# Economic feasibility of subsurface irrigation in Eastern Ontario and Southern Quebec

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Barnett, N.G., Madramootoo, C.A. and Mejia, M.N. 1997. **Economic feasibility of subsurface irrigation in Eastern Ontario and Southern Quebec**. Can. Agric. Eng. **39**:177-186. A study was conducted to determine the economic benefits of subsurface irrigation using field results and historical climatic and grain price data. The experimental field site was under a ridge-till system with corn (*Zea mays* L.) and soybean (*Glycine Max* Merr.) strip cropping. During the 1995 and 1996 growing seasons, water consumption was monitored. The costs of all necessary system components as well as power consumption were taken into account. Climatic data were tabulated to compare the years of study with the long term averages. Crop yields of irrigated and non-irrigated sections of the field were measured. The experimental results were used to predict expenses and economic returns of subsurface irrigation at a larger scale (25 ha). When strip cropping is taken into consideration, crop yields from irrigated land were increased by 10% and 21% as compared to yields from non-irrigated land, in 1995 and 1996, respectively. Benefits from scenarios of a low yield response (+5%) and a high yield response (+25%) were also analyzed using discount rates of 8% and 12%. Depending on yield increase, grain prices, and discount rate used, the benefit/cost ratios ranged from 1.08 to 7.21. Subsurface irrigation increased returns by $3.59/ha per year at the low end to $264.35/ha per year at the high end. Judging from past climatic data of the region, the economic benefits of subsurface irrigation would most likely fall in the range of $60.85/ha per year to $140.48/ha per year. Keywords: subsurface irrigation, watertable management, corn-soybean strip cropping, yield response, economic benefits.

Une étude fut entreprise pour déterminer les bénéfices économiques de l'irrigation souterraine en utilisant des données au champ et une historique du climat et des prix pour les grains. Au site expérimental une culture intercalaire en bandes de maïs (*Zea mays* L.) et de fève soja (*Glycine Max* Merr.) sur billons fut utilisée. Durant les saisons de croissance de 1995 et 1996, la consommation en eau fut enregistrée. Les coûts de tout les nécessaires du système et de consommation en énergie furent pris en considération. Les données climatiques furent classées afin de comparer les années d'étude aux moyennes à long terme. Le rendement des parcelles irriguées et non-irriguées fut mesuré. Les résultats expérimentaux furent utilisés pour prédire les coûts et recettes de l'irrigation souterraine à grande envergure (25 ha). Lorsque la culture intercalaire en bandes fut prise en considération, les rendements avec irrigation furent 10% et 21% plus élevés que sans irrigation en 1995 et 1996, respectivement. Les bénéfices pour un cas d'amélioration du rendement faible (+5%) ou important (+25%) furent aussi analysés en utilisant des taux d'escompte de 8% et 12%. Dépendant de l'augmentation en rendement, les prix pour le maïs et la fève soja et le taux d'escompte utilisé, les rapports bénéfices/coûts varièrent d'un minimum de 1.08 jusqu'à un maximum de 7.21. L'irrigation souterraine augmenta les recettes de $3.59/ha/année au plus bas jusqu'à $264.35/ha/année au plus haut. Jugeant de l'historique climatique de la région, les bénéfices économiques de l'irrigation souterraine se trouveraient entre $60.85/ha/année et $140.48/ha/année. Mots clefs: irrigation souterraine, gestion de la nappe phréatique, culture intercalaire en bandes de maïs-fève soja, bénéfices économiques.

## INTRODUCTION

Corn and soybean are economically important crops in Ontario and Quebec and, consequently, take up a large proportion of arable land. In total, 814,500 ha of soybean and 977,100 ha of corn were grown in 1995 in both provinces. In Ontario, the area given to corn production has dropped from 890,000 ha in 1984 to 698,100 ha in 1995 (Statistics Canada 1996). This reduction is due in part to the shift towards more soybean production in the province. Area cropped to soybean has increased from 417,000 ha in 1984 to 734,500 ha in 1995 (Statistics Canada 1996). For the same period in Quebec, land cropped to corn has increased from 220,000 ha to 279,000 ha, while the area cropped to soybean has increased from 239 ha in 1976 to 80,000 ha in 1995 (Statistics Canada 1996). With recent record low grain stocks and high grain prices, this trend is likely to continue. In 1996 for instance, the area given to corn production in Quebec was estimated to increase by 9% to reach 305,000 ha, while soybean production was estimated to increase by 19% to reach 95,000 ha (Quebec Farmers' Advocate 1996). As the area planted to these important cash crops increases, so does the potential for agricultural pollution to occur since fertilizer inputs and drainage are required for the profitable production of these crops in the area. Best management practices (BMPs) which reduce agricultural pollution and increase productivity are needed to optimize corn and soybean production.

There is now an increased emphasis on cropping systems as well as modifying irrigation and drainage practices to reduce the level of pollutants in drainage effluent. Practices such as conservation tillage and strip cropping are being actively promoted to reduce both pollution from agricultural land and input costs. Another practice that has been shown to reduce total nitrate nitrogen ($NO^-_3$-N) concentrations from subsurface drains while enhancing crop performance is watertable management (WTM) (Kalita and Kanwar 1993).

