# Combining flood irrigation and controlled subsurface drainage to irrigate maize in a temperate subhumid climate

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Nsengiyumva, D., Papineau, F. and Broughton, R.S. 1997. **Combining flood irrigation and controlled subsurface drainage to irrigate maize in a temperate subhumid climate.** Can. Agric. Eng. 39:151-156. Efficient, cost effective removal of sediment from river water used for subsurface irrigation is required to protect the subsurface drain pipes from clogging. Flood irrigation of a field combined with controlled drainage was assessed as a potential method of filtering river water used for subsurface irrigation. This system of irrigation consists of applying river water on a small section of the field from which water soaks into the soil to subsurface drain pipes under the flooded area. With the outlet of the subsurface drainage system closed, the water is distributed throughout the whole system, thereby subsurface irrigating the crops. Results indicate that water applied to the flooded section of the field redistributes within a few hours through the entire field. Sealing of the soil of the flooded section with sediment from the river water was not detected. Also, the yield of maize from this method of irrigating was comparable to that obtained under conventional subsurface irrigation. Based on this one-year study, flood irrigation combined with controlled drainage appears to be a practical option for using sediment laden river water to irrigate crops on relatively flat, subsurface drained fields.

Une méthode efficace et peu coûteuse est nécessaire pour réduire le contenu en sédiments de l'eau de rivière utilisée pour l'irrigation souterraine, en vue de préserver le bon fonctionnement du système de drains souterrains. Une méthode d'irrigation, la submersion d'une partie du terrain combinée au drainage contrôlé, a été testée parmi d'autres solutions potentielles. Cette méthode consiste à appliquer l'eau de la rivière sur une petite section du champ sous culture d'où l'eau s'infiltre dans le sol pour atteindre les drains souterrains. Le contrôle de drainage consiste à fermer la sortie du système de drainage au niveau de la chambre de contrôle. Ainsi, l'eau qui atteint cette chambre est repoussée en arrière pour être redistribuée dans tout le système de drains souterrains, irrigant ainsi souterrainement les plantes. Les résultats montrent qu'à partir de la partie inondée, l'eau se redistribue en quelques heures dans tout le champ. La formation de croûte à la surface du sol par les particules fines contenues dans l'eau d'inondation, qui était appréhendée au début de l'experience, ne s'est pas matérialisée. Cette méthode d'irrigation est comparable au système d'irrigation souterraine conventionnelle en ce qui concerne les rendements du maïs. D'après ces résultats d'une saison de recherche, il appert que l'irrigation par submersion combinée au drainage contrôlé s'avère être une alternative intéressante pour l'irrigation des cultures avec de l'eau chargée de sédiments, lorsque la topographie, le sol et la nappe phréatique sont propices à l'utilisation d'une telle méthode.

## INTRODUCTION

Previous research on flat sandy soils in the St-Lawrence lowlands, Quebec, has indicated that subsurface irrigation using subsurface drainage systems increases the average yields of maize and soybean by as much as 25 to 30% (Memon et al. 1987; Galganov 1991). Subsurface irrigation costs much less than any other type of irrigation, if the topography, soil type, and soil depth are suitable (Drouet 1989).

To ensure proper functioning of subsurface drainage/irrigation drain pipes, water free of sediment must be used. Galganov (1991) found that the use of conventional trickle irrigation system filters and specially made geofabric filters was not practical for removing sediment from river water, as they required excessive maintenance. Hence, an improved method of filtering the river water, before conveying it into the subsurface drain pipes, is required. Indeed, a blocked drain, as a result of poor quality irrigation water, will have detrimental effects on both irrigation and drainage.

Other solutions to the filtration problem of sediment in the river water used for subsurface irrigation have been tried (Nsengiyumva 1994; Nsengiyumva et al. 1996). Two systems have been designed, operated, and evaluated. The first system consisted of filtering the water through filter basins covered with grass and a geotextile. The second system consisted of a combination of flooding a part of a field and controlled drainage, the water being filtered as it moved through the soil towards the subsurface drainage/irrigation drain pipes. This paper presents the results mainly pertaining to the second system. The other system is fully described in Nsengiyumva (1994) and Nsengiyumva et al. (1996). Briefly, this system consists of a series of filter basins among which some are covered with inundation resistant grasses and the others are covered with a geotextile. In each basin, 75 mm diameter pipes are placed in two trenches filled with gravel and/or sand. The water is then pumped from the river to the basins and the filtered water is conveyed to the control chamber of the irrigation system through a series of collector pipes, one for each basin.

