Mid Project Report
Volume III

Appendix B
Staff Papers
Section 3 of 4

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Staff Paper #28

ROLLER BEDSHAPER FOR BASIN-FURROW IRRIGATION

N. Illsley and A. Cheema

INTRODUCTION

Good irrigation water management implies getting enough water to the root zone to satisfy the evapotranspiration needs of the crop. At the same time, a minimal amount of water should be allowed to penetrate below the root zone to maintain a proper salt balance in the soil. This requires a uniform application of water over the surface of the field. With surface or flood irrigation, this uniformity is partially dependent on how precisely the field has been leveled. The degree of precision felt necessary and yet practicable for Pakistani fields (2 ha) is ± 2.5 cm from the average elevation.

To achieve this degree of precision, accurate surveying and staking are required, followed by tractor-drawn scrapers and land planes to transport and level the soil. This is expensive and time consuming. Due to the size of the machinery used, it becomes less practical to level the smaller fields, with two acres being about the minimum size.

A possible alternative to precision land leveling is the cultivation of crops on beds, with irrigation water applied through small (15 cm deep by 25 cm wide) furrows between the beds. Assuming the beds to be 50 to 100 cm wide with furrows about 15 cm deep, the levelness of the field can vary ± 7 cm, as compared with ± 2.5 cm for flood irrigation, and still deliver water to the root zone of all the crop without flooding any portion of the beds. Water will always reach to within less than a half-bed width of the plants. There will still be portions of the field which are either over or underirrigated, but because the method of water movement through the soil from the furrows to the root zone is capillary, at the end of an irrigation period, the only excess water will be that standing in the furrows. This is about one quarter the amount that would be standing in the same field if it were not bedded.

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[1] Agricultural Engineers, Water Management Research Project, Colorado State University.

ADVANTAGES OF BASIN-FURROW IRRIGATION

Depending on local conditions advantages of this method over level basin flooding include:

1. Energy consumption in land preparation is lower.
2. Greater field unevenness can be tolerated without over or underirrigating portions of the crop.
3. Small field size does not limit use of this method.
4. Lower water delivery rates may be used.
5. Crusting is minimized and a porous mulch seedbed is easier to maintain.
6. The furrows can act as guides for controlling cultivation implements.
7. Beds can be walked on sooner after irrigation.
8. This method can be used in more saline conditions.
9. Deep percolation losses are reduced.
10. There is less risk of crops being drowned by heavy rains.
11. Fertilizer can be applied during bedshaping.

Energy Consumption

Because of the nature of the operation, precision land leveling for flood irrigation requires scrapers and land planes. These implements are best operated with medium sized tractors in the 40 to 60 HP range (depending on the type of soil being moved). Less powerful tractors have difficulty loading and unloading the scraper bucket. A bedshaper making two beds and two furrows can be pulled with a 35 HP tractor.

Precision land leveling requires large amounts of soil to be moved from the high areas to the low areas. For example, if a one acre field has half of its surface averaging 7.5 cm higher than the desired final field elevation, it would involve moving 303 m^3 of soil from the high areas to the low areas with an average travel distance of half the length of 11 cm producing 4 cm of fill to form the bed. This amounts to about 93 meters^3 of soil dug per acre.

Once dug, the soil would be moved an average of about 25 cm to form the bed. A bedded field having 15 cm deep furrows should be able to have undulations of as much as ± 6 cm without their causing either dry areas or flooded areas. Typically, the bedshaper leaves the texture and surface of the field in an ideal condition for planting. Once the transporting with scrapers is done, the field must still be finished with a land plane, requiring at least three passes over the field for adequate levelness. Finally, after leveling, the seedbed must be prepared by plowing, discing and/or harrowing.

On lands that have a gentle slope in one direction, beds can be established on the contour. This will reduce or even eliminate the need for earth moving. If a field is too uneven, it can be leveled in one direction to within tolerances acceptable for bed cultivation. In the second direction, that is, across the beds, a slope does not interfere because the water does not flow in that direction.

Therefore, preparation of fields for bedded irrigation should require far less energy than leveling the same fields for level basin irrigation.

Field Unevenness

With beds using furrows that are at least 15 cm deep, a tolerance in elevation of ± 5 cm will still leave 1/2 cm for water depth and freeboard in the furrows. Water will be within a few centimeters laterally of all the plants. Although over and underirrigation will still exist, it will be less severe than with flooding. Even if the furrow is too shallow at the high areas of the field, it is very easy to dig these sections deeper by hand by walking along on the bed which remains unsaturated.

With a 6 cm average depth of water in the furrows, the lowest elevation portions of the furrows would have 12 cm of standing water when irrigation is finished. With a 60 cm bed width, this would result in an overirrigation of about 9.6 liter/m^2 of bedded area. If the field was flood irrigated, there would be 60 liter/m^2 over the same area.

Field Size

Scrapers and land planes are typically large implements that are not suited for use on small fields, with about two acres being the minimum feasible size. Scrapers could conceivably be scaled down in size to work with animal power in smaller fields, but land planes must be of sufficient length to accomplish their planing action. On the other hand, a bedshaper mounted on a three-point hitch is as maneuverable as the tractor it is mounted on and can even be backed into corners of fields. The bedshaper, like any other piece of equipment, loses efficiency when used in small fields due to the proportion of time spent in turning around. But it is not as costly a problem as with trailing implements such as scrapers. The bedshaper is a machine that can be scaled down. The limitations are the size of furrow required for the irrigation water and the energy input required to operate it. A small model that made a single furrow 12 cm deep with 20 cm of bed on either side was used experimentally with a team of two bullocks.

Water Delivery Rate

Flood irrigation requires a large enough stream flow into the field so that the infiltration rate of the water into the ground is insignificant compared to the rate at which the water is progressing across the field. With furrows, uniform irrigation can be accomplished with much smaller flow rates for two reasons; first, the irrigator has the choice of how many furrows he wishes to turn the water into at any one time, thus regulating the rate of flow of water into the field and usually the irrigation water advances much more rapidly in a furrow than it does over a flat field. This reduces the time lag between when the head of the furrow and the tail of the furrow are wetted. Therefore, the water penetration is more uniform over the length of the field.

Also, the compacting effect of the bedshaper roller reduces the infiltration rate of the bottom of the furrow allowing the use of smaller stream flows in the furrows.

Crusting and Mulch

Crusting of the soil surface can become a serious problem, especially with fine soils that are alkaline. Crust forms either after flood irrigation or heavy rains. Crust can seriously impair the emergence of delicate seedlings and thus reduce the crop stand. A crust will also have a higher soil moisture evaporation rate than a coarse textured soil surface. The problem of crusting from irrigation is eliminated with bed irrigation, and crusting caused by rain is reduced because the furrows provide field storage for rain so that there is less chance of water standing on the surface of the bed where the crop is grown. In addition, standing water in the furrows after rainfall would move laterally into the beds, with the soil moisture then rising vertically by capillarity, which would soften any crust that might have formed around the plant.

Guiding Machinery

Furrows provide a permanent guide in the field for other equipment. Tractor wheels and implement wheels can follow the furrows for precise positioning of equipment with respect to the crop. The furrow openers of the bedshaper can be used alone to clean out the furrows, and cultivator sweeps can be attached for precision weeding at the same time. The roller portion of the bedshaper is an effective crust breaker and has been successfully used to break up crusts when heavy rain fell before the crop had sprouted. It can also be used after sprouting so long as the plants are tender enough not to be damaged by being bent to the ground.

Walking on Beds

The center of the bed will receive the least water and will dry out the soonest after irrigation. This will allow walking through the field sooner after irrigation for weeding or other cultural practices, than if the entire field had been flooded.

Salinity Tolerance

Salts move through the soil with the soil moisture. This is why saline soils with a high water table frequently display the white concentrated salt on the surface. With furrows and beds the moisture is moving horizontally from the furrow toward the center of the bed. This movement will concentrate the salt at the center of the bed which is beyond the root zone of the crop growing at the edge of the furrow.

Minimize Deep Percolation

By using the roller to compact the bottom of the furrows, the moisture cross section profile will be shallower and broader than with a simple furrow. This will reduce the proportion of water lost to deep percolation. The degree of spread is dependent on both the soil and pressure exerted by the roller. The moisture cross sections should resemble those drawn in Figure 1. The compacted furrows allow for more rapid advance of the furrow stream, which allows smaller depths of application for a single irrigation, which in turn will result in less deep percolation loss.

Crop Drowning

The usual problem from heavy rains is the actual drowning of a crop from excessive water standing on the surface of the ground for extended periods of time. Again, the water storage capacity of the furrows will alleviate this problem. This was well demonstrated at the Cotton Research Center at Multan during the heavy rains of 1978. Level fields containing cotton plants 15 to 20 cm high were completely destroyed, while adjoining fields planted on beds maintained a reasonable stand.

Fertilizing

Fertilizer can be placed in the bed at the original ground level. This can be done by dropping the fertilizer just ahead of the bedshaper so that the fertilizer is covered by the soil from the furrow when it is spread by the roller. This would place the fertilizer at about the 5 cm depth with the heaviest concentration at the edge of the furrow.

Hand broadcasting is the typical method of fertilizing now. The fertilizer is not uniformly distributed. It is mixed into the upper 25 cm of soil by plowing prior to seeding. This results in only part of the fertilizer reaching the potential root zone of the crop.

DEVELOPMENT OF BEDSHAPER

The bedshapers designed and made in Pakistan were developed to test the concept of bed cultivation under local conditions and to test the concept of a roller to shape the bed. It was also of interest to see if a suitable machine could be fabricated locally. The machines fabricated to date, although successful, are not the ultimate design, and no doubt could be improved. Further, time did not permit the development of the attachments such as planters and cultivators which would be desirable additions to the basic bedshaper.

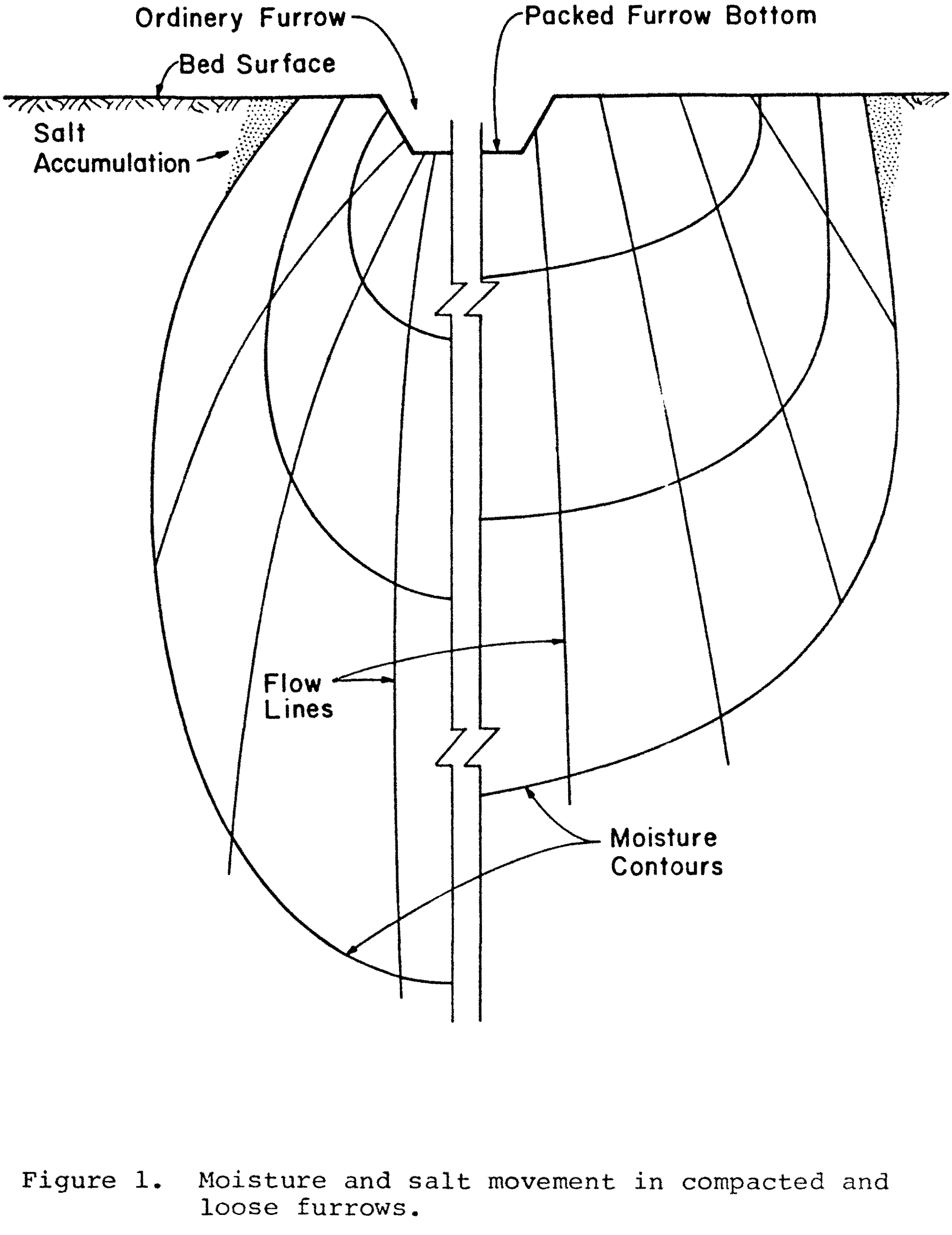


Figure 1. Moisture and salt movement in compacted and loose furrows.

Purpose

Bed cultivation is not a new idea and is commonly used for a variety of reasons. The overriding reason to try beds in Pakistan is to help manage the use of irrigation water on the fields. Water is in short supply and too much is being wasted. It was expected that with a given quantity of water more land could be irrigated producing more crops, with less water lost to deep percolation, which contributes to the rising water table problem.

Criteria

When developing an implement to perform a certain task, many factors must be considered both as to the functioning of the machine and the conditions under which it is to be made. Do not use a sledge hammer to drive a tack, nor use a tack to hang a sledge hammer.

When the proper size and sophistication of machine is decided, consideration must also be given to what equipment, materials, and skills are available for fabricating the machine.

With this in mind, the following criteria were considered in designing the bedshaper.

1. The implement must be able to shape beds of the various widths typically used and make furrows adequate for good irrigation practices.