With WTM, the watertable can be lowered by drainage to facilitate field operations in the spring and fall and raised by controlled drainage (CD) and/or subsurface irrigation (SI) to provide plants with needed water during the growing season. Thus, in addition to improving drainage water quality by reducing leaching of agrochemicals from the soil profile, WTM can increase the profitability of corn and soybean production in two major ways. First, since WTM helps to retain more $NO^-_3$-N in the soil for plant use, fertilizer costs can be considerably reduced. Second, and more tangible is the improved crop yields which result from water being made available to the plants in times of need. According to Drury et al. (1996), the climatic factor most limiting to fertilized corn grain yields is insufficient rainfall during the growing season, particularly in July. Because evapotranspiration (ET) exceeds precipitation in the St. Lawrence lowlands during the summer months, crop yields in subsurface-drained fields are often reduced due to dry spells which are exacerbated by excessive drainage. During dry spells, WTM by CD alone cannot provide adequate water to the plant roots. To supply plants with additional moisture in times of need, SI can be employed to pump water back into subsurface drains. SI minimizes the risk of crop losses from uncertain rainfall, thereby stabilizing yields from year to year.

While some surface irrigation methods also reduce crop losses, SI may be the most efficient irrigation method for subsurface-drained fields for several reasons. First, SI eliminates water losses by evaporation encountered when using surface irrigation. Second, SI uses rainfall and drainage water more effectively. Third, SI distributes water uniformly. Fourth, SI may reduce the use of certain pesticides and the quantity of fertilizers leached by tile drains. Last, SI does not take up productive land area or create obstacles in the field, making it suitable for grain crops such as corn and soybean. Since SI uses less energy, labor, and water, it is more economical than a sprinkler system (Doty et al. 1983; Broughton 1995). SI systems require flat topography, coarser textured soils, an impermeable soil layer at 1-2 m depth, and the presence of a pipe drainage system (Dodds et al. 1996). Fortunately, these requirements are met in most of Ontario and Quebec. For instance, in two counties in Quebec, it is estimated that 15,000 ha are well-suited for SI (Papineau 1988).

The environmental benefits of WTM/SI are well documented (Gilliam et al. 1979; Broughton 1995; Lalonde et al. 1996). In addition to being "environmentally friendly," BMPs must also be economically feasible and sustainable in order to be widely adopted. Drouet et al. (1989) found that SI netted positive economic returns in 4 of 5 years for monocropped corn in a sandy field in southern Quebec. In a very dry year, yields in a subirrigated field were double those in a conventionally drained field. Even in wet years, SI increased corn and soybean yields substantially on a silt loam soil in eastern Ontario (Mejia and Madramootoo 1996). Farmers, water management specialists, and environmentalists in eastern Canada have expressed interest in WTM/SI as a method of reducing agricultural pollution and boosting crop yields. Several companies in Ontario and Quebec now market automated SI systems. However, farmers have generally refrained from investing in irrigation equipment for grain production in eastern Canada, because of the high capital cost and relatively low commodity prices.

The objective of this study was to determine the costs and benefits associated with controlled WTM/SI as compared to a conventional drainage technique (i.e., free drainage and no subsurface irrigation). A two year study was performed on a small field (3.2 ha) strip cropped with corn and soybeans. The data taken from the field were used to estimate the benefits and costs required for a larger scale subsurface irrigation system. Cropping practices and soil for the 25 ha field are assumed to be the same as those in the experimental field. A long term benefit/cost analysis was done using historical climatic and price data.

## MATERIALS AND METHODS

### Site description

The experimental site is situated in Bainsville, eastern Ontario (45°11'N, 74°23'W). The field is bordered on the east side by a deep ditch and on the south side by a highway. From the ditch, the field plot extended west 125 m. The average field slope was 0.06 % (Lalonde 1993). The soil is a stone-free Bainsville silt loam, underlain by a clay layer at a depth of 1 m. Water for subsurface irrigation was pumped from a ditch located 800 m directly south of the field experiment. The selection of this pump location was based on its proximity to an electrical power source and Lake St. Francis.

### Drainage system layout

The drainage system was installed in 1991 and consisted of fifteen laterals at a spacing of 18.3 m and at an average depth of 1.0 m which discharged individually to a drainage ditch. The experimental layout is shown in Fig. 1. Each lateral was 125 m in length; the first 10 m section from the outlet was a 75 mm diameter non-perforated polyethylene pipe to minimize seepage to the ditch and the other 115 m in the field was made of 100 mm diameter corrugated and perforated polyethylene drainage pipe with a filter sock. The 10 southern-most drains (A-J) had watertable control chambers at the outlets (Fig. 2) with irrigation lines feeding into the risers. The other 5 laterals (K-O) drained freely into the ditch.

### Subsurface irrigation system

Water was pumped into the riser of the control chambers for laterals A-J, irrigating a total of 10 plots. A 0.75 kW pump was used to pump water to the laterals. A datalogger was installed to record the total operating time of the pump in order to estimate power consumption. A polyethylene water line carried the water to the field from the pump. The first 168.3 m of water line were made of 38.1 mm diameter pipe. For the remainder of the water line (392 m), two 25.4 mm diameter pipes were used. Originally, only one 25.4 mm line had been used; however, another had to be installed in parallel because of insufficient water supply. At the field, the water line branched into two sections. A water meter was installed to record total volume of water used. The system was capable of delivering 0.95 L/s.

### Water application

The irrigation pump was operated nearly-continuously from June 10 to August 31, 1995 and from June 17 to September 16, 1996 in order to maintain the watertable relatively constant. The pump was shut off only when rainfall alone was able to keep the watertable within the desired range (500-750 mm below the soil surface). Significant losses appeared to be due to deep seepage. Maximum irrigation rate was approximately 3.7 mm/day.