Filtration is the purification process whereby the liquid to be treated is passed through a porous medium. During this passage, some of the suspended and colloidal impurities in the liquid are left behind in the pores or openings or upon the medium itself (El-Morsy 1992).

The important processes of filtration are straining, sedimentation, and chemical and biological activity (Clark et al.

1971; Huisman 1978 cited by El-Morsy 1992). The straining process occurs principally at the interface between the filter medium and water. Initially, materials larger than pore openings at the interface are strained. During the filtration process, material deposited as a mat on the surface builds up and further enhances the straining process; however, it also restricts passage of water through the filter bed. Mechanical straining takes place almost entirely at the surface of the filter, where it clogs the upper millimetres of the filter bed.

Sedimentation removes particulate suspended matter of finer sizes than the pore openings by precipitation upon the sides of the medium particles in exactly the same way as in any ordinary settling tank. Each pore space acts as a tiny sedimentation basin (Clark et al. 1971). According to Huisman (1978) cited by El-Morsy (1992), adsorption is another additional mechanism for removal of smaller particles during filtration, retaining finely divided suspended matter next to colloidal and molecular dissolved impurities.

Bio-chemical activity is related to the matter accumulated on the sides of the filtration medium particles. This matter is oxidized by chemical and biological agents and the ultimate result is the clogging of the filter bed. For instance, soluble ferrous and manganous compounds are transformed into ferric and manganic oxide hydrates forming a thin coating around the particles (Huisman 1982 cited by El-Morsy 1992).

Based on the previous theory, it was thought that applying water directly onto the crop land might be an alternative to the filtration of polluted river water by means of filter basins as described above. This would have the advantage of eliminating all the inconveniences and costs associated with basin construction, while permitting crop irrigation and avoiding drain clogging problems. This system relies in large part upon the infiltration process to improve water quality. In such a system, as reported by Hunt and Lee (1976), the wastewater is renovated by the soil, plants, and microorganisms as it moves through the soil profile. Bouwer (1976) indicated that most of the quality improvement of the effluent water as it moves through the ground is obtained in the top meter of the soil profile. Notably, here is where nearly complete removal of suspended solids occurs.

In this study, the technique used consisted in combining flooding a part of a field with controlled drainage. The water is filtered while soaking into the soil. The subsurface drains under the flooded area are located at more than 1.2 m depth. The water is considered completely filtered before reaching them. With the outlet of the subsurface drainage system fixed with a watertable level control device, the water is distributed throughout the whole field served by the subsurface drainage system, thereby subsurface irrigating the crops.

However, with such a method of irrigation, there are potential side effects to consider:

1. crop damage due to excessive water stress or insufficient air in the root zone in the flooded area,
2. reduction of the infiltration capacity of the soil due to soil surface sealing with the sediment contained in the river water,
3. loss of nutrients through leaching, volatilization of ammonia, and denitrification of nitrates, and
4. introduction of new or excessive amounts of weed seeds brought onto the crop land with the irrigation water.

The objective of this study was to assess the technical feasibility of flood irrigating a portion of a corn field in order to filter any sediment in the water and subsequently to distribute the filtered water via subsurface drain pipes and then subsurface irrigate the rest of the field by capillary rise. Field plots were established to evaluate the hydrologic and agronomic consequences of growing corn crops in two irrigation regimes: the flood irrigation combined with controlled drainage method and the conventional subsurface irrigation method. Evaluations were based on yield of maize, response of the watertable to flooding, and water intake and infiltration into and through the soil.

## MATERIALS AND METHODS

To determine the benefits of flood irrigation of a part of a field combined with controlled drainage, a field experiment was conducted. The experimental plots were installed on a farm in the county of Richelieu, QC. The subsurface drainage system existing in the experimental plots had been installed with a trenchless plough in 1981 with 14 m spacings between laterals. The 100 mm inside diameter lateral drain pipes were at a minimum of 1.2 m depth at the end of the laterals and at a maximum of 1.6 m at the junction with the collector. The soil profile is composed of about 0.3 m of loamy-sand topsoil on top of 0.2 to 0.4 m of sand laying over clay. Most of the soil on this farm is classified as a sandy loam.