2. Only locally available materials and local shop skills and facilities should be used for its fabrication.

3. The cost of the implement should not be beyond the reach of the average tractor owner.

4. The bedshaper should require as little energy as practical to operate.

5. The implement should be both simple and rugged so that repairs are both infrequent and easily made.

6. The bedshaper should be compatible with other field equipment both presently in use and anticipated in the near future.

Existing Bedshapers

Two versions of bedshapers have been introduced in Pakistan. The first is a design brought in by USAID. It consists of a flat steel plate about two meters wide by one meter long. Two adjustable furrow packers that are shaped like a small boat hull are mounted underneath the plate. The whole assembly is built on a three-point hitch for mounting on a tractor. Its weight, of about 300 kilos, is necessary in order to pack the beds smoothly. This bed shaper does not actually dig its own furrows, but rather must follow another implement such as a lister which digs the furrows; then, the bedshaper smooths and shapes the beds. Thus far, the one unit that has been built was only used on a few demonstration plots.

The second bedshaper was imported from Australia by the Cotton Research Center at Multan. This machine has proven very successful at the Cotton Research Center, but there has been no effort to introduce it into the mainstream of Pakistani agriculture. It remains a tool for research on cotton and is both larger and more costly than the CSU machine.

Roller Bedshaper Design

This machine consists of a furrow opener followed by a roller system (Fig. 2). The furrow opener lifts and windrows the soil, and the roller system spreads the soil, crushes the clods and smooths the top of the bed, compacting both the bed surfaces and furrow surfaces. The roller thus controls the shape of the bed and the furrows.

The bed shaper is a bolt-on attachment to the cultivator frames commonly used in Pakistan. Although made by many manufacturers, these frames are virtually identical because they have been copied from just a few original imports. The frame consists of two parallel 2.5 m pieces of 5 cm angle iron, spaced 50 cm apart on a three-point hitch. The angle iron is drilled at 2.5 cm spacings so that attachments can be bolted onto the frame at any desired spacing.

The furrow opener is made of sheet metal about 2 mm thick (Fig. 3). It is a "V" shaped plow, with a 30° included angle. The wings are 45 cm high by 50 cm long. The sides of the opener are bent inwards diagonally so that the bottom is 12 cm wide, and the sides rise to give a 30° or 45° slope to the furrow banks (both slopes were tried). The front edge of the opener curves forward at the bottom, and the bottom is arched concave to improve penetration (Fig. 3).

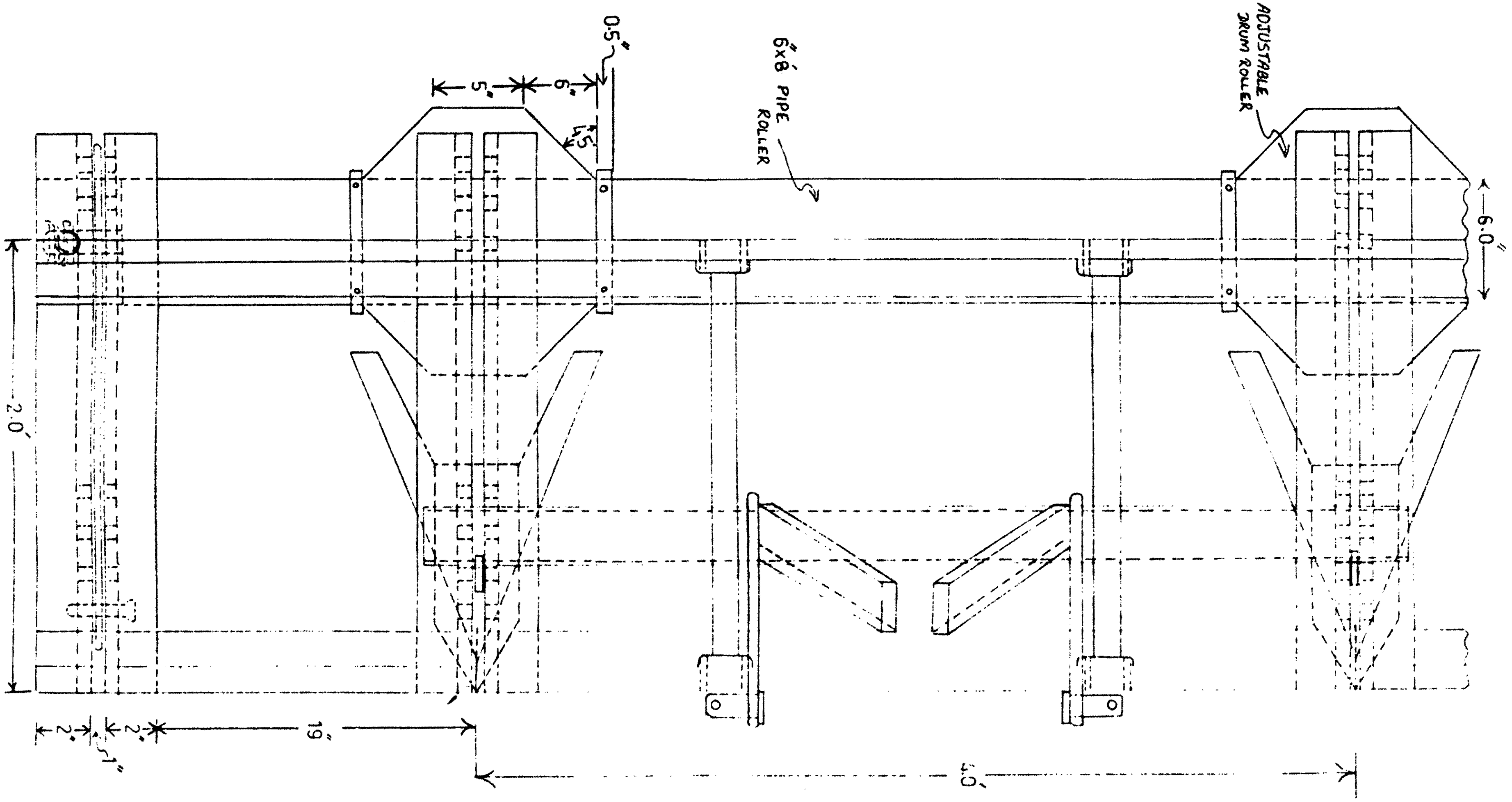


Figure 2a. Plan view of bedshaper showing frame, furrow openers, and roller assembly.

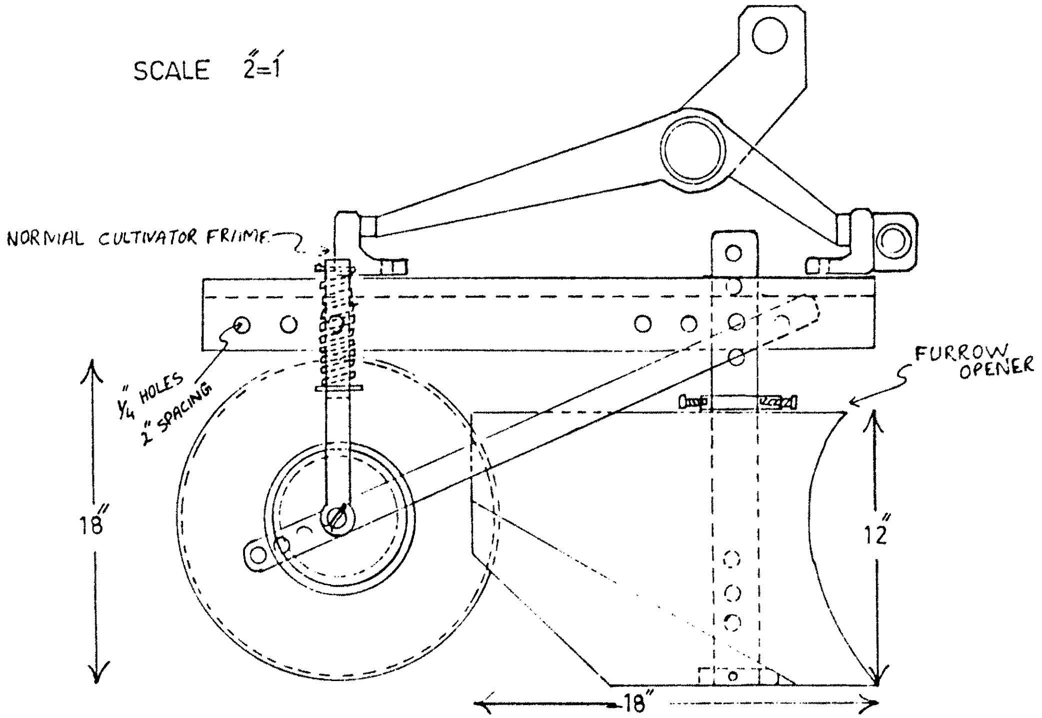
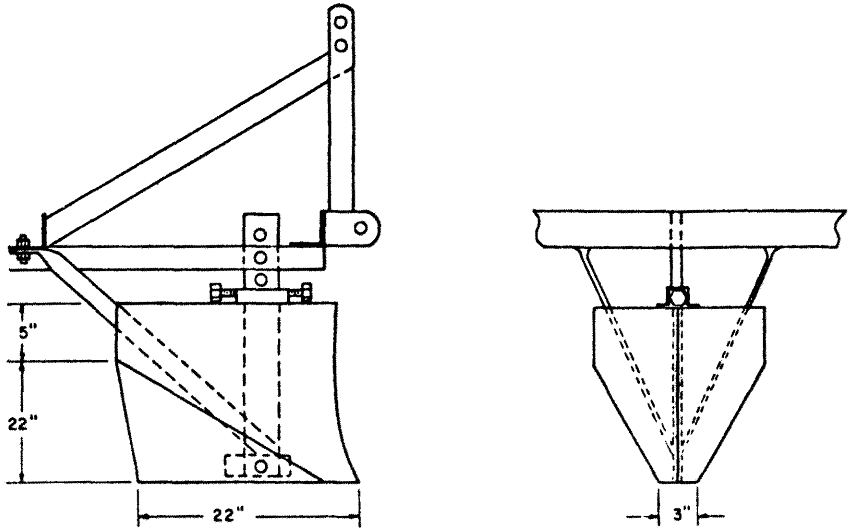
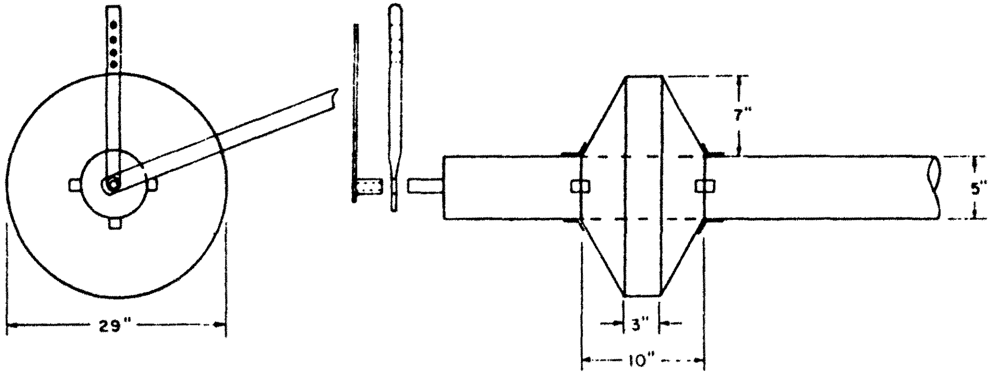


Figure 2b. Side view of bedshaper.



side Opener front



side Roller front

Figure 3. Essentials of bedshaper components.

The opener is supported on a vertical shank that is pinned to the inside sole about 20 cm back from the tip. The shank passes through an adjusting slot on the top of the opener. The adjusting slot allows precise adjustment of the tilt of the opener in order to control penetration. To attach the opener to the frame, two pieces of angle iron are bolted between the front and rear frame bars in such a way that they form a slot for the shank to pass through and be held with a bolt onto the angle iron braces. Multiple holes in both the shank and the angle irons provide adjustment of the opener position.

The shank of the opener absorbs the vertical loads. The lateral and longitudinal loads are taken up by braces that run from the bottom of the shank up diagonal to the rear frame member. This method of mounting allows any number of openers to be used on the frame, and any desired bed width can be made.

The roller assembly is essentially one long piece of pipe with furrow cones fastened on it at the desired spacings. The pipe is thin wall steel, 2.4 m long and 13 cm in diameter. The ends of the pipe, 5 mm steel, are capped with discs and 25 mm stub axles, 5 cm long, are welded on the caps. The cones are made of 1.5 mm sheet steel and held to the rollers either by set screws or band type clamps.

The roller is attached to the frame by two arms at each end. One arm is vertical and spring mounted to keep constant downward pressure on the roller. The second arm is a draft arm, running diagonally up to the forward frame member. Both arms are mounted on a short piece of pipe that acts as a bearing on the stub axle of the roller. The pipe is welded to the vertical arm and the diagonal arm is drilled to slip over the pipe. There is no need for diagonal bracing for the roller because the cones must follow in the furrows left by the openers.

A unique feature of the roller is that it rotates at less than ground speed. The cones that shape the furrows are three times the diameter of the pipe that rolls the bed. These cones are wedged in the furrow where there is greater traction than on the bed, and the cones, with their greater radius, have a mechanical advantage over the pipe in determining the speed at which the roller rotates. The result of this lower speed of the pipe is that it has a bulldozing action on the windrow of soil and spreads the soil more evenly across the bed before it is actually rolled. As only one point on the radius of the cone will be turning at actual ground speed, all the rest of the cone and roller assembly will be having a troweling effect on the soil surface. At the bottom of the furrow, this gives some compaction which should facilitate even water distribution across the field.

Results and Discussion

Using a 35 HP tractor, this bedshaper will pull two 20 cm deep furrows and smooth the equivalent of two beds (one full bed between the furrows and two half beds on the outside of the two furrows). If the implement is not penetrating deeply enough, the furrows will still be properly shaped, but the center of the bed will not be finished due to insufficient soil in the windrow for spreading. If the penetration is too deep, the draft increases and the windrows tend to spill over the top of the opener and the inside corners of the roller, leaving this loose spill in the furrow. Regardless of the depth adjustment, the edges of the bed are well shaped and firm. This is the critical area where the crop is normally planted.

Although this machine was developed to work as a unit for making complete beds, it was found that either the openers alone or the roller alone could be used for certain field conditions. In one instance, heavy rain had fallen after planting and before emergence. The resulting crust was effectively broken by using the roller alone on the beds. Although it was not tried, the furrow openers should be able to work independently for reconditioning the furrows, or for acting as guides which follow the furrows and control the position of other equipment such as seeders or cultivators.