### Agronomic practices

A ridge-till system was practiced for both years. In 1995, two-thirds of the experimental field was cropped to soybeans and one-third to corn. The rotation was designed so that corn was cultivated on land that had been cropped to soybeans the two previous years. The nitrogen fixing ability of the soybean plant allows a reduction of fertilizer inputs. In 1996, the field was planted half to corn and half to soybean in alternate strips. Inoculant was not used on the soybean seeds in either year. Both corn and soybean were cultivated twice in both years to control weeds. The corn rows were fertilized with 28% urea/ammonium nitrate at a rate of 130 kg/ha in 1995 and 140 kg/ha in 1996. Fertilizer was not applied to the soybean rows in either year. For the proposed 25 ha field, a strip cropping pattern of 50% corn and 50% soybean was assumed for all scenarios.

### Environmental and crop growing factors

Using on-site weather data, evapotranspiration (ET) and corn heat units (CHU) were calculated for both years. The Blaney-Criddle equation was used to calculate ET:

$$u = k * p\ (0.46T + 8.13) \qquad (1)$$

where:

$u$ = monthly evapotranspiration (mm),
$k$ = crop coefficient for corn (0.42 for May; 0.8 for June; 1.15 for July; 0.87 for August; 0.55 for September) (FAO 1977),
$p$ = monthly percent of total daylight hours (Environment Canada Climatic Normals,1960-1990 at McGill University Weather Station, Montreal, QC) (Environment Canada, 1993), and
$T$ = Average monthly temperature (°C) (Schwab et al. 1993).

The corn heat units (CHU) were calculated using Eq. 2 (Brown and Bootsma 1993).

$$CHU = (1.80\ (T_{\min} - 4.4) + 3.33\ (T_{\max} - 10) - 0.084\ (T_{\max} - 10)^2)0.5 \qquad (2)$$

where:

$T_{\min}$, $T_{\max}$ = minimum and maximum temperature (°C).

The CHU were accumulated from the date of seeding until the date of grain physiological maturity.

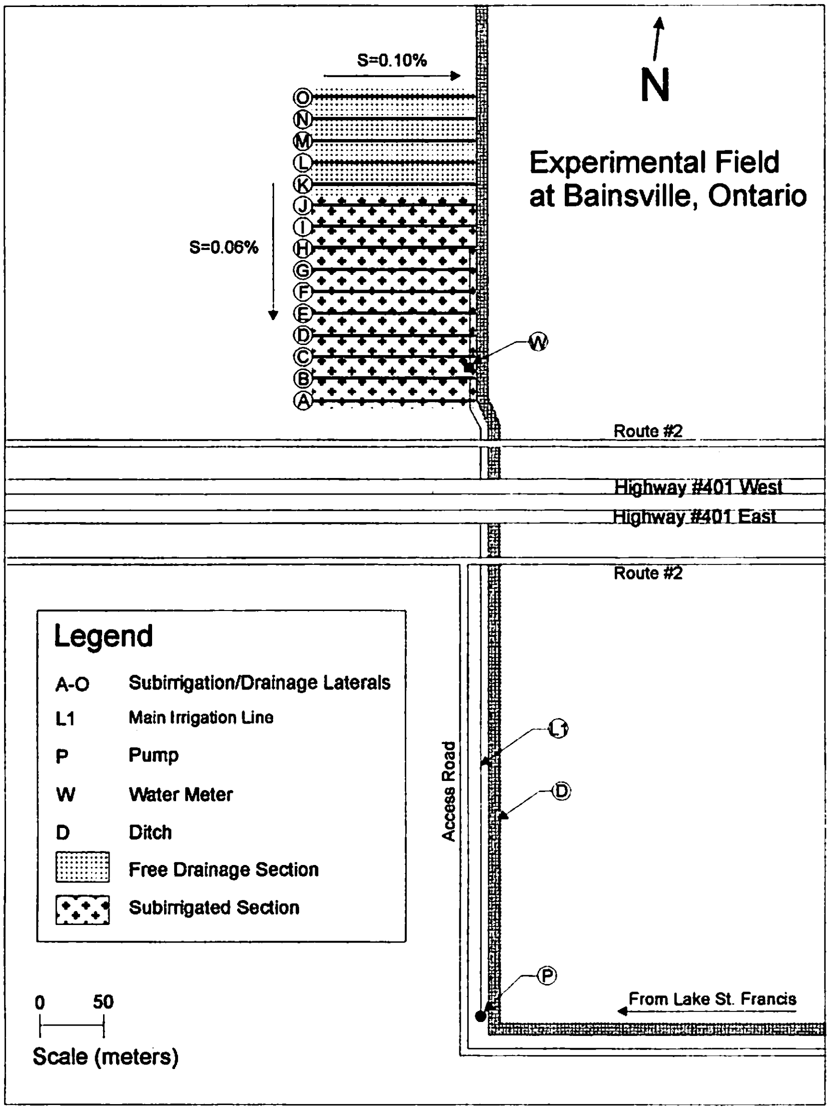

Fig. 1. Experimental system at Bainsville, ON.