The experiment utilized portions of two fields seeded to grain corn (Fig. 1). The north field, a 2.8 hectares area, was divided into a side-by-side series of seven plots measuring 900 $m^2$ (30 m x 30 m) each. Three of the plots (F-1, F-2, F-3) were prepared for flood irrigation treatments by addition of perimeter dikes approximately 100 mm high. The four remaining plots (NF-1, NF-2, NF-3, NF-4) utilized the two spaces between the three flood basin plots and space on the outside of each end plot. These four plots constituted replicates of the non-flooded treatment and received water from rainfall and capillary rise from groundwater. Figure 2 shows a sketch of the system's hydraulics. The south field covered 5 hectares and was conventionally "subsurface irrigated" (SUB treatment). The drainage/irrigation systems of the 2.8 (north) and 5 hectares (south) fields are completely independent. The north field drains towards control chamber # 1 (CC-1), whereas the south field drains towards control chamber # 2 (CC-2).

Flooding of the three F-plots in the north field was done in rotation, one basin at a time, generally from about 1800 h to about 1000 h of the following day. During this time, the equivalent of 12 mm of water was applied on the basin. This represents the estimated irrigation requirement of 3 d, i.e. 4 mm/d, assuming an evaporation of 1.5 mm/d. Flooding was delayed when it rained.

Conventional subsurface irrigation was applied to the south field (SUB treatment) at a rate of 2.5 mm/d on a continuous basis. This was accomplished by applying water in grass filter basins conveying filtered river water to the control chamber of the subsurface drainage/irrigation system. Figure 3 shows the hydraulics of this system. The daily