A seeder attachment should be developed to follow the bedshaper, and a precision cultivator could replace the rollers, using the furrow openers to guide the implement along the established furrows.

A bedshaper was developed during the summer of 1978. Since then, five tractor-drawn units have been manufactured for government departments, and two additional units have been sold to private farmers. The shop making these units is keeping one bedshaper for display.

A small bullock-drawn model was made using a single furrow opener and two bed rollers of 75 mm PVC pipe. The implement made suitable small beds and could be pulled by an average pair of bullocks. However, the implement rocked sideways on the opener, making it difficult to hold level because it was only making one furrow. A team of bullocks does not have enough strength to pull two furrows. Furthermore, it is difficult to drive bullocks in a line straight enough that the resulting beds will be of uniform width.

The initial machines were demonstrated to both farmers and government officials at the Mona Research Center on private farmers' fields; at Niaz Begh on the On-Farm Water Management Research fields; at Chichiwatni, Khaniwahl, and near Multan on farmers' fields; and at the Agricultural University, Faisalabad, where the engineers are working with the firm that has been making the bedshapers.

Hopefully, the advantages of bed cultivation will become sufficiently obvious that the machine will gain general acceptance by the farmers.

Staff Paper #29

ECONOMIC FEASIBILITY OF CONCRETE LINING FOR THE BENI MAGDOUL CANAL AND BRANCH CANAL

Gamal Ayad, G. Nasr Farid, and Gene Quenemoen

April, 1978

The Beni Magdoul Canal, supplied from the Mansouria Main Canal in the Giza Irrigation District, is 2.92 kilometers in length and serves 860 feddans. A lateral branch of this canal is 0.84 kilometers in length and serves 140 feddans within the 860 feddan area. The Beni Magdoul Canal was lined with concrete in 1977 and the lateral branch was lined in 1978.

This report discusses the economic feasibility of lining these canals.[1] Economists from the Egyptian Water Use Management Project (EWUP) investigated this matter, obtained relevant data from the Giza Irrigation Department and from EWUP personnel, and prepared this report. It will be obvious to the reader that the report is incomplete. The EWUP economists were unable to obtain, in the short time available, sufficient reliable data to make a scientifically defensible analysis. However even though a complete and thorough analysis is not possible given limitations on time and research resources, it was decided to report our exploratory efforts in this staff paper.

Methodology

The economic feasibility of an investment which gives rise to a flow of annual benefits and annual costs can be evaluated through a discounted cash flow analysis. The general form of benefit-cost flow analysis is shown in the following equation:

$$PV = \frac{a_1}{(1 + r)^1} + \frac{a_2}{(1 + r)^2} + \ldots + \frac{a_n}{(1 + r)^n}$$

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[1] This analysis involves not only the lining of this particular canal but also other changes in the irrigation system itself such as reduced number of outlets, reduced level of water in the canal and a shift from a rotation system to constant low.

Where: PV is the amount of the initial investment,
a is the amount of net annual benefits for any given year,
r is the rate of return,
n is the number of years for payoff or the "life" of the project,

In our analysis we shall attempt to determine the rate of return (r), given the initial cost (PV), the net annual benefits (a) and the number of years of life of the ditch lining project (n).

Initial Investment

The cost of lining and adjusting outlets on the main canal was LE 40,755.[1] Although the costs are not completely tabulated for the lateral branch canal it is estimated that they will be about LE 6,000[2].

These amounts do not include the cost of planning, design and construction supervision which was provided by the Water Research Institute. One can make a case for not including these costs since they were provided as part of the on-going work of a government agency with social responsibilities. If they are included it has been estimated that they should be approximately seven percent of construction costs or LE 3,245[3].

It has also been proposed that the Government can sell reclaimed land to the farmers which will reduce the initial investment. Lined canals require smaller ditches and after backfilling along the lined canals it is estimated that 1/2 feddan per kilometer of ditch can be restored. For this project two feddans of restored land would have a potential value of approximately LE 10,000 if sold to the farmers.

Some EWUP staff members argue that the restored land should not necessarily be sold to farmers but should provide the basis for better roads or it should be rented to farmers for agricultural purposes. In this case it would provide a flow of annual benefits which would be easy to evaluate if rented but difficult to evaluate if used for improved roads.

Alternative amounts of initial investment, depending on the assumptions made, will be considered later in the "analysis".

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[1] Information supplied by Engineer Farouk

[2] Ibid

[3] This suggestion was made by Engineer Zaki

Annual Benefits - Costs

The initial capital investment in lining canals is expected to cause a flow of benefits and cost through time. It is desirable for economic feasibility analysis, to quantify these benefits and costs. In some cases this is relatively easy, in some cases it can be done with carefully designed and sometimes lengthy research efforts and in some cases it is practically impossible. The following discussion starts with the easy and moves toward the difficult. In all cases we will attempt to derive "net" benefits or costs which is the difference in before and after situations.

Annual Cleaning and Maintenance

The cost of removing sediment from unlined canals is currently about LE 0.235 per cubic meter. This is based on data from the Giza Irrigation District regarding the 1978 costs of cleaning the El Shimi Canal. Also according to the Giza Irrigation District records the Beni Magdoul Canal was cleaned each six years for the past eighteen years. The average cost, using current cleaning prices, was LE 66 per year.

Data on cleaning lined canals were not available. Based on the gradient of the Beni Magdoul Canal and its lined branch, EWUP engineers estimated it would cost LE 60 to LE 100 per year. It was also estimated that the annual cost of repairing the lined canals would be LE 300.

The difference between cleaning and maintenance costs for the lined and unlined canals appears to be in favor of the unlined. This can be considered as an annual "cost" associated with lining or a negative "benefit."

Water Saved

Historic records are available for water released from the Mansouria Main Canal into the Beni Magdoul Canal. Since lining the canals the amount of water now being released from the Mansouria Main Canal is reduced more than 25 percent[1].

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[1] Estimated by Engineer Farouk

This means a saving of more than 4,000 cubic meters per feddan for all the land served by the Beni Magdoul Canal.

The value of this water is difficult to determine. Technically its value is determiend by its "use value" for some other alternative. If it is simply released into the Nile to flow into the sea its value may be negligible, perhaps only as an aid to navigation. If, however, it is used for highly profitable agricultural or industrial purposes its value may be substantial. It has been pointed out that "water saved" has different values depending on location. Free flowing waste water on the upper reaches of the Nile may be released back into the river for use downstream. If the quality of the released waste water is not impaired, then 'saving" it may have little value or meaning. Perhaps at this time the value of water saved must be arbitrarily determined by policy makers. The total value of water saved for the 860 feddans under different price assumptions follows:

LE 0.001 per cubic meter	LE 3,440
LE 0.003 per cubic meter	LE 10,320
LE 0.005 per cubic meter	LE 17,200

Land Restoration

As previously mentioned lined ditches require less land area. When old ditches are lined the back fill provides more land for roads and/or agricultural production. In both cases there is a benefit. The amount of land restored in this process varies depending on the condition of the old ditch. It is estimated that 1/2 feddan will be restored for each kilometer of ditch or approximately two feddans on the project[1]. The cash rent for the land in this area is about LE 70 per feddan[2]. At this rate the lining should generate about LE 140 annual benefits if the land can be leased to farmers.

Increased Agricultural Production

Lined canals provide flow of water rapidly to final points of destination with minimum seepage loss. Often lining makes it possible to provide continuous flow delivery which permits farmers to irrigate

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[1] Estimated By Engineer Farouk

[2] Information provided by Economist Lotfy

when they need water rather than following the traditional water rotation system. The more efficient handling of water can lead to lowering the water table and more timely application of water which should increase production. However this increased production may cost more than production under the old system because of lifting the water higher from the deeper lined ditches, using more fertilizer and other costs associated with more intensive cropping. Careful studies are needed to measure the value of increased production which may become possible as a result of canal lining. We have not been able to obtain data from such studies applicable to the Beni Magdoul Canal. An estimate was made by the Field Team Leader for the Mansouria Study Site that the value of net increased production would be LE 4,300 but this is admittedly only a guess and not based on empirical data. Also if this benefit is to go to the investor (presumably the government) it must be taxed away from the farmers.

Other Benefits

Numerous other benefits are often mentioned for lining canals. Most of them are extremely difficult to evaluate and quantify. A partial list follows:

1. Health - reduction in breeding areas for snails and mosquitoes.
2. Reduction in size and concentration of field drainage facilities. This assumes that lined canals make it possible to accomplish better on-farm water management.
3. Reduction in costs of pumping from the drains in the Lower Delta.

Analysis

It is clear that several equations can be constructed to evaluate the benefits and costs of lining the Beni Magdoul Canals. The values one puts into these equations depends upon the assumptions one makes and the degree of data reliability one requires. Several alternatives follow:

$$40{,}755 = \frac{-44 + 3{,}440 + 140}{(1 + r)^1} + \frac{-44 + 3{,}440 + 140}{(1 + r)^2} + \ldots + \frac{-44 + 3{,}440 + 140}{(1 + r)^n}$$

This equation assumes no cost is assigned to planning, design and construction supervision, canal cleaning costs are LE 44 more after lining, water saved has a value of LE 0.001 per cubic meter and restored land is rented to farmers at LE 140. Rates of return are:

n = 10 then r = -2.73 percent
n = 20 then r = 0.13 percent
n = 30 then r = 7.86 percent

$$40{,}000 = \frac{-294 + 4{,}300 + 10{,}320}{(1 + r)^1} + \frac{-294 + 4{,}300 + 10{,}320}{(1 + r)^2} + \ldots + \frac{-294 + 4{,}300 + 10{,}320}{(1 + r)^n}$$

This equation assumes a charge for planning design and construction supervision, selling restored land to farmers, canal cleaning costs and maintenance are LE 294 more after lining, a value of LE 4,300 is placed on increased production, and the value of water saved is LE 0.003 per cubic meter. Rates of return are:

n = 10 then r = 34.38 percent
n = 20 then r = 35.55 percent
n = 30 then r = 35.58 percent

Conclusion

At the present time EWUP does not have adequate data to provide a scientifically defensible economic analysis of canal lining at Beni Magdoul. Since lining canals is one means for improving on-farm water management in Egypt it will be given consideration along with other means, for further investigation at the conclusion of the problem identification phase of EWUP, scheduled for July 1, 1978, for the Mansouria Study Site.

It is recommended that any decisions to make substantial investments in canal lining for Egypt should await adequate economic feasibility analysis. To do otherwise involves a high risk of misallocating scarce national resources. EWUP may generate valuable data for such an analysis depending on decisions regarding research plans which will be made at the conclusion of the problem identification phase.

Staff Paper #30

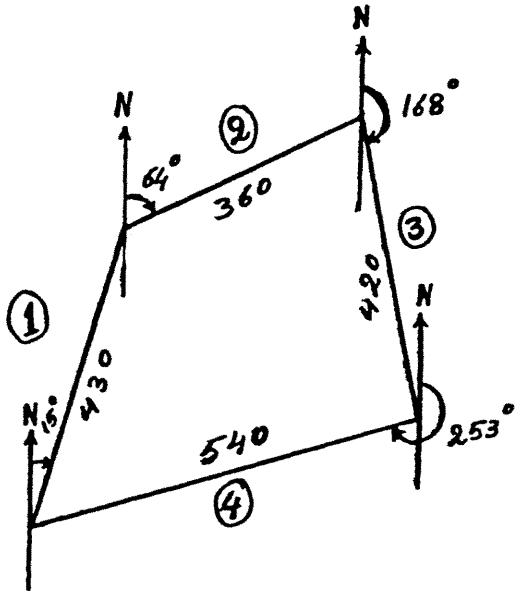
PROGRAMS FOR CALCULATORS
HP-67 AND HP-97

Gamal A. Ayad

February, 1979

AREA OF A POLYGON PROGRAM
FOR CALCULATORS HP-25, HP-67 AND HP-97

j(side)	aj(angle)	aj side length
1	15	430
2	64	360
3	168	420
4	253	540



PROGRAMME FOR THE POCKET CALCULATOR HP-25

Area of a polygon

This programme calculates the area of polygon of n sides, defined by:

$$\alpha_j,\ a_j \qquad j = 1, 2, \ldots, n$$

where α_j is the angle (in degrees) the side j forms with North measured in clockwise direction, and a_j is the length of this side.

Let

$$\Delta X_j = a_j \operatorname{Sin} \alpha_j$$

$$\Delta Y_j = a_j \operatorname{Cos} \alpha_j ,$$

and let

$$X_i = \sum_{j=1}^{i} \Delta X_j$$

$$Y_i = \sum_{j=1}^{i} \Delta Y_j$$

The area of the polygon (A), and the closure error (distance between the starting and ending point) expressed as percent of the perimeter (C), will respectively be:

$$A = \frac{1}{2} \sum_{i=1}^{n} (Y_i \Delta X_i - X_i \Delta Y_i) + \frac{Y_n}{n} \sum_{i=1}^{n} X_i - \frac{X_n}{n} \sum_{i=1}^{n} Y_i$$

$$C = 100 \times \sqrt{X_n^2 + Y_n^2} \Big/ \sum_{i=1}^{n} a_i$$

The area calculated represents the area of a closed polygon obtained by shifting the vertices of the given polygon along the lines parallel to the line passing through the starting and ending point. The vertex i is shifted by the i/n fraction of the distance between starting and ending point.