## RESULTS AND DISCUSSION

### Environmental and crop growing factors

The long term averages for climatic data affecting corn and soybean production are shown in Table I. The average growing season temperatures in 1995 and 1996 were both 8.6% above the long term average. Accumulated CHU in 1995 and 1996 were slightly above the long term average by 1.3% and 2.2%, respectively. Total ET during the 1995 growing season was 3.7% above the long term average, while 1996 CHU was 6.8% below average. For the entire growing season (May-September), total precipitation in 1995 was 13.8 % below the average, while rainfall in 1996 was 20.1% above the average.

With respect to corn and soybean plants, May-June is a period of germination and vegetation growth, while July-August is a period of flowering and grain filling. For both corn and soybean, moisture availability is most critical as flowering is initiated. The second most critical time is germination, followed by the vegetative and grain filling stages (FAO 1979). Rainfall in September would have very little or no benefit at all to the crop since maturity will have been reached. In eastern Canada, moisture reserves are generally abundant at the germination stages due to spring snowmelt.

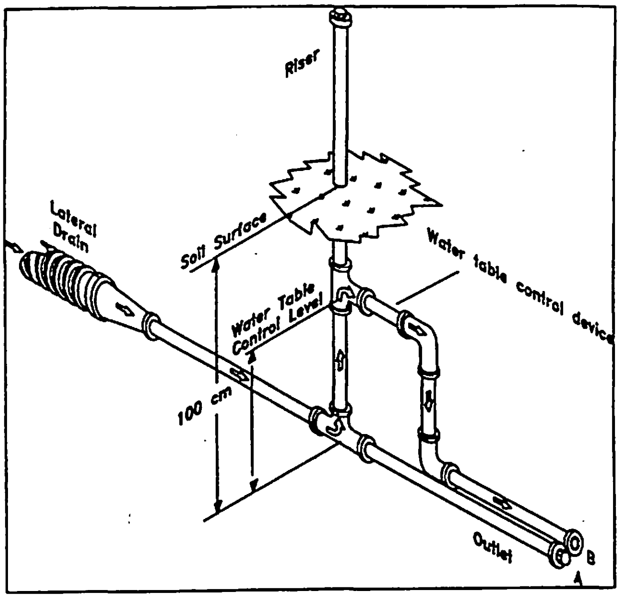

Fig. 2. Control structure outlet (after Lalonde 1993).

For both 1995 and 1996, precipitation for the May-June period was 15.1% and 14.3%, respectively, below the 30-year average, while precipitation for the July-August period was 14.0% and 22.3%, respectively, above the 30-year average. There were many large rainstorms during the month of July. Prior to this, very dry conditions existed due to an unusually hot, dry period in June.

In spite of the above-average rainfall for July and August in both years, there was not enough rainfall to meet the high ET and crop demands of the period. Particularly in mid-July, 1995 and 1996, soil moisture content was much lower in the free drainage area than in the subirrigated area. However, just enough soil moisture was replenished in the free drainage area by timely rainfalls received in July to prevent wilting in the non-irrigated section. The combination of high temperatures in June along with abundant rainfall in July resulted in very good crop growing conditions, for both irrigated and non-irrigated crops. Although there were substantial yield increases with SI, the yield response to SI was moderate and would most likely be higher in years when July and August are drier than normal.

### Water consumption

During the 1995 season a total of 4743 $m^3$ of water was applied to the irrigated section of the experimental field. This was equivalent to an irrigation depth of 223 mm. In 1996, 5315 $m^3$ of water was applied for an irrigation depth of 248 mm. Table II shows the contributions of irrigation and rainfall to meeting ET demand for both years.

In 1995 and 1996, rainfall alone was not adequate to meet crop ET requirements in June, July, and August and the water deficits for these months were much higher in the non-irrigated FD plots than in the SI plots. Subsurface irrigation was beneficial during these months as it supplemented rainfall to meet crop ET requirements.

**Table I: Climatic and growing conditions in southwestern Quebec and eastern Ontario**

| | Temp[a] (ºC) | ET[a] (mm) | CHU[a] | Precipitation[b] (mm) | | |
|---|---|---|---|---|---|---|
| | May-Sept. | May-Sept. | May-Sept. | May-Sept. | May/June | July/Aug. |
| Long term average | 16.7 | 744.2 | 2801 | 394.1 | 145.5 | 158.2 |
| 1995 average[c] | 18.1 | 771.8 | 2838 | 339.9 | 123.6 | 180.4 |
| % from average | +8.6 | +3.7 | +1.3 | -13.8 | -15.1 | +14.0 |
| 1996 average[c] | 18.1 | 693.9 | 2862 | 473.2 | 124.7 | 193.4 |
| % from average | +8.6 | -6.8 | +2.2 | +20.1 | -14.3 | +22.3 |

a Environment Canada Weather Station at Coteau-du-Lac, QC (1979-1995); [b] Environment Canada Weather Station at Lancaster, ON (1951-1980); [c] Field site weather data recorded at Bainsville, ON (1995-1996).