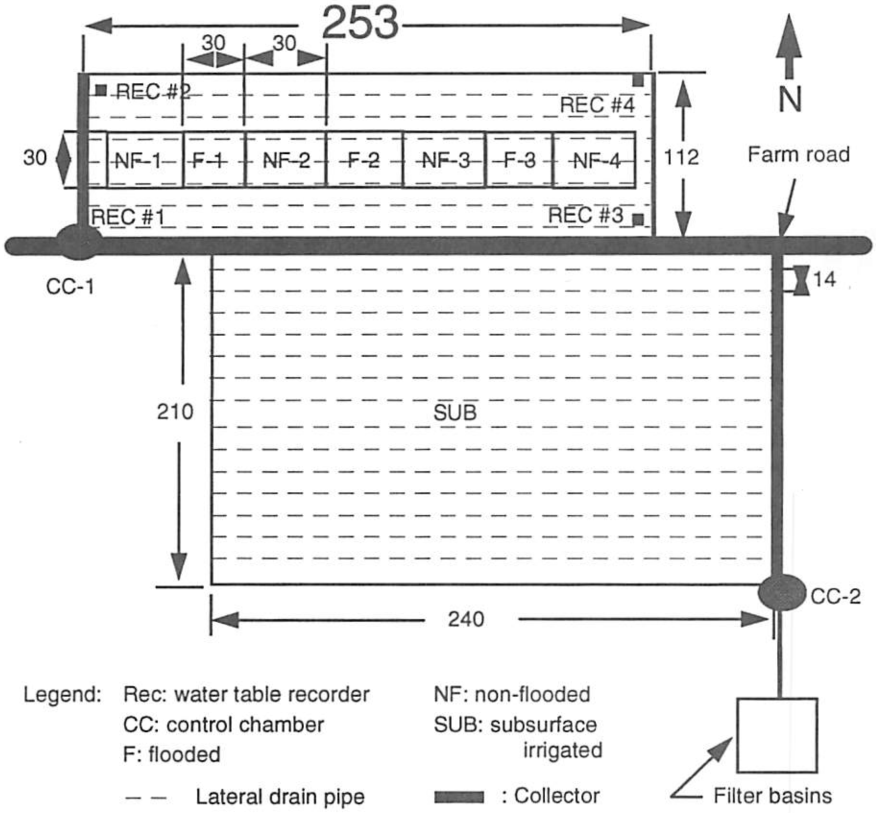


**Fig. 1. Layout of the experiment. (Diagram not to scale; all dimensions in metres)**

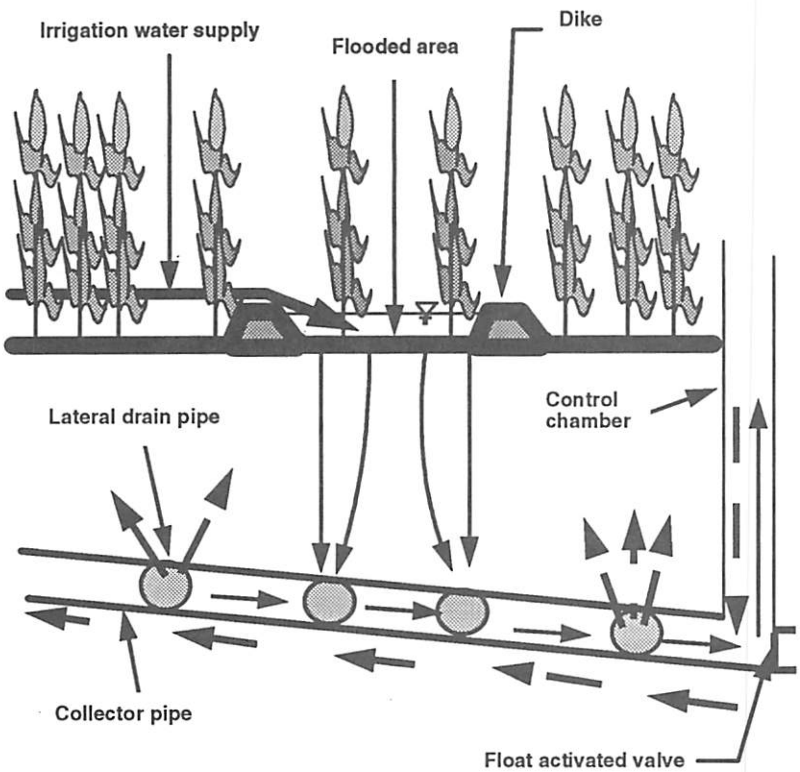


**Fig. 2. Hydraulics of flood irrigation combined with controlled drainage, north field.**

irrigation requirement was determined according to the estimates made by Gallichand and Broughton (1993). In the conventional system, it was hypothesized that no evaporation from the soil surface was taking place.

To measure the distribution of the irrigation water in the north field, watertable observation pipes were installed above and at mid-space between the lateral drain pipes. On the four corners of the field, watertable recorders were installed to record continuously the watertable level, particularly, to determine the response time of the watertable to flooding. Recorder #2 did not function properly and its readings were ignored in analysis.

Both the quality and quantity of river water applied to each field were measured. The quantity of water was monitored using flow-meters. The quality of the water was evaluated by weighing total suspended solids from samples taken before the start of each irrigation. This was done using the vacuum filtration method, as described by Greenberg et al. (1985), using Whatman qualitative filters #4, 55 mm in diameter. These filters retain particles larger than 20 to 25 μm. The average concentration of total suspended solids in the non-filtered river water was 15.6 mg/L. Initially, we speculated that with such amount of sediment content, no problem would be observed on the subsurface drainage/irrigation system. However, Nsengiyumva (1994) and Nsengiyumva et al. (1996) found that the use of this water can very quickly clog the geotextile covering the drain pipes.

Infiltration tests were performed before and after the irrigation season, using a double-ring infiltrometer as described by Bouwer (1986), both on the flooded and the non-flooded sections of the north field. Before the start of irrigation, 12 tests were performed on randomly selected sites in the whole field. At the end, 3 tests were performed in each of the flooded and non-flooded plots.

Just before the farmer harvested his corn, yields were measured following the method of the "Régie des Assurances Agricoles du Québec (1986)". Briefly, the method consisted of:

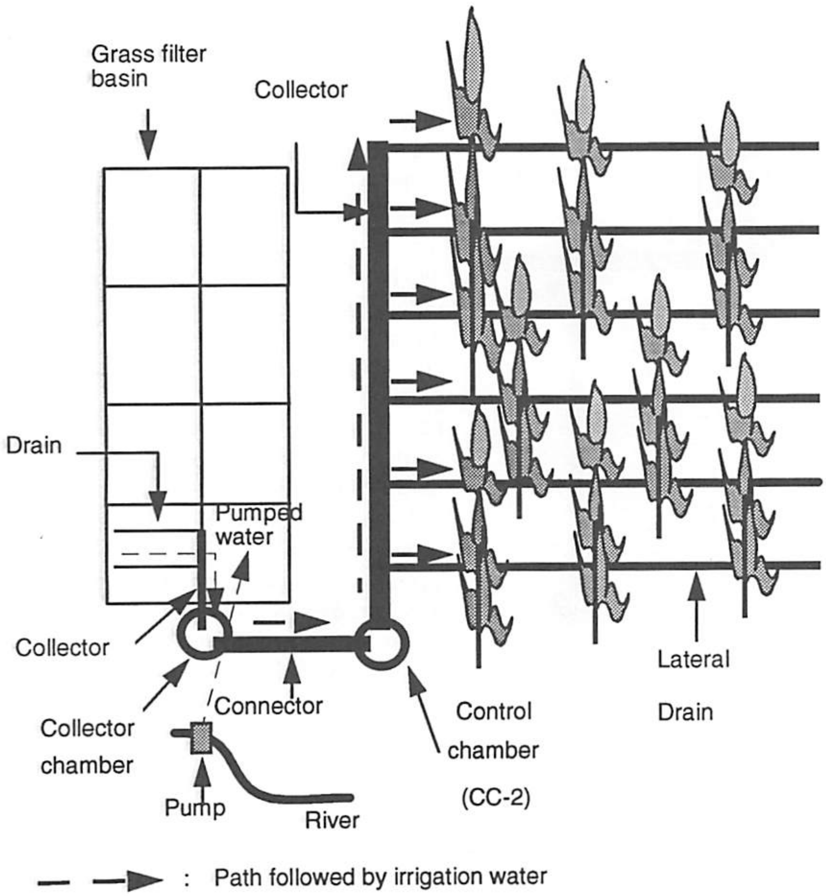


**Fig. 3. Hydraulics of the conventional subsurface irrigation system, south field.**

1. randomly selecting sites to harvest,
2. hand harvesting all the cobs on the site except the very small ones which could not be collected by the harvesting machine, and
3. weighing all the cobs collected,
4. randomly choosing a sample of 10 cobs for each site, oven drying them, and calculating the 15% moisture content grain yield for each site. In the north field, 3 sites of 15 $m^2$ (10 m long x 1.5 m wide, i.e. 3 rows of corn) were harvested in each site. In the south field, 6 sites of the same size were harvested.

## RESULTS AND DISCUSSION

### Response of the watertable to flooding

The reaction of the watertable following flooding was quite rapid in the north field. Figures 4a and 4b show that within 2 to 8 hours after commencement of flooding, the watertable started rising in the control chamber as well as in the farthest corners of the field from the control chamber. Water level charts following all other flooding gave similar responses at the recorder sites. Measurements at the watertable observation pipes indicated that the watertable in the field rose the same way as at the corners.

### Infiltration rate

An asymptotic logarithmic equation

$$Y = a - b \ln (X) \qquad (1)$$

where

$Y$ = infiltration rate (m/d),
$X$ = time (d), and
a, $b$ = coefficients to be estimated

was fitted to the infiltration data measured before and after the irrigation season. Figure 5 shows the raw data points and the fitted curves and the statistics pertaining to these curves are shown in Table I. From these curves, it can be said that the asymptotic values of the water infiltration rates reduce to about the same value for both the flooded and non-flooded plots, as compared to the infiltration rates measured before flooding started. Over the period between measurements, flooding did not have much effect on the infiltration rate of the water into the soil. The reduction in infiltration rate with time varied less between treatments than the normal variation associated with rates during the growing season as shown from the curves obtained in July and September in the non-flooded plots. In the long term, flooding a portion of the field year after year might reduce infiltration rates. However, we think that this will not likely occur because of tillage practised each year. Furthermore, the farmer has the choice of changing the flooded area from year to year.

### Corn yield

Table II shows the maize yield recorded on the flooded, non-flooded, and subsurface irrigated treatments. From this table, it is seen that the average 15% moisture content grain corn yields were 12,338, 11,672 and 10,194 kg/ha for the "non-flooded", "flooded", and "subsurface irrigated" plots, respectively. Using the General Linear Models Procedure of SAS software, it was found that these yields were not statistically significantly different at $\alpha = 0.05$. Hence, flooding did not negatively affect the maize yield. These yields compare favourably with the yields previously obtained in the same area with subsurface irrigation (Memon et al. 1987; Drouet 1989).