Programm

Display		Key entry
Line	Code	
00	//////////////////	
01	14 34	f STK
02	14 33	f REG
03	24 03	RCL 3
04	74	R/S
05	23 51 00	ST + 0
06	14 09	f → R
07	25	Σ +
08	22	R↓
09	21	x ⇄ y
10	22	R↓
11	14 73	f LASTx
12	24 04	RCL 4
13	23 51 02	STO + 2
14	61	X
15	21	x ⇄ y
16	24 07	RCL 7
17	23 51 01	STO + 1
18	61	X
19	41	−
20	41	−
21	13 03	GTO 03
22	34	CLx
23	02	2
24	71	÷

Display		Key entry
Line	Code	
25	14 21	f $\bar{x}$
26	24 02	RCL 2
27	61	X
28	24 04	RCL 4
29	24 03	RCL 3
30	71	÷
31	24 01	RCL 1
32	61	X
33	41	−
34	51	+
35	01	1
36	00	0
37	00	0
38	00	0
39	00	0
40	71	÷
41	74	R/S
42	24 04	RCL 4
43	24 07	RCL 7
44	15 09	g → P
45	24 00	RCL 0
46	71	÷
47	33	EEX
48	02	2
49	61	X

Registers	
R_0	Σa_i
R_1	ΣX_i
R_2	ΣY_i
R_3	n
R_4	Y_i
R_5	USED
R_6	USED
R_7	X_i

REMARK: This programme is made to calculate area in hectares for input in metres. Should different units be used, the conversion factor 10 000 given in lines 35-39 should be changed:

Input	Output	Conversion factor
Metres	Sq.metres	1.000
Feet	Acres	43 560
Feet	Sq.feet	1.000
Metres	Feddans	4200.8335
Metres	Acres	4046.856
Metres	Hectars	EEX 4
Metres	sq. kms.	EEX 6
Metres	sq. miles	259 ENT EEX6x

Example:

j (side)	α_j (angle : degrees)	a_j (length : metres)
1	15	430
2	64	360
3	168	420
4	253	540

A = 17.16 ha.   C = 0.42%.

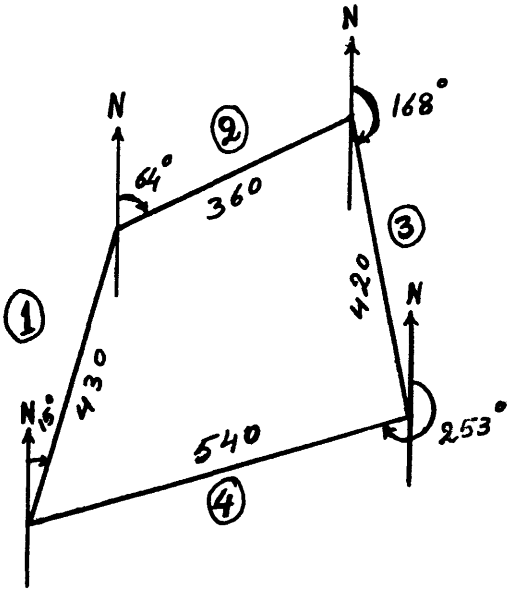
Instructions

Step	Instruction	Input	Keys				Output
1	Enter programme						
2	Initialize		GTO	0	0	R/S	0.00
3	Perform 3 for	α_j	↑				
	$j = 1, 2, \ldots, n$	a_j	R/S				j
4	Calculate area		GTO	2	2	R/S	A
5	Calculate closure error		R/S				C
6	For a new case go to 2		GTO	0	2	R/S	

Area of a Polygon Program for the Calculators
HP-67 and HP-97

Same example:

j(side)	aj(angle)	aj side length
1	15	430
2	64	360
3	168	420
4	253	540



Instructions:

Step	Instruction	Input	Keys	Output
1	Load program			0.00
2	Enter angles and Side lengths	Angle 1 (15°)	ENTER↑	15.00
		Side 1 (430)	$\boxed{C}$	1.00
		Angle 2 (64°)	ENTER↑	64.00
		Side 2 (360)	$\boxed{C}$	2.00
		Angle 3 (168°)	ENTER↑	168.00
		Side 3 (420)	$\boxed{C}$	3.00
		Angle 4 (253°)	ENTER↑	253.00
		Side 4 (540)	$\boxed{C}$	4.00
3	Calculate area		$\boxed{A}$	172068.89
4	Calculate error		$\boxed{E}$	0.42

* This program is designed to calculate area in square metres for inputs in metres. Should different units be used, the following steps should be added after step # 73 of the program steps.

Inputs	Outputs	Adding	No. of adding steps
Metres	Feddans	4200.8335 ÷	10
Metres	Acres	4046.856 ÷	9
Metres	Hectars	$\boxed{\text{EEX}}$ 4 ÷	3
Metres	Sq. Kms.	$\boxed{\text{EEX}}$ 6 ÷	3
Metres	Sq. Miles	259 $\boxed{\text{ENTER}}\boxed{\text{EEX}}$ 6x÷	8
Feet	Acres	4356 ÷	5
Feet	Sq. feet	None	None

Exercises

1)

Side	Angle	Side length in meters
1	150°	250
2	270°	250
3	30°	250

Solution should be: (Area = 27063.29 m^2, error = 0.00%)

2)

Side	Angle	Side length in metres
1	270	25
2	0 or 360	25
3	90	25
4	180	25

Solution should be: (Area = 625.00 m^2, error = 0.00%).

3) Use the example's data assuming that the side lengthes should be in metres and the area in feddans.

Solution should be: (Area = 40.96 feddans, error = 0.42%).

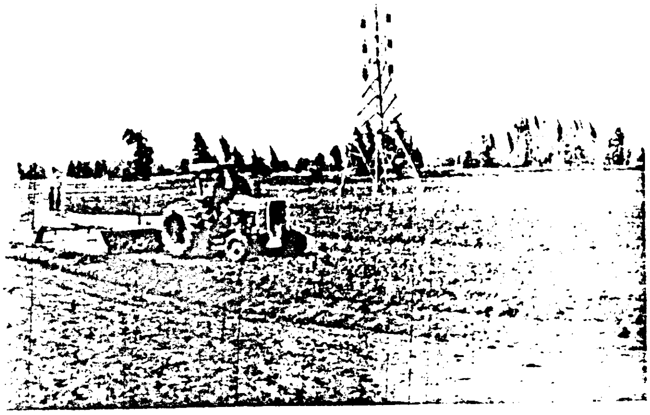
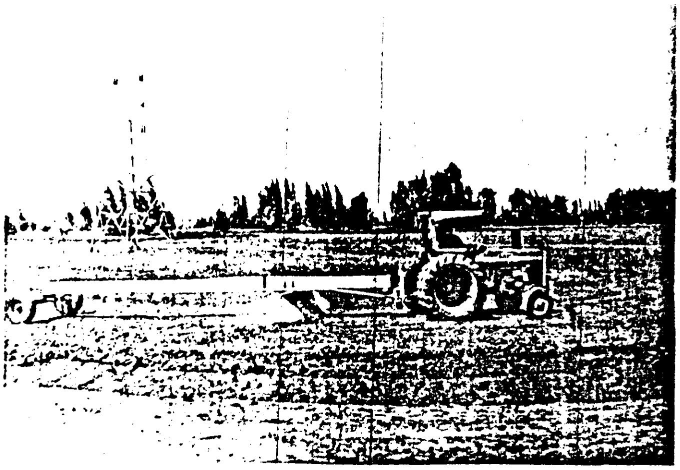
PROGRAM STEPS FOR CALCULATORS HP-67 AND HP-97

Step	Key entry	Step	Key entry	Step	Key entry	Step	Key entry
001	LBLC	021	RCL7	041	ENT ↑	061	X
002	STO 3	022	X	042	RCL2	062	STOD
003	X ⇄ Y	023	2	043	→ P	063	RCL 1
004	SIN	024	÷	044	RCLO	064	RCL 9
005	STO 5	025	STOA	045	÷	065	÷
006	LST X	026	RCL 1	046	EEX	066	RCL 2
007	COS	027	RCL 4	047	2	067	X
008	STO 6	028	X	048	X	068	STOC
009	RCL 3	029	2	049	PRTX	069	RCLD
010	X	030	÷	050	CLX	070	RCLC
011	STO 4	031	STOB	051	ENT ↑	071	—
012	ST+2	032	RCLA	052	ENT ↑	072	RCL 8
013	RCL 5	033	—	053	ENT ↑	073	+
014	RCL 3	034	ST+8	054	CLRG	074	X<0?
015	X	035	1	055	RTN	075	CHS
016	STO 7	036	ST+9	056	LBLA	076	PRTX
017	ST+1	037	RCL 9	057	RCL 2	077	RTN
018	RCL 3	038	RTN	058	RCL 9		
019	ST+0	039	LBLE	059	÷		
020	RCL2	040	RCL 1	060	RCL 1		

GMA/ls

Gamal Ayad

MAR. 19 1979

LAND LEVELING PROGRAM
For Calculators HP-67 and HP-97

Prepared by:

Gamal Ayad
Ag. Economist
March 5, 1979

Egypt Water Use and Management Project

Gamal Ayad

LAND LEVELING PROGRAM
For HP-67 and HP-97 Calculators

Prepared by Econ.
Gamal M. Ayad
March 5, 1979

This program calculates the depths of cuts and fills (C & F), the volume of each and the C/F ratio for leveling in one or two directions.

Before running the program the following data must be stored in the storage registers.

STO A = Number of stations in one strip in the direction of the first slope.
STO B = Slope in meters per grid spacing for the direction of the first slope.
STO C = Number of stations in one strip in the direction of the second slope.
STO D = Slope in meters per grid spacing for the direction of the second slope.
STO E = Grid spacing in meters.
STO 2 = The mean of all original land elevations. (The mean will be calculated and automatically stored in STO 2, or any desired mean value may be stored manually (entered) in step 3 of the instructions).

- If the program is used for only one-direction slope, neglect storage registers C and D.

- If the program is used for dead-level, neglect the storage registers A,B,C and D. (if HP-97 is used, store data in storage register "A". The depths of cuts and fills will then be grouped on the print-out.)

- Elevation readings are prefered. Rod readings will give reverse meaning for cuts and fills.

- Other units may be used as well as meters.

.../...

Instructions for Using the Program

	Steps (what)	Procedure (how to do it)	input Data/units	Keys	outputs Data/Units
1	Load program.	Insert prerecorded magnetic card or enter keystrokes of program steps manually. 1)			0.000
2	Store data in storage registers A through E.	Enter manually.			
3	Store elev. mean in storage register "2" (procedure) "a" or "b".	<u>a. Automatic:</u> Enter each original land elevation (in any sequence), each followed by pressing key "E".	First elevation. Second elevation. "n" elevation.	$\boxed{E}$ $\boxed{E}$ $\boxed{E}$	First elevation. Second elevation. "n" elevation.
		<u>b. Manual:</u> Enter desired value of the mean followed by pressing keys $\boxed{STO}$ $\boxed{2}$.	Desired mean.	$\boxed{STO}\boxed{2}$	Desired mean
4	Calculate the depths of cuts and fills.	Starting at the highest designated elevation level, and proceding along one strip in the direction of the first slope, enter the original land elevation reading of each station followed by pressing key "A". Enter each strip in order.	First elevation. Second elevation. "n" elevation.	$\boxed{A}$ * $\boxed{A}$ $\boxed{A}$	- = cut or + = fill - = cut or + = fill - = cut or + = fill
5	Calculate the volumes of cuts and fills and the C/F ratio.**	Press key "C".		$\boxed{C}$***	volume of cuts(-). volume of fills(+) C/F ratio. 0.000000000 0.000

---

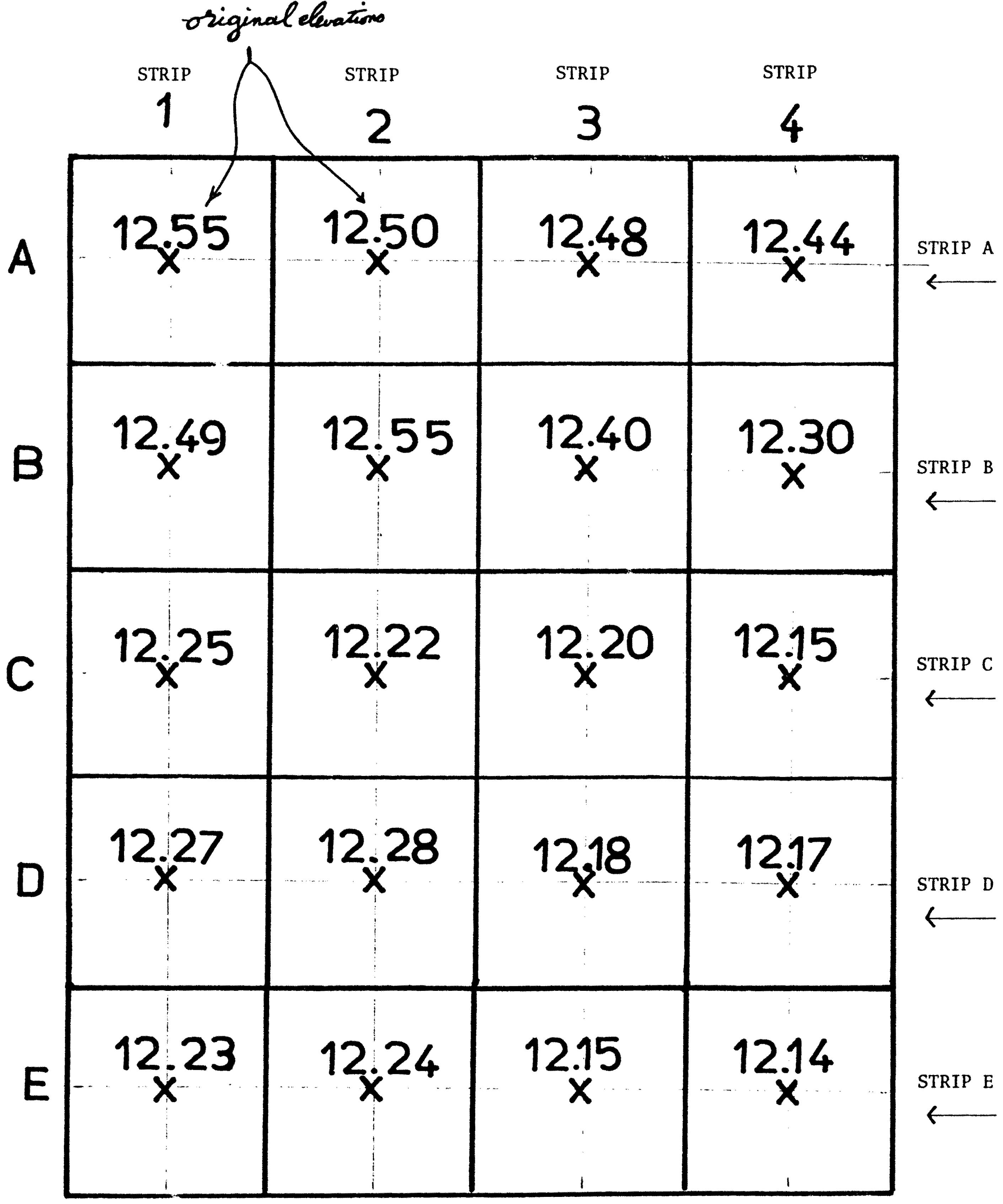
* Remember, with the HP-67, the flashing decimal point indicates that the cut or fill value will disappear after few seconds and the last elevation keyed in will appear. The disappeared values can be retrieved by pressing keys $\boxed{h}$ $\boxed{x \rightleftarrows y}$

** The C/F ratio can be changed by entering a different mean in step 3, procedure "b".

*** Immediately after 0.000000000 appears, all storage registers are cleared (erased) and the program is ready for another run.