**Table II: 1995 and 1996 irrigation, precipitation, and ET (mm)**

| | 1995 | | | Water deficit | | 1996 | | | Water deficit | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Irrigation | Rainfall | ET | FD | SI | Irrigation | Rainfall | ET | FD | SI |
| May | 0 | 85 | 69 | 0 | 0 | 0 | 67 | 67 | 0 | 0 |
| June | 58 | 45 | 176 | 131 | 73 | 41 | 57 | 169 | 112 | 71 |
| July | 96 | 189 | 283 | 94 | 0 | 85 | 159 | 273 | 114 | 29 |
| August | 69 | 92 | 176 | 84 | 15 | 90 | 35 | 176 | 141 | 51 |
| September | 0 | 69 | 68 | 0 | 0 | 32 | 155 | 75 | 0 | 0 |

FD = Free drainage plots
SI = Subirrigated plots

### Soil moisture

Although irrigation losses due to deep seepage likely occured in both years, soil moisture data showed that subirrigation increased the gravimetric moisture content of the soil in the irrigated plots. The soil samples were taken at drain midspacing, at 3 depths (0-200 mm, 200-400 mm and 400-700 mm) and at 36 different locations in the field. The soil moisture averages for the 0-700 mm depth for the 1995 and 1996 growing seasons are presented in Tables III and IV, respectively. The extra soil moisture in the subirrigated plots helped to partially overcome moisture deficits, which were very high during June, July, and August of both years.

### Crop yields

Harvest samples were hand-picked from 5 m sampling strips at 36 locations in the field. After shelling, the grains were weighed and compared on a dry-weight basis. The yields were compared using a one-tailed Student's *t*-test. Differences in yield between irrigated plots and free drainage plots are shown in Table V for corn and in Table VI for soybean.

**Table III: Soil moisture data for 1995 growing season**

| Date | Gravimetric soil moisture content (%) | |
|---|---|---|
| | Subirrigated section | Free drainage section |
| May 2 | 21.5 | 19.4 |
| July 14 | 19.0 | 13.8 |
| August 14 | 19.2 | 17.4 |
| August 31 | 18.0 | 13.3 |

**Table IV: Soil moisture data for 1996 growing season**

| Date | Gravimetric soil moisture content (%) | |
|---|---|---|
| | Subirrigated section | Free drainage section |
| July 16 | 20.6 | 18.8 |
| July 29 | 24.8 | 21.2 |
| August 19 | 25.1 | 21.3 |
| September 4 | 24.9 | 18.5 |

**Table V: 1995 and 1996 corn yield comparisons**

| | Subirrigated corn yield | | Non-irrigated corn yield | | SI yield response | Significance level |
|---|---|---|---|---|---|---|
| Year | Mean (t/ha) | Standard deviation | Mean (t/ha) | Standard deviation | (%) | *t*-test probability |
| 1995 | 12.0 | 1.09 | 11.08 | 1.24 | 8.3 | $0.1005^{ns}$ |
| 1996 | 7.30 | 0.42 | 6.84 | 0.54 | 6.7 | 0.0630* |

*Significant at the 95% confidence level. $^{ns}$ Not significant at the 95% confidence level.

In both years, soybean yields were significantly different at the 95% level. Corn yields were significantly different at the 95% level in 1996, but were only marginally significant (P=0.1005) at the 90% level in 1995 due to excellent crop growing conditions that year. Nevertheless, the advantages of subsurface irrigation over non-irrigated/free drainage were obvious as the highest average yields for both corn and soybean were found in the subirrigated plots in both years. In 1995, subirrigated corn yielded 0.92 t/ha more than dryland corn, while subirrigated soybean produced 0.34 t/ha more than dryland soybean for yield increases of 8.3% and 10.7%, respectively. In 1996, the subirrigated plots produced 0.46 t/ha more corn and 0.82 t/ha more soybean than the non-irrigated plot for yield increases of 6.7% and 34.8%, respectively. In a lysimeter study in Quebec, Madramootoo et al. (1995) found similar soybean yield responses to SI on a sandy loam soil. Cooper et al. (1991) found yield increases with subirrigated soybean as well, while Drouet et al. (1989) found yield increases with subirrigated corn.

When strip cropping is taken into account (i.e., weighted averages of corn and soybeans: 33.3% corn and 66.7% soybean in 1995 and 50% corn and 50% soybean in 1996), total production from subirrigated land was increased by 10% in 1995 and by 21% in 1996 as compared to production on non-irrigated land. In general, 1996 yields were lower than in 1995 due to a late spring.

### Subsurface irrigation costs

Forecasted costs for a field scale subirrigation system are presented in Table VII. Since it is assumed that SI systems will be installed on farms that already have a subsurface drainage system, the irrigation costs are an incremental cost to the drainage system already in place. Cost estimates include annual maintenance and have been converted to a per hectare basis.

### Economic analysis

The costs incurred from the subsurface irrigation of the experimental field (2.1 ha) were not deemed to be representative of the costs that would be derived from large scale subirrigation. Both initial capital costs and annual costs for a subsurface irrigation system decrease as project size increases. For this reason, a subsurface irrigation system for a 25 ha field was priced. It was assumed that the water would be pumped a short distance (30m) directly into a subsurface collector drain for a field scale set up. The shorter pumping distance dramatically reduces the total pressure head requirement, as compared to the present experimental set up. It was assumed that the water was conveyed by two 50 mm diameter pipes.

A cost/benefit analysis was done for the large field scale system. For the large field scale analysis, it was assumed that the rates and duration of water application and yield benefits would be similar to those obtained in the experimental field. The analysis is carried out on a per hectare basis.

The design life of pumps and components varies between 32,000 and 50,000

## Table VI: 1995 and 1996 soybean yield comparisons

| | Subirrigated soybean yield | | Non-irrigated soybean yield | | SI yield response | Significance level |
|---|---|---|---|---|---|---|
| Year | Mean (t/ha) | Standard deviation | Mean (t/ha) | Standard deviation | (%) | $t$-test probability |
| 1995 | 3.51 | 0.25 | 3.17 | 1.24 | 10.7 | 0.0156* |
| 1996 | 3.18 | 0.24 | 2.36 | 0.54 | 34.8 | 0.0002* |

*Significant at the 95% confidence level.