**Table I: Regression statistics of the fitted infiltration curves following Eq. 1**

| Statistic | July 1993 | NF Sept. 1993 | F Sept. 1993 |
|---|---|---|---|
| Number of data points | 139 | 74 | 51 |
| Standard deviation | 1.435 | 1.438 | 1.548 |
| R squared | 0.72 | 0.72 | 0.63 |
| a coefficient | 11.432 | 9.67 | 8.822 |
| b coefficient | -1.564 | -1.542 | -1.45 |

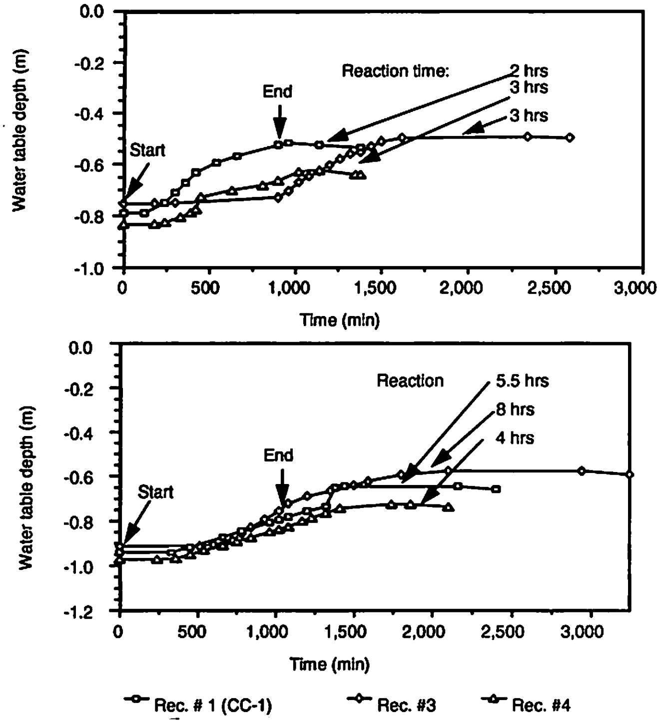


**Fig. 4. Watertable response to flooding: (a) Basin (plot) F-3; (b) Basin (plot) F-2; Start = commencement of flooding; End = flooding ceased.**

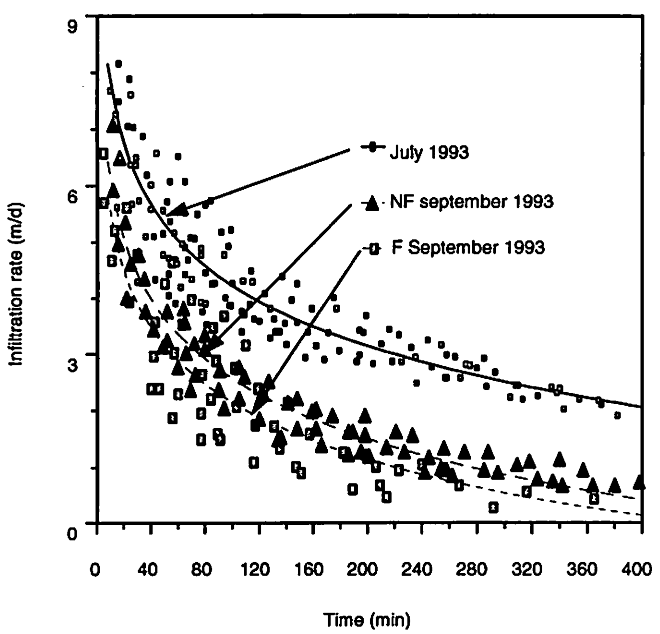


**Fig. 5. Average water infiltration rate into the soil with time measured in July and in September on the flooded (F) and non-flooded (NF) plots.**

**Table II: Maize yield**

| Site | Yield adjusted to 15% moisture (kg/ha) | Average yield per plot (kg/ha) | Average yield per treatment (kg/ha) |
|---|---|---|---|
| SUB - 1 | 12088 | | |
| SUB - 2 | 10850 | | |
| SUB - 3 | 9200 | | |
| SUB - 4 | 9615 | | |
| SUB - 5 | 10817 | | |
| SUB - 6 | 8592 | | 10194 |
| F1 - 1 | 10922 | | |
| F1 - 2 | 4485 | | |
| F1 - 3 | 12223 | 9210 | |
| F2 - 1 | 13338 | | |
| F2 - 2 | 10622 | | |
| F2 - 3 | 13117 | 12359 | |
| F3 - 1 | 11155 | | |
| F3 - 2 | 15383 | | |
| F3 - 3 | 13803 | 13447 | 11672 |
| NF1 - 1 | 14861 | | |
| NF1 - 2 | 13450 | | |
| NF1 - 3 | 10672 | 12994 | |
| NF2 - 1 | 13394 | | |
| NF2 - 2 | 6185 | | |
| NF2 - 3 | 12349 | 10643 | |
| NF3 - 1 | 13651 | | |
| NF3 - 2 | 12590 | | |
| NF3 - 3 | 12357 | 12866 | |
| NF4 - 1 | 15071 | | |
| NF4 - 2 | 12350 | | |
| NF4 - 3 | 11125 | 12848 | 12338 |

