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IMPROVING FARM IRRIGATION SYSTEMS BY AUTOMATION*

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ABSTRACT

Automation can make surface irrigation more attractive to the irrigator by reducing labor and energy requirements. Where lands and soils are well suited for surface irrigation, it is often more economical to improve surface systems than to convert them to energy intensive systems requiring many times more energy.

Canal systems need to be improved to facilitate on-farm automation by providing water on demand at the farm turnout. Improvements required to partially satisfy this need include: greater use of automatic control facilities, increasing the storage capacity of the system by constructing small regulating reservoirs and providing additional freeboard, improving turnouts to allow acceptance or rejection of the farm delivery, and improved water-measurement devices to measure water volumetrically. Where these improvements are not made, small farm reservoirs may be needed to provide water on demand and to facilitate automation of the farm system.

Many surface systems can be improved by replacing open ditches with buried pipelines and gated surface pipe. Systems with pipelines can be improved by using automated valves and controls with existing facilities. Both programable controllers and manually reset timers can be used for either fully automatic or semiautomatic operation.

Runoff was reduced about 45 per cent on experimental test plots using cutback furrow irrigation streams. Less water was applied with timer-controlled, semiautomatic irrigation than with manual irrigation. This resulted in higher production efficiencies in terms of crop yield per unit of water applied.

Irrigation efficiencies with present systems having long lengths-of-run can be improved by using either surface or buried pipe laterals to divide the

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total field length into two or more subruns. This is usually not practical unless the system is automated.

RESUME ET CONCLUSIONS

L'automatisation peut rendre l'irrigation superficielle plus attrayante à celui qui irrigue en réduisant les exigences de labeur et d'énergie. Le labeur peut être réduit jusqu'à un tiers et quelquefois à un dixième de celui exigé par des réseaux non-automatisés. Pour les terrains bien adaptés à l'irrigation superficielle, il est souvent plus économique de faire améliorer les réseaux superficiels que de les faire convertir à des réseaux qui utilisent beaucoup plus d'énergie.

Le degré d'automatisation, soit semi-automatique ou totalement automatique, et la mesure à laquelle un réseau peut être automatisé, dépend en grande partie du système par lequel est portée l'eau. Les réseaux des canaux doivent être améliorés pour faciliter l'automatisation sur la ferme elle-même, en fournissant de l'eau "sur demande" à l'ouvrage de prise d'eau. L'automatisation est donc plus facile à réaliser et eue exige moins d'attention de l'ouvrier. Les systèmes d'irrigation automatiques doivent être capables d'accepter ou de rejeter l'eau. La plupart des réseaux d'irrigation ne sont pas conçus pour accommoder ces débits d'eau variables et imprévisibles. Les améliorations de satisfaire au moins partiellement ce besoin comprennent: une meilleure utilisation des facilités de contrôle automatique; l'augmentation du volume d'eau que l'on peut mettre en réserve, en construisant de petits réservoirs de régulation, et en fournissant une revanche additionnelle; l'amélioration des ouvrages de prise d'eau de distribution pour qu'elles admettent ou rejettent le débit d'eau; et de meilleurs moyens de mesurer l'eau volumétriquement. Là où les amendements ne sont pas faits, on aura besoin peut-être de petits réservoirs sur la ferme pour qu'ils fournissent l'eau "sur demande" et qu'ils facilitent l'automatisation du système d'irrigation.

L'automatisation peut être utile particulièrement avec l'arrosage par calants ou avec la méthode des bassins d'infiltration car ces deux méthodes exigent beaucoup de changements fréquents. On a développé les vannes d'eau automatisés, des ouvrages de prise d'eau à buse, les robinets pneumatiques et les ouvrages de prise d'eau semi-automatiques pour ces sortes de réseaux d'irrigation.

On peut aussi améliorer les réseaux d'irrigation superficielle en remplaçant les fossés ouverts par des conduites enterrées et par des conduites superficielles qui opèrent sur le principe d'un vérin. Les réseaux possédant des conduites peuvent être améliorés en employant des contrôles et des robinets automatisés avec les aménagements qui existent déjà. On peut employer les contrôleurs capables d'être réglés d'avance et des synchronisateurs remontés à la main, soit pour une opération tout à fait automatique, soit pour une opération semi-automatique.