## Table VII: Subirrigation costs (25 ha field estimate)

| Item | Cost ($) |
|---|---|
| Capital costs | |
| Myers 200M 30-1 jet pump (2.25 kW) | 753 |
| 159 L pressure tank | 229 |
| Accessories and installation (estimate) | 500 |
| 2 * 50.8 mm water line (30m) (estimate) | 276 |
| Miscellaneous pipe fittings and clamps | 50 |
| Capital costs total | 1808 |
| Capital costs per hectare | $72.32 |
| Variable costs | |
| Electricity (est.) (operates @80% time) | 562 |
| Maintenance @5% of capital costs (est.) | 90 |
| Variable costs total | 652 |
| Variable costs per hectare | $26.08 |

hours, or between 16 and 25 years (James 1988). This corresponds to an annual usage of between 1280 hours and 3125 hours. The irrigation pump for the experimental field operated approximately 1800 hours during the summer of 1995. Due to the fact that the pump was subject to continuous operation, a design life of 14 years or 25,200 hours was used, assuming that the pump operates 1800 hours every year. From the pressure discharge curve of the large field scale pump, operating time would be similar to that of the experimental field pump. It is assumed that the pressure tank, accessories, and installation are expenses that are incurred only when a pump is installed.

James (1988) stated that plastic water pipe has an effective life span of 10 years. From observing installations in the local area, most unburied water pipe does not last 10 years. A more realistic value is 7-8 years. A life span of 7 years is used for the economic analysis. The economic analysis period is 14 years, the life span of the water pump. Thus, during the analysis period, waterlines would have to be replaced every 7 years, but the effect of the components' salvage value can be ignored, as both pump and pipe will require replacement at the end of the analysis period. It was assumed that worn out components will have negligible salvage value.

### Economic calculations

The results of the analysis are presented in three methods: project present worth, equivalent annual worth, and benefit/cost ratio. The sensitivity of the economic return with respect to discount rate, crop prices, and increment in yield was determined. Discount rates of 8% and 12% were used. Three grain prices were used in the analysis: the market prices in 1995 and 1996, the average prices over the past 5 years, and the average prices over the past 17 years (Table VIII). Yield increments used for subsurface irrigated fields were those from both years of the actual study and from a projected 5% (low) and 25% (high) yield increase over the average of the 1995 and 1996 harvest yields. Strip cropping was assumed to be 50% corn and 50% soybean. The current price used for the low and high yield response scenarios was an average of the 1995 and 1996 prices.

Costs of a subirrigation system were divided into capital costs and annual costs. Capital costs were further subdivided into two categories; those made at year one of the project (all components) and those made at year 7 of the project (pipe replacement). The 7 year costs were converted to a present value basis using the discount formula:

$$P = F/(1+r)^n \tag{3}$$

where:

$P$ = present value of money,
$F$ = future amount of money (i.e. pipe cost at year 7),
$r$ = discount rate, and
$n$ = period (14 years).

Following the conversion of all capital costs to a present value, all annual costs and benefits were converted to a present value. It was assumed that annual cash inflows and outflows are made at the end of each fiscal year. The formula used was:

## Table VIII: Historic grain prices for corn and soybean

| Year | Corn ($/t) | Soybean ($/t) |
|---|---|---|
| 1995 | 160.00 | 321.48 |
| 1996 | 183.19 | 343.75 |
| Average (1995-1996) | 171.60 | 332.62 |
| Average (past 5 years) | 142.21 | 297.49 |
| Average (past 17 years) | 126.62 | 274.97 |

Prices obtained from Ontario Corn Producers' Association and Ontario Soybean Growers' Marketing Board.

$R$ = expenditure or revenue (received or made at end of time period $i$), and
$r$ = interest rate.

After the the conversion of all costs and benefits to a present value, project value was presented in three different methods. The total present value of the project was calculated by subtracting the present value of the costs from the present value of the benefits:

$$\textit{Project Present Value } (PW) = P_{benefits} - P_{costs} \qquad (5)$$

The resultant annual benefits from the project were calculated by:

$$\textit{Annual Return} = \textit{Project Present Value / Present Value factor} \qquad (6)$$

The present value factor obtained from Eq. 4 varies with the discount rate used (8.90 for 8% and 7.42 for 12%). For both project present value and annual return, a positive result indicates a financial benefit, while a negative return indicates a financial loss. To calculate the benefit/cost ratio, the present value of the project benefits is divided by the present value of the annual costs:

$$\textit{Benefits/Costs} = \textit{Present Value of Benefits/Present Value of Costs} \qquad (7)$$

A benefit/cost ratio of more than one indicates that the project will generate income greater than costs.