## CONCLUSIONS

The yield benefits drawn from flood irrigating a portion of a field combined with controlled drainage are comparable with those of conventional subsurface irrigation. However, when the irrigation water used is taken from a river containing sediment, flood irrigation presents an advantage over conventional subsurface irrigation with regard to preventing clogging of subsurface irrigation/drainage pipes. For the former, the water is filtered while soaking into the soil towards the drains. For the latter, a method of filtering the water before it enters the subsurface pipes must be provided. Hence, when soil, topography, and watertable conditions are appropriate and if the irrigation water contains considerable amounts of sediments, flood irrigation combined with controlled drainage is a practical alternative of adequately irrigating crops. No difficulties were found in the year that this system of irrigation was monitored. However, the ability of this technique to act as an adequate filter over the long term is inconclusive from the data collected in this single season study and should be the subject of further investigation.


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## REFERENCES


Bouwer, H. 1976. Improvement of wastewater quality by movement through soils and aquifers. In *Biological Control of Water Pollution*, eds. J. Tourbier and R.W. Pierson, Jr., 259-268. Philadelphia, PA: University of Pennsylvania Press.

Bouwer, H. 1986. Intake rate: Cylinder infiltrometer. In *Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods*, 2nd edition, ed. A. Klute, 825-844. Madison, WI: American Society of Agronomy.

Clark, J.W., W. Viessman, Jr. and M.J. Hammer, 1971. *Water Supply and Pollution Control*, 2nd edition. Scranton, PA: International Textbook Company.

Drouet, M.P. 1989. An Economic Analysis for Subsurface Irrigation of Maize in Quebec. Unpublished M.Sc thesis. McGill University, Montreal, QC.

El-Morsy A., 1992. Textile Utilization in Slow sand Filtration. Unpublished Ph.D thesis. El-Mansoura University, Mansoura, Dakahleya, Egypt.

Galganov, Y. 1991. Subsurface Irrigation of Soybean. Unpublished Ph.D. thesis. McGill University, Montreal, QC.

Gallichand, J. and R.S. Broughton. 1993. Besoins en eau pour l'irrigation des cultures du sud-ouest du Québec. Bulletin Technique 19. Conseils des Productions Végétales du Québec, Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec, Québec, QC.

Greenberg, A.F., R.R. Trussel and L.S. Clesceri. 1985. *Standard Methods for the Examination of Water and Wastewater*, 16th edition. Washington, DC: American Public Health Association.

Huisman, L., 1978. Development of Small-scale Slow Sand Filtration. Progam in Water Technology 11, 159.

Huisman, L., 1982. Slow Sand Filtration. International Reference Centre for Community Water Supply and Sanitation, World Health Organisation, Geneva, Switzerland.

Hunt, P.G. and C.R. Lee. 1976. Land treatment of wastewater by overland flow for improved water quality. In *Biological Control of Water Pollution*, eds. J. Tourbier and R.W. Pierson, Jr., 151-160. Philadelphia, PA: University of Pensylvania Press.

Memon, N.A., B. Von hoyningen Huene, J. Gallichand and R.S. Broughton. 1987. Subsurface irrigation and drainage on sandy soil in Southern Québec. *Canadian Agricultural Engineering* 29: 137-142.

Nsengiyumva, D. 1994. Field Evaluation of Three Systems for Filtering Polluted River Water for Use in Subsurface Irrigation. Unpublished Ph. D. thesis. McGill University, Montreal, QC.

Nsengiyumva, D., F. Papineau and R.S. Broughton. 1996. Use of grassed basins to filter water for subsurface irrigation: System design, construction and performance. *Canadian Water Resources Journal* 21(2):109-120.

Régie des Assurances Agricoles du Québec. 1986. Procédure par programme - Maïs grain. 100 Grenier Charlemagne, Montreal, Québec, QC.