On a réduit l'écoulement de 36 pour cent jusqu'à 20 pour cent dans les parcelles expérimentales en réduisant le débit du courant dans les sillons. Les techniques d'automatisation peuvent être employées pour diminuer le débit du courant dans les sillons. Une telle technique emploie deux champs d'étendue égale que l'on irrigue indépendamment pour mouiller d'avance tous les sillons et ensuite que l'on irrigue conjointement par la même source d'eau pour réduire le débit du courant des sillons par 50 pour cent.

La quantité de l'eau appliquée à des parcelles de betterave-sucrière et de maïs avec un système d'irrigation semi-automatisée et contrôlée par des synchronisateurs était 188 et 191 mm moins que la quantité appliquée avec l'irrigation manuelle avec pas de différence importante dans les rendements. L'écoulement était 5 pour cent et 7 pour cent moins. Le rapport du rendement à l'eau appliquée était 26 pour cent et 24 pour cent plus haut avec l'irrigation automatisée.

On peut améliorer l'efficacité de l'irrigation avec des systèmes actuels qui possèdent de très longs sillons en employant des conduites latérales superficielles ou enterrées pour diviser la longueur du champ et en mettre plus d'un seul sillon. Le système n'est pas pratique d'ordinaire à moins qu'il ne soit automatisé. En 1974 les rendements des haricots étaient 15 pour cent plus grands que normale sur un champ de 5.7 ha qui était irrigué avec un tel système de courts sillons. Avec cette méthode d'irrigation on a beaucoup réduit l'écoulement et l'érosion.

I. INTRODUCTION

About three-fourths of the irrigated land in the United States is irrigated by surface methods, and most irrigation systems are operated manually. Past improvements of surface irrigation systems have consisted primarily of lining earthen ditches, installing concrete and metal check and turnout structures, and using siphon tubes. More recently, many systems have been improved by using gated surface pipe and buried pipelines, especially since the development of plastic pipe. Many systems can be further improved by automating all or part of the system.

This paper summarizes some of the requirments and considerations needed to improve farm surface irrigation systems by automation. Also described are ways in which present farm systems can be automated, in whole or in part, using methods, equipment, and techniques that have been developed and tested in recent years. Some effects of automation and new irrigation techniques on irrigation application and water-use efficiency are also presented.

II. CHARACTERISTICS OF SURFACE SYSTEMS

LABOR REQUIREMENTS

Surface irrigation characteristically has a high labor requirement. The primary motivation or incentive for improving surface systems has been to reduce labor and simplify irrigation. Many surface systems have been converted to sprinklers for this reason. Automation can reduce irrigating labor to one third, and in some cases, one tenth of that required for non-automated systems, depending on the system and the degree of automation used.

ENERGY REQUIREMENTS

Surface irrigation systems require much less energy than sprinkler systems. Batty, et al[3] estimated that sprinkler systems require from 4 to to over 13 times more total energy than do surface systems. Total energy inputs included that needed to manufacture the materials, level the land, install the system, and provide the necessary pressure. Water was assumed to be available to the farm at ground elevation, but it was assumed to be pumped with a 1·5-m (5-ft) head for surface irigation. With a 910-mm (36-in) net annual irrigation requirement, the annual "pumping" energy per acre varied from 41 kilowatt-hour (kW-hr) for surface systems without a reuse system to 56 kW-hr for a system with runoff recovery as compared with 896 kW-hr for solid se t and permanent sprinkler systems and 1825 kW-hr for traveler sprinklers. Similar results were reported by Chen, et. al.(5) in which sprinkler systems, designed for minimum total energy requirements, required from 6 to over 21 times more energy than surface systems, even with substantial energy inputs for land leveling.

As energy shortages become more acute and energy costs increase, it may be more economical and necessary to improve surface systems rather than convert them to energy-intensive systems to achieve greater irrigation efficiencies and to reduce labor requirements. This is particularly true on erosion-resistant soils with moderate to low intake rates and less than 1·5 per cent slopes, and on fields that have been or can be levelled and are well-suited for surface irrigation.