Knowing the economic impact of subsurface irrigation is important. This study provided practical and useful information. The results of all economic calculations are presented in Tables IX through XII. The sensitivity analysis determined that the benefit/cost ratios of subsurface irrigation would be in the range of 2.38 to 3.01, based on 1995's 10% yield increase and from 3.21 to 4.30, based on 1996's 21% yield increase. A low 5% increase in yield would give a bene-

**Table IX: Economic analysis for proposed 25 ha field with subsurface irrigation setup using 1995 yield data**

| | 1995 Grain prices Discount rate | | Past 5 year average grain prices Discount rate | | Past 17 year average grain prices Discount rate | |
|---|---|---|---|---|---|---|
| Item | 8% | 12% | 8% | 12% | 8% | 12% |
| Capital costs at year 1 | 72.32 | 72.32 | 73.32 | 72.32 | 72.32 | 72.32 |
| Capital costs at year 7 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 |
| PW of costs at year 7 | 7.61 | 5.90 | 7.61 | 5.90 | 7.61 | 5.90 |
| Annual costs | 33.61 | 33.61 | 33.61 | 33.61 | 33.61 | 33.61 |
| Annual benefits | 128.25 | 128.25 | 116.00 | 116.00 | 105.00 | 105.00 |
| Difference | 94.64 | 94.64 | 82.39 | 82.39 | 71.39 | 71.39 |
| PW of annual benefits | 842.65 | 702.56 | 733.58 | 611.63 | 635.64 | 529.97 |
| PW of project | 762.72 | 624.34 | 653.65 | 533.41 | 555.71 | 451.75 |
| Resultant annual benefit | 85.66 | 84.10 | 73.41 | 71.85 | 62.41 | 60.85 |
| PW of benefits | 1141.91 | 952.07 | 1032.84 | 861.13 | 934.90 | 779.47 |
| PW of costs | 379.19 | 327.73 | 379.19 | 327.73 | 379.19 | 327.73 |
| Benefits/cost ratio | 3.01 | 2.91 | 2.72 | 2.63 | 2.47 | 2.38 |

**Table X: Economic analysis for proposed 25 ha field with subsurface irrigation setup using 1996 yield data**

| | 1995 Grain prices Discount rate | | Past 5 year average grain prices Discount rate | | Past 17 year average grain prices Discount rate | |
|---|---|---|---|---|---|---|
| Item | 8% | 12% | 8% | 12% | 8% | 12% |
| Capital costs at year 1 | 72.32 | 72.32 | 72.32 | 72.32 | 72.32 | 72.32 |
| Capital costs at year 7 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 |
| PW of costs at year 7 | 7.61 | 5.90 | 7.61 | 5.90 | 7.61 | 5.90 |
| Annual costs | 33.61 | 33.61 | 33.61 | 33.61 | 33.61 | 33.61 |
| Annual benefits | 183.07 | 183.07 | 154.68 | 154.68 | 141.87 | 141.87 |
| Difference | 149.46 | 149.46 | 121.07 | 121.07 | 108.26 | 108.26 |
| PW of annual benefits | 1330.76 | 1109.52 | 1077.98 | 898.77 | 963.92 | 803.67 |
| PW of project | 1250.83 | 1031.30 | 998.05 | 820.55 | 883.99 | 725.45 |
| Resultant annual benefit | 140.48 | 138.92 | 112.09 | 110.53 | 99.28 | 97.72 |
| PW of benefits | 1630.01 | 1359.03 | 1377.24 | 1148.27 | 1263.18 | 1053.18 |
| PW of costs | 379.19 | 327.73 | 379.19 | 327.73 | 379.19 | 327.73 |
| Benefits/cost ratio | 4.30 | 4.15 | 3.63 | 3.50 | 3.33 | 3.21 |

**Table XI: Economic analysis for proposed 25 ha field with subsurface irrigation setup (for a low 5% crop yield increase)**

| | 1995- 1996 Grain prices Discount rate | | Past 5 year average grain prices Discount rate | | Past 17 year average grain prices Discount rate | |
|---|---|---|---|---|---|---|
| Item | 8% | 12% | 8% | 12% | 8% | 12% |
| Capital costs at year 1 | 72.32 | 72.32 | 72.32 | 72.32 | 72.32 | 72.32 |
| Capital costs at year 7 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 |
| PW of costs at year 7 | 7.61 | 5.90 | 7.61 | 5.90 | 7.61 | 5.90 |
| Annual costs | 33.61 | 33.61 | 33.61 | 33.61 | 33.61 | 33.61 |
| Annual benefits | 61.89 | 61.89 | 52.83 | 52.83 | 47.74 | 47.74 |
| Difference | 28.28 | 28.28 | 19.22 | 19.22 | 14.13 | 14.13 |
| PW of annual benefits | 251.80 | 209.94 | 171.13 | 142.68 | 125.81 | 104.89 |
| PW of project | 171.87 | 131.72 | 91.20 | 64.46 | 45.88 | 26.67 |
| Resultant annual benefit | 19.30 | 17.74 | 10.24 | 8.68 | 5.15 | 3.59 |
| PW of benefits | 551.05 | 459.44 | 470.39 | 392.19 | 425.07 | 354.40 |
| PW of costs | 379.19 | 327.73 | 379.19 | 327.73 | 379.19 | 327.73 |
| Benefits/cost ratio | 1.45 | 1.40 | 1.24 | 1.20 | 1.12 | 1.08 |