1) Program steps on page 8.

EXAMPLE



	STRIP 1	STRIP 2	STRIP 3	STRIP 4	
A	12.55	12.50	12.48	12.44	STRIP A ←
B	12.49	12.55	12.40	12.30	STRIP B ←
C	12.25	12.22	12.20	12.15	STRIP C ←
D	12.27	12.28	12.18	12.17	STRIP D ←
E	12.23	12.24	12.15	12.14	STRIP E ←

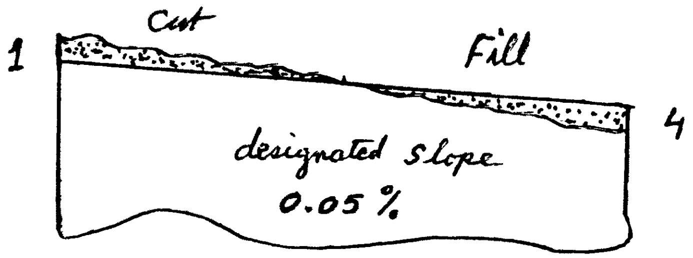
Grid spacing = 10 metres

I

if we want to level the land in this example in one direction slope for 0.05% (the highest level at strip (1) and the lowest level at strip (4)).

1. Load program.
2. 4 $\boxed{\text{STO}}$ $\boxed{\text{A}}$
   0.005 $\boxed{\text{STO}}$ $\boxed{\text{B}}$
   10 $\boxed{\text{STO}}$ $\boxed{\text{E}}$
3. 12.55 $\boxed{\text{E}}$ 12.50 $\boxed{\text{E}}$ .... 12.14 $\boxed{\text{E}}$
4. 12.55 $\boxed{\text{A}}$ - 0.233 } This is the first strip # A (all cuts)
   12.50 $\boxed{\text{A}}$ - 0.188
   12.48 $\boxed{\text{A}}$ - 0.173
   12.44 $\boxed{\text{A}}$ - 0.138
   12.49 $\boxed{\text{A}}$ - 0.173 Second strip # B .

   and so on till the end of the field (the last elevation will be 12.14).
5. Press $\boxed{\text{C}}$ - 123.600 (volume of cuts in cubic metres).
   123.600 (volume of fills in cubic metres).
   1.000 C/F ratio

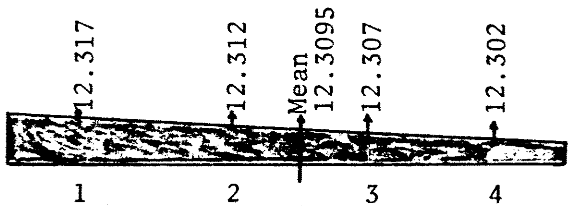


Print-out slip

```
Strip  A   { - 0.233
           { - 0.188
           { - 0.173
           { - 0.138

Strip  B   { - 0.173
           { - 0.238
           { - 0.093
           {   0.002

Strip  C   {   0.067
           {   0.092
           {   0.107
           {   0.152

Strip  D   {   0.047
           {   0.032
           {   0.127
           {   0.132

Strip  E   {   0.087
           {   0.072
           {   0.157
           {   0.162
```

press C

```
    - 123.600
      123.600
        1.000
  0.000000000
        0.000
```

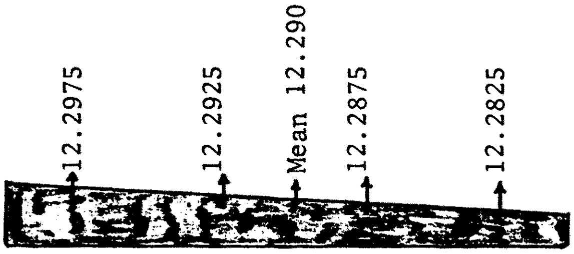


	1	2	3	4
A	12.55 -0.233	12.50 -0.188	12.48 -0.173	12.44 -0.138
B	12.49 -0.173	12.55 -0.238	12.40 -0.093	12.30 0.002
C	12.25 0.067	12.22 0.092	12.20 0.107	12.15 0.152
D	12.27 0.047	12.28 0.032	12.18 0.127	12.17 0.132
E	12.23 0.087	12.24 0.072	12.15 0.157	12.14 0.162

After this run if you want to change the mean elevation from 12.3095 to 12.29, repeat the same steps except storing the new mean manually (procedure "b").

1. Program is already loaded.
2. 4 $\boxed{\text{STO}}$ $\boxed{\text{A}}$
   0.005 $\boxed{\text{STO}}$ $\boxed{\text{B}}$
   10 $\boxed{\text{STO}}$ $\boxed{\text{E}}$
3. 12.29 $\boxed{\text{STO}}$ $\boxed{\text{2}}$
4. 12.55 $\boxed{\text{A}}$
   12.50 $\boxed{\text{A}}$

   till the end of elevations.
5. Press $\boxed{\text{C}}$



	1	2	3	4
A	12.55 -0.253	12.50 -0.208	12.48 -0.193	12.44 -0.158
B	12.49 -0.193	12.55 -0.258	12.40 -0.113	12.30 -0.018
C	12.25 0.048	12.22 0.073	12.20 0.088	12.15 0.133
D	12.27 0.028	12.28 0.013	12.18 0.108	12.17 0.113
E	12.23 0.068	12.24 0.053	12.15 0.138	12.14 0.143

Print-out slip

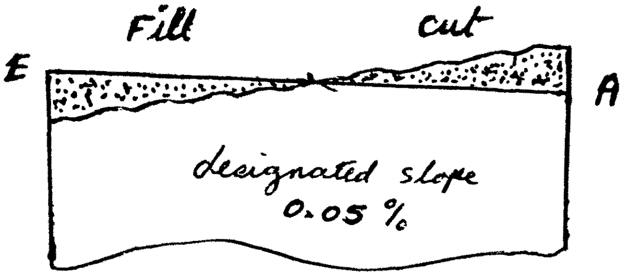
```
Strip A      - 0.253
             - 0.208
             - 0.193
             - 0.158

Strip B      - 0.193
             - 0.258
             - 0.113
             - 0.018

Strip C        0.048
               0.073
               0.088
               0.133

Strip D        0.028
               0.013
               0.108
               0.113

Strip E        0.068
               0.053
               0.138
               0.143

               - 139.000
When             100.000
Press   C          1.390
             0.000000000
                   0.000
```

II

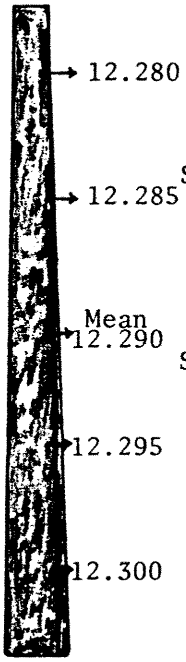
Now, if we want to level the example's land in another direction (the highest level at "E" strip and the lowest level at "A" strip, in a slope of 0.05%, using the value 12.29 as a desired mean elevation).

1. Load program .
2. 5 $\boxed{\text{STO}}$ $\boxed{\text{A}}$
   0.005 $\boxed{\text{STO}}$ $\boxed{\text{B}}$
   10. $\boxed{\text{STO}}$ $\boxed{\text{E}}$
3. 12.29 $\boxed{\text{STO}}$ $\boxed{\text{2}}$
4. 12.23 $\boxed{\text{A}}$
   12.27 $\boxed{\text{A}}$
   12.25 $\boxed{\text{A}}$ Strip 1
   12.49 $\boxed{\text{A}}$
   12.55 $\boxed{\text{A}}$
   12.24 $\boxed{\text{A}}$ Strip 2

   and so on till the end of the land (the last elevation will be 12.44).
5. Press $\boxed{\text{C}}$.



	1	2	3	4
A	12.55 -0.270	12.50 -0.220	12.48 0.200	12.44 -0.160
B	12.49 -0.205	12.55 -0.265	12.40 -0.115	12.30 -0.015
C	12.25 0.040	12.22 0.070	12.20 0.090	12.15 0.140
D	12.27 0.025	12.28 0.015	12.18 0.115	12.17 0.125
E	12.23 0.070	12.24 0.060	12.15 0.150	12.14 0.160
	1	2	3	4



Print-out slip

```
Strip 1          0.070
                 0.025
                 0.040
               - 0.205
               - 0.270

Strip 2          0.060
                 0.015
                 0.070
               - 0.265
               - 0.220

Strip 3          0.150
                 0.115
                 0.090
               - 0.115
                 0.200

Strip 4          0.160
                 0.125
                 0.140
               - 0.015
               - 0.160

            - 145.000
              106.000
                1.368
  C         0.000000000
                0.000
```

III

if you want to level the land in the same example in tow directions slopes. One of the slopes is 0.05%, highest level at strip (1) the lowest at strip (4). The second slope is 0.10%, the highest level at strip (A) and the lowest at strip (E), using 12.29 as a mean elevation.

1. Load Program .

2. 4 $\boxed{\text{STO}}$ $\boxed{\text{A}}$
   0.005 $\boxed{\text{STO}}$ $\boxed{\text{B}}$
   5 $\boxed{\text{STO}}$ $\boxed{\text{C}}$
   0.01 $\boxed{\text{STO}}$ $\boxed{\text{D}}$
   10 STO $\boxed{\text{E}}$

3. 12.29 $\boxed{\text{STO}}$ $\boxed{2}$

4. 12.55 $\boxed{\text{A}}$
   12.50 $\boxed{\text{A}}$
   12.48 $\boxed{\text{A}}$
   12.44 $\boxed{\text{A}}$
   till the end of the field

Outupts

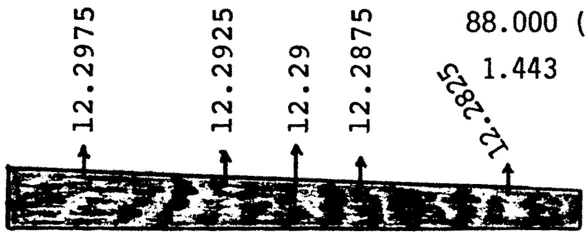
5. Press $\boxed{\text{C}}$ - 127.000 (volume$^{m^3}$ of cuts)
   88.000 (volume of fills)
   1.443 C/F ratio

Printed out slip

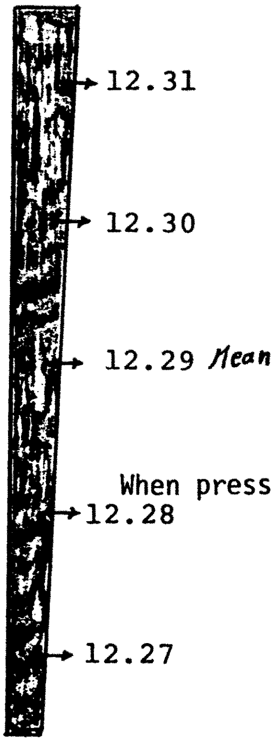
Strip A	- 0.233
	- 0.188
	- 0.173
	- 0.138
Strip B	- 0.183
	- 0.246
	- 0.103
	- 0.008
Strip C	0.048
	0.073
	0.088
	0.133
Strip D	0.018
	0.003
	0.098
	0.103
Strip E	0.048
	0.033
	0.118
	0.123

When press $\boxed{\text{C}}$

- 127.000
88.000
1.443
0.000000000
0.000



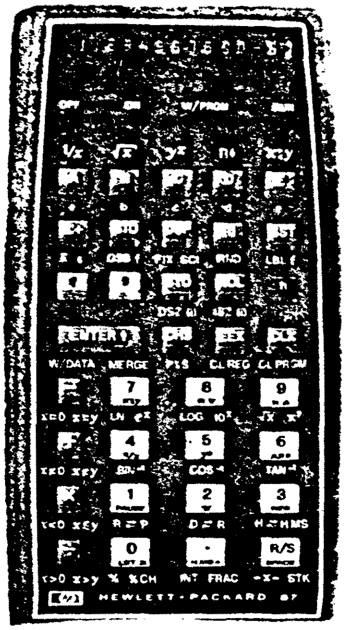
	1	2	3	4
A	12.55 -0.233	12.50 -0.188	12.48 -0.173	12.44 -0.138
B	12.49 -0.183	12.55 -0.246	12.40 -0.103	12.30 -0.008
C	12.35 0.048	12.22 0.073	12.20 0.088	12.15 0.133
D	12.27 0.018	12.28 0.003	12.18 0.098	12.17 0.103
E	12.23 0.048	12.24 0.033	12.15 0.118	12.14 0.123
	1	2	3	4

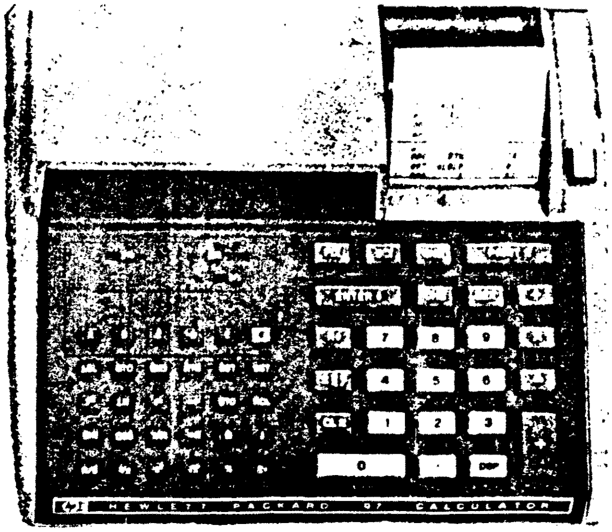


Program Steps

Step No.	Key Entry	Step No.	Key Entry	Step No.	Key Entry	Step No.	Key Entry	Step No.	Key Entry
001	LBL E	021	LBL d	041	+	061	ST+1	081	X<0?
002	STO I	022	RCL A	042	-	062	1	082	CHS
003	ST+8	023	2	043	RCLD	063	STO 7	083	PRTX
004	1	024	÷	044	X	064	GTO d	084	CLX
005	ST+9	025	.	045	RcL0	065	RTN	085	DSp 9
006	RcL8	026	5	046	+	066	LBLC	086	PRTX
007	RcL9	027	+	047	RcL2	067	Spc	087	DSp2
008	÷	028	RCL 7	048	+	068	RcLE	088	CLRG
009	STO2	029	-	049	RcL5	069	X^2	089	CLX
010	RCLI	030	RcLB	050	-	070	RcL6	090	ENT↑
011	RTN	031	X	051	PRT X	071	X	091	ENT↑
012	LBLA	032	STo0	052	X<0?	072	PRTX	092	ENT↑
013	DSp 3	033	RCLC	053	ST+6	073	RcLE	093	RTN
014	STo5	034	2	054	X>0?	074	X^2		
015	1	035	÷	055	ST+4	075	RcL4		
016	ST+7	036	.	056	RcL5	076	X		
017	RcLA	037	5	057	RTN	077	PRTX		
018	RcL7	038	+	058	LBLB	078	RcL6		
019	X>Y?	039	RCL 1	059	SPC	079	RcL4		
020	GTOB	040	1	060	1	080	÷		

MAR. 5 - 1979





INTERNAL RATE OF RETURN PROGRAM FOR CALCULATORS HP-67 AND HP-97

Prepared by:

GAMAL M. AYAD
AG. ECONOMIST
JUNE, 1979

EGYPT WATER USE AND MANAGEMENT PROJECT

INTERNAL RATE OF RETURN PROGRAM

FOR HP-67 AND HP-97

For a flow of costs and returns through time the program solves for the internal rate of return for a maximum of 35 years. Add the costs and returns each year, costs negative and returns positive.