III. AUTOMATING SURFACE SYSTEMS

Not only can automation reduce surface irrigation labor requirements, but an automated surface system can also reduce runoff and the associated erosion. Many existing systems and structures can be modified for semi-automatic operation. Some pipeline systems can be automated by merely adding automatic components, such as valves, timers, and controllers. Other systems first should be improved with either buried or surface pipelines and then automated. Level basin irrigation is relatively easy to automate. Land leveling using laser-beam controls can further enhance surface irrigation(16).

WATER SUPPLY SYSTEM

The degree of automation. whether semi-or fully automated, and the extent to which a system can be automated depends largely on the farm water delivery policies. When farms receive water on a rotation basis, the controls are usually semi-automatic. The irrigator must decide which fields or crops are to be irrigated and the irrigation sequence. In addition, he must open gates or valves to receive the water and begin the irrigation. The automatic controls are programmed for only one irrigation at a time and are reprogrammed before the next irrigation.

Automation is easier to achieve and requires less operator attention when water is available "on demand," like that from wells and on-farm reservoirs. Tensiometers or other controls can then be used to automatically begin and end irrigations according to crop needs.

OPEN CHANNEL DELIVERY SYSTEMS

Open channel delivery systems limit the degree to which many farm systems can be automated. Most systems that receive water from canals or laterals cannot accept or reject water on demand as required for full automation. Canal systems, which generally were not designed to supply automated farm systems, do not have the necessary temporary storage nor the necessary controls. Most changes in farm-water delivery require at least 24 hours advance notice, and some systems require 2 or more days. Most canal delivery systems must be modified or improved before farm systems can be fully mechanized and automated.

Automated systems will usually reduce total water deliveries because runoff will be less and the depth of application will be better controlled. However, greater flexibility is needed to adjust to the variable, unscheduled deliveries, as automated farm systems accept and reject water. Because most present canal system capacities are limited, the number of farm systems that can accept or reject water at any given time, as well as the maximum delivery rate, must also be limited. However, open channel systems usually have greater flow capacities and can accomodate larger variations in farm deliveries than can pipeline supply systems. Greater storage capacity may be required using a series of relatively small regulating reservoirs throughout the length of the canal system along with automated, quick-responding control gates as discussed by Merriam[14].

If water is to be available on demand, improved turnout structures may be needed to permit accepting or rejecting flows. They may consist of orifices, meter gates, float valves, or other control devices which will deliver the correct flow when water is being drawn from the canal, but which will not be adversely affected if submerged when other gates or valves are closed to reject flow.

Where water is allocated by quantity, or the quantity is measured for billing purposes, improved water measurement devices are also needed. Variable deliveries for automated systems require "totalizing" measurement devices rather than "flow-rate" types presently used with constant-flow deliveries. If flow rate devices, are used, they must be equipped with recorders or integrators to measure the volume of water delivered.

ON-FARM RESERVOIRS

Water can be supplied to the farm distribution system on demand from a farm reservoir or holding pond. Continuous or intermittent deliveries can be made to these reservoirs. Often farm runoff can be eliminated when a reuse system is used with the reservoir. In some cases, this may be the only way to provide water on demand until the canal system is automated to deliver water on-demand. Besides simplifying water deliveries, farm reservoirs also provide greater flexibility in water management. For example, reservoirs can accumulate small continuous flows to allow irrigation with larger, more-efficient streams. Where other conditions are suitable, irrigation by efficient border methods may be possible. Trash and plugging problems are reduced because water withdrawn from the reservoir is usually cleaner than that supplied by the canal. Sediment in the water delivered by most canals plus that from the reuse system is deposited in the reservoir. Although the sediment seals the reservoir and reduces seepage losses, some reservoirs still may need to be lined. A small farm reservoir with a capacity of 5,000 m^3 (4 acre-feet) is shown in Figure 1.

AUTOMATING OPEN CHANNEL SYSTEMS

Open ditches are still used on most surface-irrigated land in the U.S. With the border and basin methods, relatively large streams and short irrigation durations are used. Automation can be particularly useful with these systems because irrigation sets must be changed frequently and many sets are requited each day. Simple, semiautomatic gates have been developed for open ditches, as well as pneumatic closures for pipe turnouts and alfalfa valves([10, 11, 12]). Most of these can be added to existing systems and structures. More recently, automated jackgates and pipe outlets have been added to existing systems where large irrigation streams are used to irrigate level basins([6, 7]).