**Table XII: Economic analysis for proposed 25 ha field with subsurface irrigation setup (for a high 25% crop yield increase)**

| | 1995 - 1996 Grain prices Discount rate | | Past 5 year average grain prices Discount rate | | Past 17 year average grain prices Discount rate | |
|---|---|---|---|---|---|---|
| Item | 8% | 12% | 8% | 12% | 8% | 12% |
| Capital costs at year 1 | 72.32 | 72.32 | 72.32 | 72.32 | 72.32 | 72.32 |
| Capital costs at year 7 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 | 13.04 |
| PW of costs at year 7 | 7.61 | 5.90 | 7.61 | 5.90 | 7.61 | 5.90 |
| Annual costs | 33.61 | 33.691 | 33.61 | 33.61 | 33.61 | 33.61 |
| Annual benefits | 306.94 | 306.94 | 261.91 | 261.91 | 236.68 | 236.68 |
| Difference | 273.33 | 273.33 | 228.30 | 228.30 | 203.07 | 203.07 |
| PW of annual benefits | 2433.67 | 2029.08 | 2032.73 | 1694.80 | 1808.09 | 1507.50 |
| PW of project | 2353.74 | 1950.86 | 1952.80 | 1616.58 | 1728.16 | 1429.28 |
| Resultant annual benefit | 264.35 | 262.79 | 219.32 | 217.76 | 194.09 | 192.53 |
| PW of benefits | 2732.93 | 2278.58 | 2331.99 | 1944.30 | 2107.35 | 1757.01 |
| PW of costs | 379.19 | 327.73 | 379.19 | 327.73 | 379.19 | 327.73 |
| Benefits/cost ratio | 7.21 | 6.95 | 6.15 | 5.93 | 5.56 | 5.36 |

fit/cost ratio in the range of 1.08 to 1.45 while a high yield response of 25% would give 5.36 to 7.21. Figure 3 illustrates the economic returns for a subsurface irrigation system on a 25 ha field evaluated at variable grain prices, discount rates, and yield responses. The cost/benefit ratio was most sensitive to the crop yield response to subsurface irrrigation and to grain price. These two factors had the most significant effect on the benefit/cost ratio. The cost/benefit ratio increased with lower discount rates. However, the effect of the discount rate on the benefit/cost ratio was minimal and not as pronounced as either grain price or yield. Depending on the combination of crop growing conditions, yield increases, market grain prices, and discount rates, net annual returns ranged from \$3.59/ha to \$264.35/ha.

Crop growing conditions were very good at Bainsville during the 1995 season. June was unusually dry, but ample water was available for non-irrigated crops when it was needed in July. Water shortages during the month of June had a low impact on crop yield. Total rainfall during the crop flowering and grain filling stages (July-August) was 14.0% and 22.3% above the 17 year average total for 1995 and1996, respectively.

Due to the fact that the growing season conditions were favorable in 1995 and 1996, the differences in yields obtained between the irrigated and non-irrigated (10% and 21%) can be considered low to moderate yield responses. This range of yield increase represents annual net returns of \$60.85/ha to \$140.48/ha. In drier years, the benefits of subsurface irrigation would most likely be higher. Based on the long term average growing season conditions of the region, a 10% yield increase is considered the least amount of return from subsurface irrigation. Calculations were also made to determine returns from low (5%) and high (25%) yield increases. Grain prices are unpredictable, so returns were calculated using

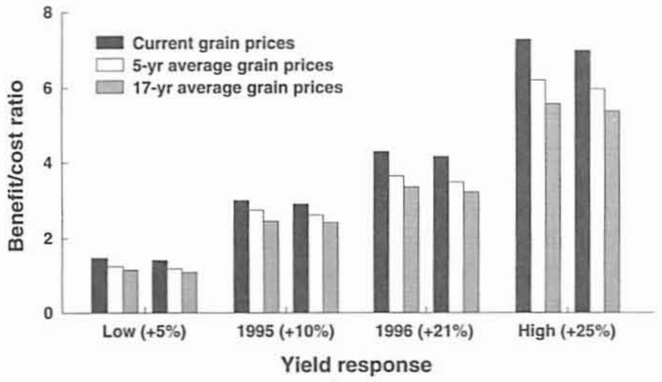

**Fig. 3. Benefit/cost ratios for subsurface irrigation on proposed 25 ha setup**

1995 grain prices as well as the average price over the past 5 years and the average price over the past 17 years. In all circumstances, subsurface irrigation at the large field scale was economically feasible.

## SUMMARY AND CONCLUSIONS

Field data from 1995 and 1996 were used to forecast the costs and yield increases that could be expected from subsurface irrigation on a 25 ha field. Grain prices and climatic data from 1995 and 1996 were compared to long term values. This comparison revealed that 1995 and 1996 grain prices were high and that 1995 and 1996 had good growing conditions for corn and soybean. The long range economic returns were calculated using 1995 and 1996 grain prices, the average grain prices over the past 5 years and the average prices over the past 17 years. Economic returns using the grain prices from the past 5 years differed little from the returns using the grain prices from the past 17 years. Yield response and grain prices had the most impact on returns.

The following conclusions were drawn from the study:

In years such as 1995 and 1996, when crop growing conditions were particularly favourable, combined corn and soybean yield response to subsurface irrigation ranged from 10-21% over non-irrigated yields on a ridge-till field with a silt loam soil. Thus, in less favourable years, at least this much can be expected from subsurface irrigation under the same conditions.

When the study results were used to forecast economic returns for a 25 ha field, the sensitivity analysis resulted in benefit/cost ratios ranging from 1.08 to 7.21 for a 14-year project with the various combinations of yield increase, grain prices, and discount rates. The practice of subsurface irrigation is economically feasible on a large scale.

For subsurface irrigation to be economically justifiable and to be assured of a positive financial return, a yield increase of at least 4.7% is required (assuming the 17-year average grain prices and a 12% discount rate).

To be assured of a positive financial return, the annual cost of subsurface irrigation (ammortized capital costs + yearly costs) should be less than $100/ha (assuming a 5% yield increase, 17-year average grain prices, and a 12% discount rate).

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