For example let us suppose you make an investment today of $2000 and at the end of the first year it yields returns of $250, the second year $260, the third year $273, the fourth $280 and then $300 each year thereafter. The initial investment is the only "cost". Thus the net flow can be depicted as:

Year	Amount	Year	Amount
0	-2000	4	280
1	250	5	300
2	260	6	300
3	273	n	300

The program solves the following equation for the value of "r".

$$0 = \frac{a_0}{(1+r)^0} + \frac{a_1}{(1+r)^1} + \frac{a_2}{(1+r)^2} + \frac{a_3}{(1+r)^3} + \cdots\cdots + \frac{a_n}{(1+r)^n}$$

$$0 = \frac{-2000}{(1+r)^0} + \frac{250}{(1+r)^1} + \frac{260}{(1+r)^2} + \frac{273}{(1+r)^3} + \frac{280}{(1+r)^4} + \frac{300}{(1+r)^5} + \cdots\cdots + \frac{300}{(1+r)^n}$$

.../...

I "n" not more than 17 (17 years period)

Step	Instructions	Input Data/Units	Keys	Output Data/Units
1	Load program. Side #1 Side #2	--	--	 Crd 0.00
2	Store data in order.*	a_0	$\boxed{\text{STO}}\boxed{1}$	a_0
		a_1	$\boxed{\text{STO}}\boxed{2}$	a_1
		a_2	$\boxed{\text{STO}}\boxed{3}$	a_2
		a_8	$\boxed{\text{STO}}\boxed{9}$	a_8
	Always when you use $\boxed{\text{F}}$ $\boxed{P\gtrless S}$ to store over 9 values you should use $\boxed{\text{F}}$ $\boxed{P\gtrless S}$ again after you finish storing (important not to forget).		$\boxed{\text{F}}\boxed{P\gtrless S}$	
		a_9	$\boxed{\text{STO}}\boxed{1}$	a_9
		a_{10}	$\boxed{\text{STO}}\boxed{2}$	a_{10}
			↓	
		a_{17}	$\boxed{\text{STO}}\boxed{9}$	a_{17}
			$\boxed{\text{F}}\boxed{P\gtrless S}$	
	* If you have zero within the data set, store a small number e.g.0.00001 instead of zero to keep the years in order. as example if a_2 in the above data is 0, you have to store 0.00001 and not 0.			
3	If you want the program to stop each time reaches the equation value and "r" value, press $\boxed{\text{B}}$ (this is an optional step), when the program stops, press $\boxed{\text{R/S}}$ to continue calculations. If you do not use this step, the values will pouse for 2 seconds and continue calculations till the end.		$\boxed{\text{B}}$	

4	If you want to start with $r = 0$, press $\boxed{\text{A}}$ **		$\boxed{\text{A}}$	same as step #5
5	If you want to start with $r \neq 0$, store "r" first (as fraction e.g. 15 % stored as 0.15) then $\boxed{\text{A}}$	r	STO $\boxed{\text{E}}$ $\boxed{\text{A}}$	r
	** The calculater will calculate the value of the left side of the equation, displays it for two seconds, then displays the "r" value. If step #3 is used the program will stop after displaying each value instead of just pquse it for 2 seconds. The "r" value will be increased by 1 percent, and the process will repeat till reaches the first negative value for the equation, then "r" value will be decreased by 0.1 percent, The program stops as soon as the first positive value for the equation is reached, and displays the equation value (if HP-97 is used the value will be printed). to display the appropriate "r" value press $\boxed{\text{R/S}}$		$\boxed{\text{R/S}}$ if step #3 was used $\boxed{\text{R/S}}$ if step #3 was used $\boxed{\text{R/S}}$ if step #3 was used $\boxed{\text{R/S}}$ if step #3 was used $\boxed{\text{R/S}}$ if step #3 was used $\boxed{\text{R/S}}$ if step #3 was used $\boxed{\text{R/S}}$ if step #3 was used or not	eq.value (+) r% eq.value (+) r + 1% eq.value (+) r + 2% eq.value (+) r + 3% eq.value (-) (r + n)% eq.value (-) (r+n)-0.1 % eq.value (+) wanted "r"

6	If you want to stop the program and use a given value for "r", press $\boxed{E}$ twice, store the "r" value, and then restart the program by pressing $\boxed{A}$	r	$\boxed{E}\boxed{E}$ $\boxed{STO}\boxed{E}$ $\boxed{A}$	0.00 r
7	To use another set of data for annual returns press $\boxed{E}$, store the new data as in step #2, make sure that the last value in the new set of data is stored in a storage followed by a cleared storage. As example if you used 12 storages to store the data in the previous run and you want to store another 8 different values for new run, simply store the new data over the old data and store 0 in storage#9 to separate the old data from the new data.		$\boxed{E}$	0.00

Note:

If you changed your mind after running the program about the statement of pausing only or with stops, to change from pausing to stops, press $\boxed{E}$ twice, then press $\boxed{B}$ and store the following "r" value by "r" $\boxed{STO}\boxed{E}$, then restart again by pressing $\boxed{A}$. If you want to change from stops to pausing press $\boxed{E}$ twice and store "r" as before, then restart by pressing $\boxed{A}$.

Another Way:

1. To set stops (stop the program if it is running by $\boxed{R/S}$) then
   $\left\{\begin{array}{l}\text{HP - 67 } \boxed{h}\boxed{SF}\text{ 1}\\ \text{HP - 97 } \boxed{f}\boxed{SF}\text{ 1}\end{array}\right\}$ Restart run by $\boxed{R/S}$
2. To set pause (stop the program if it is running by $\boxed{R/S}$) then
   $\left\{\begin{array}{l}\text{HP-67 } \boxed{h}\boxed{CF}\text{ 1}\\ \text{HP-97 } \boxed{f}\boxed{CF}\text{ 1}\end{array}\right\}$ Restart run by $\boxed{R/S}$

II when "n" is up to 35 (35 years)

For the first n = 0 ⟶ 17 follow exactly the previous instructions, when the program finishes the calculation the appropriate "r" value is obtained. Then calculate for two or three more values of "r+1%", "r+2%" and "r+3%" record the equation value for each value of "r".

For the rest of the data n = 18 ⟶ 35, press $\boxed{\text{E}}$, store the appropriate "r" you have from the first 17 years by "r" $\boxed{\text{STO}}\boxed{\text{E}}$ then run the program by pressing $\boxed{\text{C}}$, get eq. values for the same "rs" used before and add each pair for the same "r". The nearest to zero difference proves the best "r" value for the whole period, see example 3.

Example 1

Year	Amount $	Year	Amount $
0	-200	4	80
1	0	5	85
2	50	6	100
3	75	7	100

Step	Instructions	Input Data/Units	Keys	Output Data/Units
1	Load program	--	--	
	Side one			Crd
	Side two			0.00
2	Store data in order.	-200*	$\boxed{\text{STO}}\boxed{1}$	-200.00
		.00001	$\boxed{\text{STO}}\boxed{2}$	0.00001
		50	$\boxed{\text{STO}}\boxed{3}$	50.00
		75	$\boxed{\text{STO}}\boxed{4}$	75.00
		80	$\boxed{\text{STO}}\boxed{5}$	80.00
		85	$\boxed{\text{STO}}\boxed{6}$	85.00
		100	$\boxed{\text{STO}}\boxed{7}$	100.00
		100	$\boxed{\text{STO}}\boxed{8}$	100.00

* Press $\boxed{\text{CHS}}$ after entering the number to change the sign to

3	(Optional) if you want stops.		$\boxed{B}$	
4	If you want to start with $r = 0$.		$\boxed{A}$ $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$ used $\boxed{R/S}$ if $\boxed{B}$	290.00 0.00 267.04 1.00 245.48 2.00 225.22 3.00 ↓ 4.77 21.00 -2.36 22.00 -2.36 22.00 -1.66 21.90 -0.96 21.80 -0.25 21.70 0.45 21.60
	End of calculations $r = 21.6\%$		used or not	

If you started with $r = 0$, the program will take 15 minutes to finish this calculation. If you have more years, the time of calculation will increase, it could be more than half an hour. THAT IS WHY IT IS DEFINITELY RECOMMENDED TO START WITH $r = 10\%$, IF YOU FOUND EQ. V. STILL HIGH NUMBER, TRY 20%, IF YOU GET NEGATIVE VALUE REDUCE "r", AND SO ON TILL YOU REACH A REASONABLE POSITIVE VALUE FOR THE EQUATION THEN LET THE CALCULATOR COMPLETE THE REST OF THE CALCULATIONS.

To solve the same example by the recommended method.

Step	Instructions	Input Data/Units	Keys	Output Data/Units
1	The same like before .			
2	" " " " .			
3	Stops (are needed) .		B	
4	Store r = 10% .	.10	STO E	0.10
	then run program.		A	112.85
			R/S	10.00
5	Prepare program for new "r" value .		E	0.00
	Store r = 20% .	.20	STO E	0.20
	reset stops statement.		B	0.20
	then run program .		A	12.26
				20.00
	Now eq.v. = 12.26 this is reasonable value to let the program start with.			
	*Change stops statement to pausing .		E	0.00
				4.77
	- Start from r = 21% .	.21	STO E	0.21
	run .		A	-2.36
				22.00
				-1.66
				21.90
				-0.96
				21.80
				-0.25
				21.70
				0.45
			R/S	21.60

By this method the whole process takes only 5 minutes to finish the calculations.

Example 2

Year	Amount	Year	Amount
	$		$
0	-1500	8	500
1	-500	9	500
2	-250	10	500
3	300	11	500
4	500	12	500
5	500	13	500
6	500	14	500
7	500		

Step	Instructions	Input Data/Units	Keys	Output Data/Units
1	Load program			
	Side #1			Crd
	Side #2			0.00
2	Store data in order	-1500	STO 1	-1500.00
		-500	STO 2	-500.00
		-250	STO 3	-250.00
		300	STO 4	300.00
	Primary Storages	500	STO 5	500.00
		500	STO 6	500.00
		500	STO 7	500.00
		500	STO 8	500.00
		500	STO 9	500.00
			F P≷S	500.00
		500	STO 1	500.00
		500	STO 2	500.00
	Secondary Storages	500	STO 3	500.00
		500	STO 4	500.00
		500	STO 5	500.00
		500	STO 6	500.00
			F P≷S	500.00

3	Stops statement.		B	500.00
4	Start with r = 10%.	.10	STO E	0.10
	Run program.		A	504.6
			R/S	10.00
5	Change "r" to 15%.		E	0.00
		.15	STO E A	-205.94
6	Change stops to pause.		E	
	Start with 14%.	.14	STO E	0.14
	Run.		A	- 88.25
				14.00
	This part will be done			- 75.0
	automatically			13.90
				- 63.45
				13.80
				- 50.88
				13.70
				- 38.19
				13.60
				- 25.40
				13.50
				- 12.49
				13.40
				0.54
	End of calculation, the		R/S	13.30
	best "r" value = 13.3%			

Example 3:

Let us calculate "r: value for a period of 30 years for the following data:

Year	Amount $	Year	Amount $	Year	Amount $
0	- 2000	10	300	20	300
1	250	11	300	21	300
2	260	12	300	22	300
3	273	13	300	23	300
4	280	14	300	24	300
5	300	15	300	25	300
6	300	16	300	26	300
7	300	17	300	27	300
8	300	18	300	28	300
9	300	19	300	29	300
				30	300

For the first 17 years follow the same instructions as in example 2. Results will be:

r value	eq. value
12.2%	3.50
13%	- 87.82
14%	-192.85
15%	-288.76

Then store the data for years 18 → 30, follow the same instructions as in example 2 except using only the above three values of "r" and use $\boxed{C}$ to start instead of $\boxed{A}$.

Remember: After you store 300 for the year 30 in storage 4 store 0 in 5 to separate the rest of the old data from the new data, as mentioned before.

r value	eq. value
13%	229.97
14%	188.94
15%	155.65

Add the negative equation values obtained from the first 17 years to the positive values obtained from the years 18 → 30, the value nearest to zero will indicate the most appropriate "r" value.

"r" value	Equation value	Equation value	Algebraic sum
	0 → 17	18 → 30	
13%	- 87.82	229.97	142.15
14%	-192.85	188.94	- 3.91
15%	-288.76	155.65	-133.11

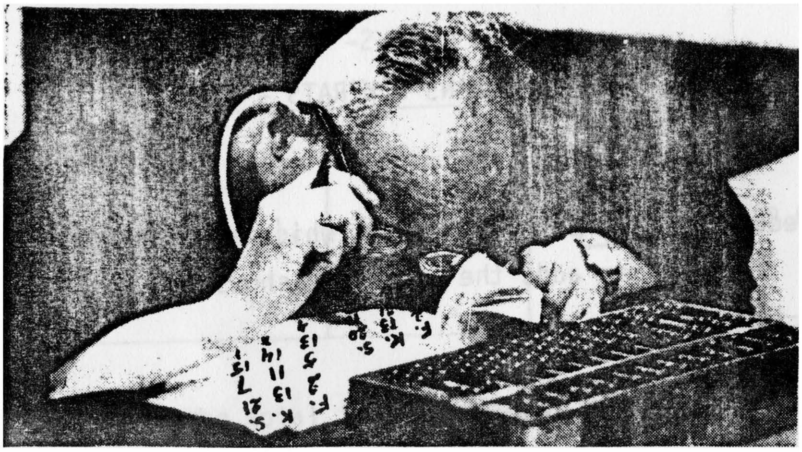
It is clear that 14% is very near the true internal rate of return (r) which satifies equation value = 0.