Concrete pipe turnouts and headgates are common in both lined and unlined ditches. These can be semi-automated by using timers and attaching a flexible tube on the outlet and a drop gate on the inlet, as shown in Figure 2.

AUTOMATING CLOSED SYSTEMS

Pipeline systems are easier to automate than open channel systems. Replacing open ditches with buried pipelines and gated surface pipe is a first step toward automation. Plastic pipe, particularly PVC, has many desirable qualities for irrigation and when it is installed and operated properly it will give long, satisfactory service. Underground pipeline systems offer many other advantages, such as better weed and rodent control, minimum loss of productive land, minimum seepage and evaporation losses, minimum maintenance, and good water control. Criteria and guidelines are available for designing and installing both concrete([1]), and plastic([2]), low pressure pipelines and their appurtenant structures.

Many open ditches can be replaced with pipelines and still operate by gravity. About 90 per cent of the surface systems converted to gated pipe in southern Idaho utilize head at the intake and slope to offset friction losses and to develop the minimum operating head. Only about 10 per cent require booster pumps to assure a minimum head of 30 cm (12 inches) throughout the length of the pipe.

AUTOMATED VALVES

Farm systems using buried pipelines and gated pipe for distribution can be readily automated by simply placing Snake River automatic irrigation valves([13]), in the surface line, or by attaching them to standard riser hydrants which fit over alfalfa valves(Figure 3). The valves operate as independent units in the field without an outside energy source. Water from the pipeline is used to close the valve. Valve opening and closing is controlled by battery powered, timer-activated, pilot valve control units. Control units use either mechanical, electronic, or electro-mechanical timers, which are manually set to control the start time and duration of the irrigation set. Commercial prototypes of the valve are now being tested and should be available in some sizes during the 1978 irrigation season. Experimental valves for 100-, 150-, 200-, 230-, 250-, and 300-mm (4-, 6-, 8-, 9,- 10-, and 12-inches) pipelines have been built and tested.

Automatic valves can be used in existing systems where pipe gates or hydrant valves are now manually opened and closed to start and end each irrigation set. Irrigation sets for the next 24-hour period can be preset so that when the pipe is in place and the gates adjusted, the required labor consists mainly of presetting the timers at the beginning of each irrigation period. Irrigations can be preset for any hour of the day or night. Water

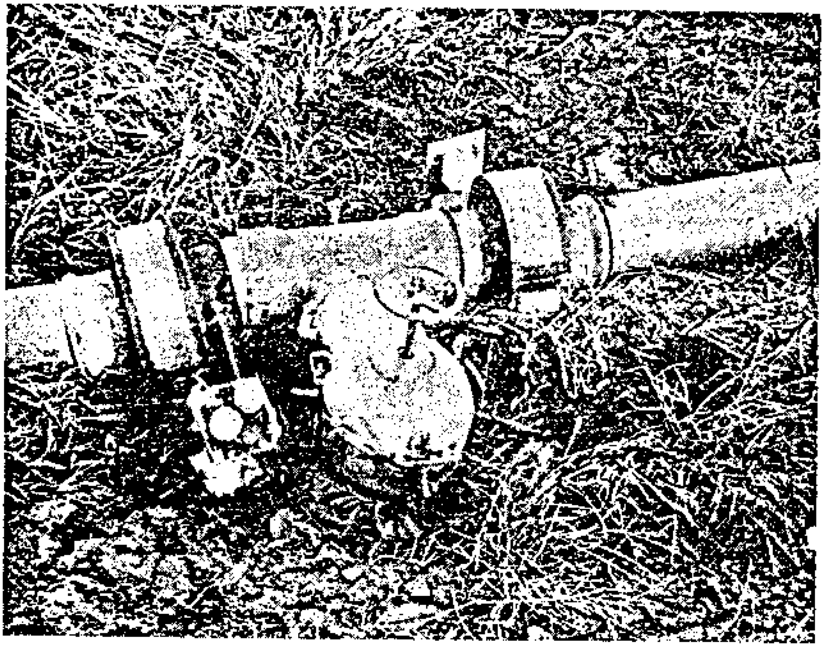

FIGURE 3 ; Snake River automatic irrigation valves installed in a gated pipe system supplied from a hydrant on an underground pipe-line riser.

