.4.3 Fulton County

- The Fulton County, Ohio site consists almost entirely of Napanee Loam.

- **Saturated horizontal hydraulic conductivities ranged from 4 x 10^{-4} cm/sec near the surface to 7 x 10^{-5} cm/sec at a depth of 1.2 m (4 ft).** The site has **two 8.1 ha** (20 acre) **fields** one that is **subirrigated with drain pipes spaced at about 4.6 m (15 ft) apart** with newer drains placed between each of the existing drains. **The control plot has clay tile lines spaced at 13.7 m (45 ft).**

- Subsurface drainage from both fields is routed to a 0.57 ha wetland with a storage capacity of 3,790 m^3. Very little surface water drainage enters the wetland. The reservoir area is 0.64 ha with a storage capacity of 8,706 m^3.

- **The combined storage of the wetland and the reservoir is 154 mm** over the 8.1 hectare subirrigated field not considering losses.

- The combined pond and reservoir area is 15% of the subirrigated field area.

2.4.4 Van Wert County

- The Van Wert County, Ohio site has Hoytville clay soils with **three 6.1 ha fields, two are subirrigated** and one with only subsurface drainage.

- **Drain lines within the subirrigated fields are spaced at 5.3 m.**

- **Saturated horizontal conductivities ranged from 4x10^{-4} cm/sec near the surface to 2x10^{-4} cm/sec** through the rest of the profile down to one meter depth.

- Surface and subsurface drainage from all 18.2 ha (45 acres) of corn and soybean cropland are routed via submersible pumps to a 0.79 ha (1.95 acre) 8,710 m^3 storage capacity wetland and subsequently to a 1.21 ha (3 acre) 12,870 m^3 capacity reservoir.

- **The wetland at Van Wert Ohio was constructed to hold the 2 year 24 hour storm event runoff (66 mm rainfall) and all the subsurface drainage from 20 hectares (50 acres) of the encompassed watershed.**

- **The storage capacity of the wetland and reservoir is 178 mm** over 12.1 ha of subirrigated fields not considering losses in the wetland and reservoir.

2.4.5 Experience Gained

Experience gained by subirrigating corn and soybeans on the fine grained silt and clay soils of northwest Ohio at these three sites and two others at Wooster and Hoytville, Ohio shows with **typical subirrigated drain spacings of 4.6 to 6.1 m (15 to 20 ft) and a water table level kept at 25 cm (10 inches) beneath the surface along the drain itself, the water table depths found at the midpoint between the drain lines will normally be about 46 to 51 cm (18 to 20 inches)** Northwestern Ohio experience also indicates:

- **The corn and soybean yield improvements from 1996 to 2001 compared to the control plots due to subirrigation were 35 and 38% during dry seasons, 14 and 10% during near average to wetter growing seasons and 20 and 17% overall.**

- Subirrigation during the two drier years of 1996 and 1999 improved mean corn and soybean yields by 45 and 15 bu/acre, respectively.

- **During the extremely wet 1997 and moderately wet 1998 growing seasons** at Van Wert County site, **subirrigation proved to be a minor disadvantage** and demonstrated that water table management requires greater attention under wetter conditions.

- Large depressions and low elevation areas within subirrigated fields became water-logged resulting in localized crop damage. Additional water table control weirs were added to better manage water tables in low areas.

- The need for a rain gauge with observation wells installed along the drains, between the drains and especially in areas within depressions.

- **Establishing a base water table early in the season makes it easier to raise water levels later.**

- After all post emergence field operations are completed and the crops are at the growth stage (third trifoliate leaf stage for soybeans and collar of the fourth leaf visible for corn) the water table level may be raised for the remainder of the growing season to 25 cm below ground along the drain lines.

- Researchers have noted that despite the close drain spacing **corn stalks are taller over the drains indicating water deficits at the sags between the drains.**

In addition to rapid removal of excess water a narrower drain spacing also provides more even distribution of water in the soil during subirrigation.

Because the water table is to be maintained at a higher level with subirrigation in comparison to conventional subsurface drainage, **it is often necessary to design with a higher drainage coefficient (38 to 51 mm per day) which results in narrower drain spacing typically 33 to 50% of that used in fields with only conventional subsurface drainage.**

2.5 Summary

Table 2.3 provides a summary of soil types drain depth and spacing, hydraulic conductivity, irrigation water applied and reservoir storage as described in this section.

Research Drain Spacing

Year	Irrigation Water Applied (mm)	Drain Spacing (m)	Drain Depth (cm)	Hydraulic Conductivity	Soil Type	Location	Reference
Ontario Research Plots							
1992	5.7	7.5	60	4.6 cm/day	Brookston Clay Loam	Woodslee	Tan et al. 2002
1993	126	7.5	60	4.6 cm/day	Brookston Clay Loam	Woodslee	Tan et al. 2002
1994	115	7.5	60	4.6 cm/day	Brookston Clay Loam	Woodslee	Tan et al. 2002
1995	223	18	100		Bainsville Silt Loam	McCrae	Meija et al. 1999
1996	248	18	100		Bainsville Silt Loam	McCrae	Meija et al. 1999
1995	78.5	6	60		Colwood Sandy Loam	Bicrel	Tan et al. 1999
1996	183.9	6	60		Colwood Sandy Loam	Bicrel	Tan et al. 1999
2000	0	4.6	60		Perth	Holiday Beach	Tan et al. 2007
2001	287	4.6	60		Perth	Holiday Beach	Tan et al. 2007
2002	203	4.6	60		Perth	Holiday Beach	Tan et al. 2007
2003	153	4.6	60		Perth	Holiday Beach	Tan et al. 2007
2004	0	4.6	60		Perth	Holiday Beach	Tan et al. 2007
2007		5			Brookston	Rammelaere	Pers comm.

Year	Reservoir Volume (mm)	Drain Spacing (m)	Drain Depth (cm)	Hydraulic Conductivity	Soil Type	Location	Reference
Northwestern Ohio Research Plots							
	154	4.6	75 to 90	$7\text{x}10^{-6}$ to $2\text{x}10^{-5}$ cm/s	Napanee Loam	Fulton	Allred et al. 2003
	130	2.4 to 4.9	75 to 90	$4\text{x}10^{-4}$ to $7\text{x}10^{-5}$ cm/s	Paudling Clay and Roselms Silty Clay	Defiance	Allred et al. 2003
	178	5.3	75 to 90	$4\text{x}10^{-4}$ to $2\text{x}10^{-4}$ cm/s	Hoytville Clay	VanWert	Allred et al. 2003

Table 2.3