Kamal Ayad

JUN. 13 1979

INTERNAL RATE OF RETURN PROGRAM STEPS FOR CALCULATORS HP-67 & HP-97

STEP	KEY ENTRY	STEP	KEY ENTRY	STEP	KEY ENTRY	STEP	KEY ENTRY	STEP	KEY ENTRY
1	•LBLA	41	STOI	81	PRTX	121	+	161	2
2	1	42	x ⇄ y	82	R/S	122	STOB	162	4
3	ST+0	43	ST+i	83	RCLE	123	R↓	163	STOI
4	RCL0	44	GTOA	84	1	124	1	164	RCLi
5	1	45	•LBL6	85	0	125	—	165	.
6	0	46	0	86	0	126	RCLB	166	0
7	X = Y ?	47	STO0	87	X	127	X⇄Y	167	0
8	GTO1	48	STOD	88	RTN	128	Y^X	168	1
9	•LBL0	49	RCLC	89	•LBL1	129	RCLA	169	ST-i
10	RCL0	50	PSE	90	1	130	X⇄Y	170	F0?
11	STOI	51	F1?	91	1	131	÷	171	GTOb
12	2	52	R/S	92	STO0	132	2	172	GTO2
13	0	53	RCLE	93	GTO0	133	2	173	•LBLC
14	X=Y?	54	1	94	•LBL2	134	STOI	174	1
15	GTO6	55	0	95	1	135	X⇄Y	175	8
16	RCLi	56	0	96	ST+0	136	ST+i	176	STOD
17	X=0?	57	X	97	RCL0	137	GTO2	177	SF0
18	GTO6	58	PSE	98	1	138	•LBL4	178	GTOA
19	STOA	59	F1?	99	0	139	0	179	•LBLb
20	2	60	R/S	100	X=Y?	140	STO0	180	1
21	3	61	RCLC	101	GTOd	141	STOD	181	8
22	STOI	62	X=0?	102	•LBLe	142	RCLC	182	STOD
23	1	63	GTO3	103	RCL0	143	PSE	183	GTO2
24	ST+i	64	X<0?	104	STOI	144	F1?	184	•LBLB
25	RCLi	65	GTO4	105	2	145	R/S	185	SF1
26	RCLE	66	CLX	106	0	146	RCLE	186	RTN
27	1	67	STOC	107	X=Y?	147	1	187	•LBLd
28	+	68	2	108	GTO4	148	0	188	1
29	STOB	69	4	109	RCLi	149	0.	189	1
30	R↓	70	STOI	110	X=0?	150	X	190	STO0
31	1	71	RCLi	111	GTO4	151	PSE	191	GTOe
32	-	72	.	112	STOA	152	F1?	192	LBLE
33	RCLB	73	0	113	2	153	R/S	193	CLX
34	X⇄Y	74	1	114	3	154	RCLC	194	STOB
35	Y^X	75	ST+i	115	STOI	155	X=0?	195	STOC
36	RCLA	76	F0?	116	1	156	GTO3	196	STOD
37	X⇄Y	77	GTOC	117	ST+i	157	X>0?	197	STOE
38	÷	78	GTOA	118	RCLi	158	GTO3	198	STO0
39	2	79	•LBL3	119	RCLE	159	CLX	199	CF0
40	2	80	RCLC	120	1	160	STOC	200	CF1
					Kamal Ayad			201	RTN



A PROGRAM FOR CALCULATORS

HP-67 AND HP-97

ADDING FEDDANS - KERATS - SAHMS, CONVERTING TO DECIMAL SYSTEM, HECTARES, ACRES, SQUARE METERS AND REVERSELY.

Prepared by:

GAMAL M. AYAD
AG. ECONOMIST

JUNE, 1979

EGYPT WATER USE AND MANAGEMENT PROJECT

ADDING FEDDANS - KERATS - SAHMS

Based on 1 feddan = 24 kerats = 576 sahms which are the agricultural land units area. The program adds the areas and shows the total in the same system, fed.-ket-sms.

Example: add the following areas:

	Feddan	Kerat	Sahm
Area 1	2	20	15
Area 2	7	--	3
Area 3	13	2	--
Area 4	9	17	22
Area 5	--	8	17
Area 6	6	--	20

Step	Instructions	Input Data/units	Keys	Output Data/units
1	Load the program (Both sides of the card)			Crd 0.00
2	Key in the first area, feddans followed by decimal point and two digits for kerats and the last two digits for sahms (f.KKSS)			
	Then press $\boxed{A}$	2.2015	$\boxed{A}$	2.2015
	Key in the second area	7.0003	$\boxed{A}$	7.0003
	" " " third area	13.02	$\boxed{A}$	13.0200
	" " " fourth area	9.1722	$\boxed{A}$	9.1722
	" " " fifth area	.0817	$\boxed{A}$	0.0817
	" " " sixth area	6.002	$\boxed{A}$	6.0020

.../...

Cont.

3	To calculate the total, press $\boxed{B}$.		$\boxed{B}$	39.0205

The result shows that the total is 39 feddans, 2 kerats and 5 sahms.

Note: If you keyed in a wrong number, e.g. if you keyed in the third area as 13.20 instead of 13.02 and you did not yet press $\boxed{A}$, simply press $\boxed{CLX}$ then key in the right number 13.02, then press $\boxed{A}$. But if you discovered the mistake after pressing $\boxed{A}$, substract it by pressing $\boxed{CHS}$, then press $\boxed{A}$, and key in the correct number.

e.g.	Press	Display
	the third area 13.20 $\boxed{A}$	13.2000
	Oops! you made a mistake. $\boxed{CHS}$ $\boxed{A}$	-13.2000
	The correct area 13.02 $\boxed{A}$	13.0200

☞ Use $\boxed{CHS}$ before $\boxed{A}$ when you want to substract an area.

If you want a subtotal within the data set, simply press $\boxed{B}$ whenever a subtotal is needed, then press $\boxed{A}$ and key in the next area.

Press	Display
The first area 2.2015 $\boxed{A}$	2.2015

.../...

The second area	
7.0003 $\boxed{A}$	7.0003
Subtotal is needed	
$\boxed{B}$	9.2018
$\boxed{A}$	9.2018
The third area	
13.02 $\boxed{A}$	13.0200
Subtotal is needed	
$\boxed{B}\boxed{A}$	22.2218
The fourth area	
9.1722 $\boxed{A}$	9.1722
The fifth area	
.0817 $\boxed{A}$	0.0817
Subtotal is needed	
$\boxed{B}\boxed{A}$	33.0109
The sixth area	
6.002 $\boxed{A}$	6.0020
TOTAL	
$\boxed{B}$	39.0205

II. CHANGING FEDDAN-KERATS-SAHMS TO DECIMAL SYSTEM (→ 0.00)

fed. ket. shm.

If you want to change the total in the last example from 39. 02 05 to decimal system, press $\boxed{C}$, e.g. 39.0205 $\boxed{C}$ display 39.09 (if the converted area is not displayed on the screan, key it in first, then press $\boxed{C}$).

III. CHANGING FEDDANS AREA FROM DECIMAL SYSTEM TO FED.KKSS SYSTEM (→ f.kkSS)

Reverse of using $\boxed{C}$. Press $\boxed{D}$

e.g. 22.14 $\boxed{D}$ display 22.0309

.../...

IV. CONVERTING DDANS* TO SQUARE METERS (f → m^2)

Press $\boxed{E}$

e.g. 14.36 $\boxed{E}$ displays 60323.97

(feddans) = (square meters)

⊞ Based on 1 feddan = 4,200.8335 sq. meter

V. CONVERTING SQ. METERS TO FEDDANS (m^2 →f)

Reverse of using $\boxed{E}$. Press $\boxed{F}\boxed{E}$

e.g. 56142.54 $\boxed{F}\boxed{E}$ displays 13.36

(sq. meters) = (feddan)

⊞ Based on 1 feddan = 4,200.8335 sq. meters

VI. CONVERTING FEDDANS* TO ACRES (f → AC.)

Press $\boxed{F}\boxed{A}$

e.g. 13.36 $\boxed{F}\boxed{A}$ dsiplay 13.87

(feddans) = (acres)

⊞ Based on 1 feddan = 1.03805 acres

VII. CONVERTING ACRES TO FEDDANS (AC. → f.)

Reverse of using $\boxed{F}\boxed{A}$. Press $\boxed{F}\boxed{C}$

e.g. 22.54 $\boxed{F}\boxed{C}$ display 21.71

(acres) = (feddans)

⊞ Based on 1 acre = 0.96335 feddan

VIII. CONVERTING FEDDANS* TO HECTARES. (f. → HEC.)

Reverse of using $\boxed{F}\boxed{D}$. Press $\boxed{F}\boxed{B}$

e.g. 56.23 $\boxed{F}\boxed{B}$ displays 23.62

⊞ Based on 1 feddan = 0.42008 hectares.

---

* Feddans must be keyed in in decimal system .

IX. CONVERTING HECTARES TO FEDDANS (HEC. → f)

Reverse of using $\boxed{F}\,\boxed{B}$. Press $\boxed{F}\,\boxed{D}$
e.g. 63.45 $\boxed{F}$ $\boxed{D}$ displays 151.04
(hectares) = (feddans)

● Based on 1 hectare = 2.38048 feddan

Gamal Ayad

JUN. 20 1979

GA/ls

PROGRAM STEPS

STEP	KEY ENTRY	STEP	KEY ENTRY	STEP	KEY ENTRY	STEP	KEY ENTRY	STEP	KEY ENTRY
1	*LBLA	41	4	82	0	123	0	164	1
2	DSP4	42	+	83	0	124	0	165	.
3	STO0	43	STO4	84	X	125	+	166	0
4	INT	44	RCL2	85	FRC	126	STOC	167	3
5	ST+1	45	2	86	1	127	RCLB	168	8
6	RCL0	46	4	87	0	128	EEX	169	0
7	FRC	47	+	88	0	129	4	170	5
8	1	48	INT	89	X	130	+	171	X
9	0	49	ST+1	90	2	131	RCLC	172	RTN
10	0	50	LSTX	91	4	132	+	173	*LBLb
11	X	51	FRC	92	+	133	RCL6	174	DSP2
12	INT	52	2	93	2	134	+	175	.
13	ST+2	53	4	94	4	135	RTN	176	4
14	RCL0	54	X	95	+	136	R/S	177	2
15	FRC	55	1	96	RCLB	137	*LBLE	178	0
16	1	56	0	97	+	138	4	179	0
17	0	57	0	98	STOC	139	2	180	8
18	0	58	+	99	RCLA	140	0	181	X
19	X	59	RCL1	100	INT	141	0	182	RTN
20	FRC	60	+	101	RCLC	142	.	183	*LBLc
21	1	61	RCL4	102	+	143	8	184	DSP2
22	0	62	+	103	RTN	144	3	185	.
23	0	63	DSP4	104	*LBLD	145	3	186	9
24	X	64	CLRG	105	DSP4	146	5	187	6
25	ST+3	65	RTN	106	INT	147	X	188	3
26	RCL0	66	*LBLC	107	STO0	148	DSP2	189	3
27	RTN	67	DSP2	108	LSTX	149	RTN	190	5
28	*LBLB	68	STOA	109	FRC	150	*LBLe	191	X
29	RCL3	69	FRC	110	2	151	4	192	RTN
30	2	70	1	111	4	152	2	193	*LBLd
31	4	71	0	112	X	153	0	194	DSP2
32	+	72	0	113	INT	154	0	195	2
33	INT	73	X	114	STOA	155	.	196	.
34	ST+2	74	INT	115	LSTX	156	8	197	3
35	LSTX	75	2	116	FRC	157	3	198	8
36	FRC	76	4	117	2	158	3	199	0
37	2	77	+	118	4	159	5	200	4
38	4	78	STOB	119	X	160	+	201	8
39	X	79	RCLA	120	STOB	161	RTN	202	X
40	EEX	80	FRC	121	RCLA	162	*LBLa	203	RTN
		81	1	122	1	163	DSP2		

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Staff Paper #31

On-Farm Water Management Investigations In Mansouria District, 1979-80

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Observations and measurements of water management practices in the Mansouria Irrigation District have been reported in considerable detail (Mona Mostafa El Kady, 1979; M. El Kady, W. Clyma, and M. Abu Zeid, 1979; EWUP, 1979). The purpose of this paper is to examine more recently obtained data from two selected farms, one in sandy soil on the El Hamami Branch Canal and the other in clay soil on the Beni Magdoul Branch Canal. The data include irrigation frequencies and amounts of water applied to most of the dominant crops grown in the region. For selected fields and crops it includes moisture-tension data obtained from mercury tensiometers. The depth to water table was measured at frequent intervals in a number of observation wells on these farms. Before irrigation and after irrigation soil moisture samples were taken to a depth of 30 cm at selected field sites.

The data from these two farms was examined and analyzed to help answer the following questions:

1. Is there over irrigation? If so, how much?

2. What frequencies and amounts of irrigation water are currently being applied to fields planted to each of the major and minor crops?

3. Can soil moisture samples, taken to the depth of the root zone, estimated at 30 cm, be used to estimate the total stored moisture available to plants?

4. What is the relative importance of over irrigation, as compared with seepage from canals and private ditches, as a factor affecting the position of the high, fluctuating water table?

5. Do crops ever suffer from drouth when the supply in the canal is adequate?

6. Can a relationship between tensiometer readings and the depth to water table be established that would be useful to predict when it is time to irrigate?

To help answer the first three questions, a very simple water budget was calculated for each crop measured on the two farms. The results appear in tables 1 through 8.

Table 1 shows the data taken from a corn field in Beni Magdoul. The first two columns are self explanatory. The irrigation amounts shown in column 3 were obtained from cutthroat flume measurements, with readings being taken about every 15 minutes. A linear variation between readings was assumed. The total application for the season was 91 cm. Column 4 shows the interval between irrigations, averaging 11 days, and the total growth period of 112 days. The average application was 9 cm per irrigation.