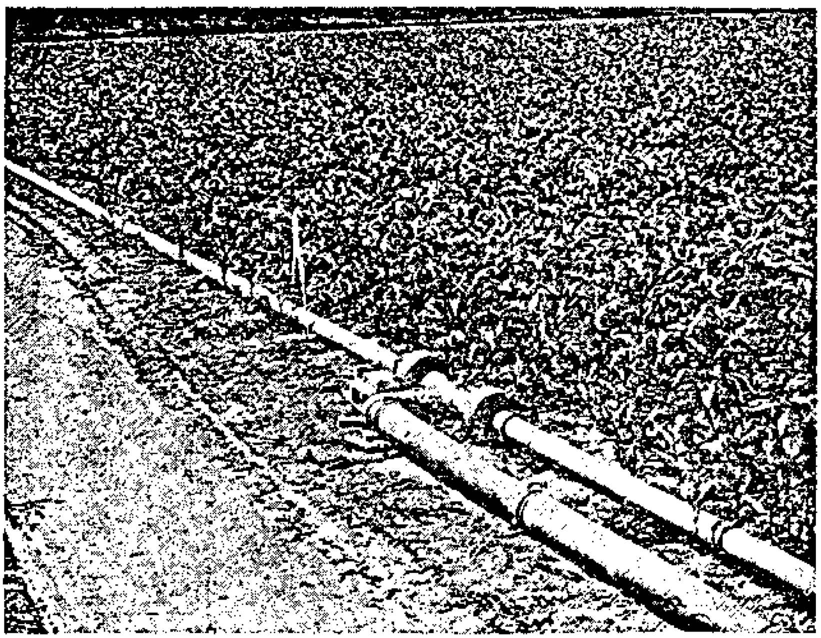

FIGURE 4 : Field setup for cutback irrigation using gated pipe. The valves are located at the center of the field or portion of the field to be irrigated

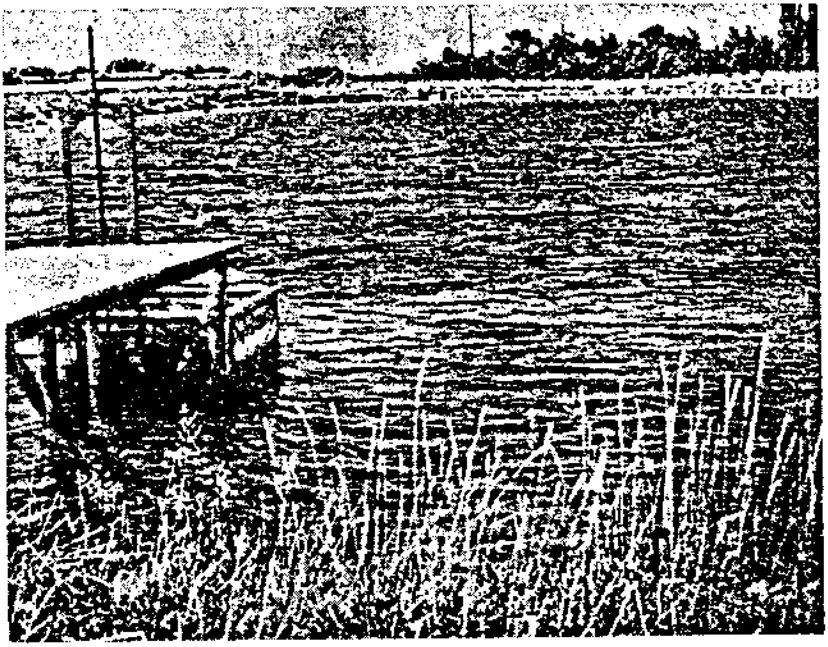

FIGURE 1 : Farm equalizing reservoir used to accumulate a small continuous canal delivery and water from a reuse system for later distribution to the farm.

FIGURE 2 : Conventional concrete pipe turnout modified for semi-automatic operation by the addition of a timer controlled tube outlet and inlet drop gate

can be used more efficiently because irrigation durations are not restricted to times that are convenient for the irrigator.

CONTROLLERS FOR AUTOMATED SYSTEMS

When water is available on demand, commercial, programmable controllers, designed primarily for sprinkler systems, may be used to control automatic valves for surface irrigation. These controllers can also be used with tensiometers. The tensiometers can be used to begin an irrigtion series or to control irrigation at each valve station independently. Most controllers monitor each station at least once daily. If the soil moisture tension is greater than the set point on the tensiometer, irrigation will proceed as programmed. If the tensiometer switch is open, indicating adequate soil moisture, that particular station is bypassed until the next day when the controller looks at all stations again. Tensiometers can be used to start irrigations, but ending irrigation with tensiometers is more difficult because of the interrelationships between stream size, length of run, soil intake rate and tensiometer location. Locating the tensiometer so as to end an irrigation at the correct time is difficult because of soil variability and the time lag between the start of irrigation and the time that the tensiometer responds to an increase in soil moisture.

Commerical controllers normally operate on 110 VAC power; however, solid state, battery-powered units may soon be available. Three-way solenoid pilot valves can be used with the controller where electrical power is available, otherwise, battery-powered motorized pilot valves are needed.

AUTOMATING TO ACHIEVE CUT-BACK FLOW

Irrigation efficiency can be increased by using cutback or reduced furrow streams. This is difficult to do with siphon tubes and open ditches because of the extra labor involved and the problem of handling the excess water during cutback. Several schemes have been proposed which can be implemented using automation[4, 8, 9, 17]. Fischbach, et al.[8] reported irrigation efficiencies up to 92 per cent when a reuse system was used to obtain cutback furrow streams. Another method, using gated pipe, is to jointly irrigate two slightly smaller than normal sets, as shown in Figure 4. One half of the total set is irrigated with a furrow stream size slightly larger than normal for that size set until water reaches the end of the field to prewet all furrows. The entire stream is then directed to the other half of the total set for the same length of time. Water is then reintroduced into the furrows of the first half so that the entire stream is distributed across the total set. With a constant, limited supply, this gives a 50 per cent cutback stream size as compared with the initial or primary furrow stream. The primary or furrow-wetting streams are larger than the nonreduced stream sizes thtat would normally be used without cutback, while the cutback streams are slightly larger than half of the normal. nonreduced, stream size. Where the system can draw additional water during the cutback mode, the cutback will be less than 50 per cent. This technique can be used on relatively flat cross slopes where the total elevation difference between the ends of the pipe does not exceed about 12 cm (0·4 ft). This elevation difference can be compensated for by turning down the gates on the highest end of the pipe and turning up the gates on the lowest end. Thsis will give approximate, uniform distribution in the cutback mode from all gates. Present systems also can be operated in this manner to obtain cutback streams be manually opening and closing valves or gates on each one half set at the appropriate times. An electronic timer is being developed that will control valve opening and closing in the proper sequence. The timer can be programmed for the desired initial or furrow-wetting flow time in each one-half set and for the soaking or secondary flow time.

IV. EFFECTS OF AUTOMATION ON IRRIGATION EFFICIENCY

AUTOMATING FULL LENGTH RUNS

Water application, runoff, and yield data were obtained for one corn and three sugar-beet plots at Kimberly, Idaho. Two of the sugarbeet plots were irrigated semi-automatically using timers, and one plot was irrigated automatically using an experimental tensiometer control unit to both start and end irrigations. Also, one nonautomated check plot of each crop was independently irrigated, using normal farm irrigation practices (typical for the area). Of 10 irrigations on the sugarbeet check plot, stream sizes were manually reduced or cutback by the irrigator for six irrigations. Runoff for these six irrigations ranged from 11 to 28 per cent with an average of 20 per cent. These values are also typical of those that can be expected from an automatically cutback irrigation system without reuse. Runoff from the four noncutback irrigations ranged from 30 to 44 per cent and averaged 36 per cent. Runoff from the corn check plot ranged from 21 to 43 per cent (noncutback). Crop yields from the plots were not significantly different. Production water-use efficiencies were determined from the average yield for the respective plots in terms of yield per volume of water applied (Table I).

TABLE I

Water application, runoff, and water use efficiency for automated and nonautomated corn and sugarbeet plots

Plot	*Gross water application*		*Runoff*	*Net water applied*		*Production water-use efficiency*	
	mm	*(in)*	*(Per cent)*	*mm*	*(in)*	*tonne/ $10^3 m^3$*	*(ton acre-inch)*
Sugar-beets							
Tensiometer control	742	(29·2)	26	544	(21·4)	2·52	(0·706)
Timer, A	691	(27·2)	20	554	(21·8)	2·71	(0·760)
Timer, B	693	(27·3)	24	526	(20·7)	2·70	(0·755)
Check (nonautomated)	897	(35·3)	28	643	(25·3)	2·09	(0·584)
Corn							
Timer	612	(24·1)	28	442	(17·4)	5·07	(1·42)
Check (nonautomated)	803	(31·6)	35	523	(20·6)	3·86	(1·08)

In general, the check plots were irrigated with either 12 or 24-hour sets, while the timed semiautomatic irrigations varied from 6 to 14 hours. One of the difficulties encountered in the field tests was nonuniform water distribution, caused by different soil intake rates in traveled and nontraveled furrows. When irrigation is automated, it is important to equalize tractor wheel travel in all furrows or else irrigate every other furrow so that all irrigated furrows have similar intake rates.

AUTOMATING REDUCED RUN LENGTHS

The efficiency of present irrigation systems with extra-long irrigation lengths-of-run can be improved by shortening the runs. This can be accomplished without shortening the total field length by using gated pipe laterals to divide the field length into two or more subruns. A system with several subruns, referred to as a multiset system, was tested by Rasmussen, et al.[15]. Shorter lengths-of-run result in better moisture distribution, higher irrigation efficiency, and smaller furrow streams, which reduce both runoff and erosion. Reducing the length-of-run by using additional cross ditches is not desirable, because it results in extra irrigating labor and smaller fields. These objections can be largely overcome by using gated pipe and automation. The pipe can be laid in the field after planting and cultivating and removed before harvesting. Or, it can be buried, as suggested by Varlev[19] and Worstell[20], so that it does not interfere with tillage operations, and large fields can be maintained for equipment maneuverability. By automating the system, irrigation labor is not significantly increased by the additional distribution laterals.

A multiset system, installed on a 5·7-ha (14-ac) field with a 460-m (1,500-ft) length of run, was tested. Four 150-mm (6-in) gated-pipe laterals with valves, timers, float-valve pressure controls, and a 200-mm (8-in) mainline were used. The slope varied from about 1 to 4 per cent. The field had been irrigated directly downslope for many years, and most of the topsoil had been eroded in areas where the slope was greatest. The field beans were irrigated with small streams of about 0·2 litres/sec (3 gpm/furrow). Subrun lengths between each of the four gated-pipe laterals were 114m (375 ft). Subsets 2 and 4 (numbered from the top) were irrigated simultaneously to prewet the furrows. Subsets 1 and 3 were then irrigated simultaneously for the duration of the irrigation. Runoff from these latter subsets continued through subsets 2 and 4, which had previously been prewet, to complete their irrigation. Runoff and erosion were greatly reduced by this method of irrigating. A total of 490 mm (19·3 in) of water were applied during the season. Runoff was 84 mm (3·3 in) or (17 per cent). With the short lengths of run, moisture distribution down the field was good with very little deep percolation. The yield was 15 per cent greater than the normal for this particular field, while average yields on the grower's other fields were about 15 per cent lower for that particular year. The grower also reported that the crop ripened more uniformly than in the past because of more uniform water distribution. Six check rows, irrigated with the normal stream size for the full length, were full of silt near the lower end of the field and were very difficult to irrigate.

An automated multiset system can satisfy some of the requirements given by van Schilfgaarde ([18]) for improving irrigation management by reducing the volume of water applied, the drainage volume, and the salt discharged, while maintaining crop yields. To do this requires short, frequent, irrigations, closely controlled amount and frequency of water application, and uniform distribution.

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