Column 5 in Table 1 shows the estimated evapotranspiration for the period since the last irrigation. It was calculated by the Blaney-Criddle method using coefficients developed in Arizona. The estimated total for the season is 53 cm, or about 58% of the total water applied.

Column 6 figures were obtained by subtracting the figures in column 5 from corresponding figures in column 3. The difference is presumed to be available to raise the water table and eventually to reach the drains. The total is about 39 cm, or nearly 43% of the water applied. The calculated leaching requirement to remove the salts carried in with the irrigation water is only about 10%, but it is difficult to irrigate with less than 20% loss to deep percolation. With this allowance, there is still about 25 cm excess application, if the measurements and estimates are sufficiently accurate. These data may or may not be typical, but this farmer is considered to be a good irrigator, so perhaps his excess application is less than average.

Column 7 figures in Table 1 represent the soil moisture depletion in the top 30 cm of the soil profile. The column is labeled "revised" soil moisture depletion because the figures have been augmented to account for the depletion that occurred from evapotranspiration during the period between the irrigation and the after-irrigation sampling, usually three days. The rate of depletion was calculated at the rate measured during the period following, before the next irrigation. Note that in all but one interval, the soil moisture depletion was less than the calculated evapotranspiration, and the total depletion was only half of the total ET. Although both sets of values are subject to some error, the very large differences between them are sufficient evidence to conclude that not all the moisture used by the plants came from that stored in the top 30 cm of soil. Apparently about half of the total used came up from below, causing the water table to recede. For the sake of future investigations, one can also conclude that soil moisture sampling to a depth of only 30 cm at this site or similar site cannot be expected to yield any useful estimate of the total quantity of moisture exchanged between the soil and the plants.

Tables 2, 3, and 4 were similarly prepared for berseem clover. Since Table 2 has the most complete data, it is chosen for discussion. Again, the Arizona coefficients were used for estimating consumptive use, but this time the coefficients for alfalfa were chosen, since berseem data was not available. Further, the monthly coefficients were shifted somewhat in an attempt to adjust for the fall planting. There is likely more error in these estimates than those for corn.

The records summarized in Table 2 show no irrigation at planting, so it was assumed that a pre-irrigation filled the rootzone. If so, the heavy irrigations September 17 and 26 went mostly to the water table. There was another excessively heavy irrigation Nov. 3, but on Dec. 31 the water applied was less than the calculated consumptive use during the 27 day interval since the last irrigation. The next irrigation didn't catch up any, so there are two zeros in the excess application column. In the calculations, it was assumed that a soil moisture deficit continued until subsequent irrigations accumulated enough excesses to refill the soil to field capacity. The total excess application tabulated was 74 cm, or 47% of the water applied. The farmer demonstrated he could apply irrigations of only three, four or five centimeters at a time, so if he had good advice on how much to apply, he could avoid contributing so much to the water table.

Table 1. ON-FARM WATER BUDGET
Corn field, Farm 5, Beni Magdoul
Date of planting April 24, 1979
Date of harvest August 14, 1979

1. Irrig. No.	2. Date of irrigation day-mo.-year	3. Irrg. amount cm	4. Time since last irrig. days	5. Estimated ET for interval cm	6. Excess appli-cation cm	7. Revised Soil moisture de-pletion cm
1	24-4-79	7.49				
2	13-5-79	6.62	19	3.93	2.69	1.94
3	31-5-79	12.41	18	4.22	8.19	3.13
4	11-6-79	4.96	11	3.43	1.53	5.05
5	21-6-79	10.22	10	4.11	6.11	1.17
6	29-6-79	7.71	8	3.82	3.89	1.27
7	7-7-79	10.32	8	4.94	5.38	1.88*
8	17-7-79	11.57	10	6.67	4.90	4.07
9	27-7-79	8.86	10	7.89	0.97	2.35*
10	3-8-79	10.59	7	5.50	5.09	2.72
Harvest	14-8-79		11	8.58		2.59*
	Totals	91	112	53	39 (43%)	26
	Means	9.1	11			

* Dummy values, calculated from averages

Table 2. ON-FARM WATER BUDGET
Berseem clover field, Farm 5, Beni Magdoul
Date of planting 2 Sept. 1979
Date of last harvest 1, April, 1980

Irrig.	Date of irrigation day-mo.-yr	Irrig. amount cm	Time since last irrig days	Estimated ET for interval cm	Excess application cm	Revised Soil moisture dep letion cm
Planting	2-9-79	?				
1	9-9-79	3.35	7	1.11	2.2	2.56*
2	17-9	14.90	8	1.65	13.3	2.92
3	26-9	13.85	9	3.14	10.7	4.26
4	4-10	5.62	8	3.20	2.4	2.85
5	14-10	9.52	10	4.51	5.0	4.21
6	3-11	21.82	20	11.23	10.6	2.36
7	17-11	7.36	14	6.9	0.5	0.61
8	4-12	14.4	17	7.8	6.6	6.37
9	31-12-79	8.53	27	11.55	0	2.94
10	28-1-80	12.23	28	12.40	0	4.74
11	8-2	9.95	11	4.92	1.8	5.79
12	14-2	10.85	6	2.69	8.2	2.98
13	21-2	11.16	7	3.14	8.0	3.46
14	28-2	8.16	7	3.14	5.0	1.83*
15	25-3-80	4.09	26	12.11	0	6.81*
Harvest	11-4-80		17	8.78		1.83*
Totals		156	212	98	74	56.5
Means		10.4	14			

* Dummy values, calculated from averages.

Table 3. ON-FARM WATER BUDGET
Berseem Clover Field, Farm 1, El Hammami, 1978-79
Date of Planting Nov. 2, 1978
Date of Last Harvest May 25, 1979

Irrig. No.	Date of irrigation mo.-day-yr	Irrig. amount cm	Time since last irrig. days	Estimated ET for interval cm	Excess application cm	Revised soil moisture depletion cm
					Assume deficit = 10 cm	
1	11-2-78	14.62			4.62	
2	11-13-78	5.5*	11	1.31	4.19	
3	12-8-78	3.0*	25	6.05	----	
4	12-19-78	5.6	11	3.91	----	2.15
5	12-29-78	7.95	10	4.19	2.40	2.43
6	2-7-79	13.19	40	16.69	----	3.68
7	2-14-79	9.7	7	3.45	2.75	
8	2-25-79	13.79	11	5.73	8.06	
9	3-10-79	11.71	13	7.36	4.35	3.13
10	3-22-79	17.88	12	7.57	10.31	
11	4-4-79	12.17	13	8.65	3.52	
12	4-15-79	8.37	11	7.26	1.11	
12	4-28-79	9.02	13	8.78	0.24	1.71
14	5-9-79	12.76	11	7.44	5.32	1.89
Last harvest.	5-25-79		16	10.90		
	totals	145	204	99	47	
	means	10.4	14			

* Estimated from the number of hours the sakia presumably ran.

Table 4. ON-FARM WATER BUDGET
Berseem field, Farm 5, Beni Magdoul
Date of planting Sept. 2, 1978
Date of harvest ____________

Irrig. No.	Date of irrig.	Irrig. amount cm	Time since last irrig. days	Estimated ET for interval cm	Excess application cm
1	Sept. 2, 1978	9.44	---		Assumed adequate
2	16	8.5*	14	2.57	5.93
3	25	6.43	9	2.84	3.59
4	Oct. 26	11.88	31	15.16	---
5	Nov. 12	12.54	17	8.68	0.58
6	Dec. 4	5.56	22	9.72	---
7	Dec. 23	3.68	19	8.78	---
8	Jan. 16, 1979	8.24	24	11.10	---
9	Feb. 24	10.38	39	19.10	---
10	Mar 15, 1979	8.33	19	9.17	---
Last harv.					
Totals		85			10.1
Means		8.50	21.6		

* Assumed value as the mean of other applications.

the total excess application, according to the figures in this table. The second irrigation seven days later was also excessive. All the irrigations which followed ranged from about 2.6 to only about 5.5 cm. Irrigation in these amounts cannot be criticised severely for being too large, even though there was probably some surplus each time. There could be a problem though if those small amounts were not distributed with sufficient uniformity. The total excess application far exceeds the calculated leaching requirement (less than 10 cm) and therefore should not be necessary to maintain soil salinity at its present level.

The ET estimates in Table 5 were adapted from measured values for cauliflower in Arizona. It was assumed that the peak use rate for tomatoes would be slightly higher and would reach about 5.3 mm per day maximum in October. The total estimated ET was 59 cm during the 172-day growing period. It is interesting to observe that, during the long periods between irrigations in November and December, the estimated ET far exceeded the water applied, yet the farmer was apparently satisfied that his irrigations were adequate. The ET estimates could be in error, but likely not that much. It is more likely that the upward flow from the water table was nearly able to keep up with ET during this cool period. The small applications were probably adequate under these circumstances.

The squash crop reported in Table 6 grew for only 60 days. Since no ET coefficient for squash were available, those for late cabbage were used instead. If the ET estimates are reasonably close, they suggest a 4-cm total excess application, which is only about 7% of the water applied. In addition much of the first irrigation had to be surplus since we have already observed that the deficit probably did not exceed 4 cm. The 10-cm initial deficit assumed in most of these tables was a generous estimate that could only occur if the top 60 cm of soil were near the wilting point. Apparently the small applications (about 3 cm) were possible because of the wide furrow spacing. The light irrigations combined with short irrigation intervals demonstrate good irrigation practice for this soil, assuming that the young plants were not stressed too much before their roots were well established.

The pepper crop described in Table 7 is interesting in that it continued for 286 days to the last harvest Then the plants were allowed to remain in the field when the next crop, corn for feed, was grown. The ET estimates were made for braccoli, since pepper coefficients were not available. However, since braccoli doesn't grow that long, it was arbitrarily assumed that the Blaney-Criddle k- values reduced linearily from 1.05 in February to 0.65 in June, after the plants passed their active growth period.

As happened in other crops, the planting irrigation was very heavy. But then the next 10 irrigations ranged only from 2 to 6 cm, a very good irrigation practice. However, the last 9 irrigations all exceeded 6 cm and all exceeded the estimated ET. After a good start for the season, it was estimated that about one third of all the water applied reached the ground water table. The average irrigation interval was 15 days, but except for the winter months. the schedule followed the 12 day rotation period fairly closely. It appears from table 7 as though 4 cm each 12 days may not have been quite enough. If so, the ideal solution would have been more frequent irrigations, not heavier irrigations. Tensiometers in this field showed no excessive moisture stress.

The soil moisture depletion column in Table 2 is interesting in that the measured values compare favorably with estimated ET whenever the irrigation interval is 11 days or less. Even the 17-day interval showed a reasonably good comparison, although the 14-day interval figures did not. However, for the long intervals (20, 27, 28 days) the measured moisture depletion was consistently much less than the estimated ET. The logical conclusion from this observation is that, in this case, the upward flow from the water table was slow at first, then increased sharply. However, the records for other crops do not consistently support this conclusion, so perhaps this apparent relationship was due to chance. The total revised soil moisture depletion was only 61% of the total estimated ET. These results support the figures in Table 1 for corn, inasmuch as they show that not nearly all the water used by the plants is obtained from the top 30 cm of soil.

The records from a berseem field in El Hammami are summarized in Table 3. Again it appears that some irrigations are unnecessarily large, especially during February and March. With the residual water table at about 75 cm depth in this sandy soil, and rising high enough to confine the roots to the top 40 cm of soil, or even less, it is usually not practical to apply more than 5 cm at one irrigation. Exceptions to this rule could occur when the leaching of residual salts is required for land reclamation, or when the field irrigation system is not capable of spreading this small amount uniformly over the field. Soil moisture sampling of the top 30 cm of soil shows an average of 5.39 cm of water in the profile three days after irrigation. The average 15-atmosphere moisture content of El Hammami soil as measured in the laboratory is 0.45 cm of water in the top 30 cm of soil, based on a measured mean bulk density of 1.67. This leaves about 4.94 cm as the total available in this zone. A crop should not be expected to extract more than 4 cm of this amount between irrigations. In fact the maximum measured depletion shown in Table 3 is 3.68 cm, even after a 40-day period. Thus it appears that a 5-cm irrigation will always be in excess of the amount needed. Even smaller applications would be desirable if they could be spread with sufficient uniformity.

The berseem field described in Table 4 appears to have been irrigated with very little contribution to the water table. In fact, the figures suggest an increasing moisture deficit in the soil after November 12. No tensiometers were installed in this field to tell the exact story, but the before-irrigation moisture samples do show a steady decline from 11.8 cm prior to the 6th irrigation to 9.3 cm prior to the 9th irrigation. However, the after-irrigation samples showed a steady increase from 12.8 cm to 14.6 cm during the same period. Thus this set of data appears to be another example of the deficit being supplied from the water table. It is also quite possible that the ET estimates are somewhat high, since they were based on alfalfa data from Arizona.

The irrigation application to selected vegetable crops is shown in Tables 5, 6, 7, and 8. All were in sandy soil in El Hammami. Tomatoes shown in Table 5 received 14 irrigations, but the first irrigation continued for four days. Surely the hope of these heavy irrigations at planting was to leach out salt. The total water applied those 4 days was 47.7 cm, while the soil moisture deficit could not possibly have exceeded 10 cm, leaving an estimated surplus of about 38 cm. for leaching. This is about 63% of

Table 5. ON-FARM WATER BUDGET
Tomato field, Farm 1, El Hammami, 1979
Date of planting Aug. 1, 1979
Date of harvest Jan. 20, 1980

Irrig. No.	Date of Irrig.	Irrig. amount cm	Time since last irrig. days	Estimated ET for interval cm	Excess application cm
1	August 1	13.91			3.91 (assuming deficit is 10 cm)
	2	15.67	1	0.06	15.61
	3	12.97	1	0.06	12.91
	4	5.12	1	0.06	5.06
2	August 11	7.31	7	0.45	6.86
3	18	4.54	7	0.73	3.81
4	29	2.58	11	1.73	0.85
5	Sept. 6	4.33	8	1.74	2.59
6	18	4.69	12	2.43	2.26
7	26	3.55	8	3.11	0.44
8	Oct. 3	3.15	7	2.98	0.17
9	11	4.57	8	3.79	0.78
10	15	4.88	4	1.90	2.98
11	23	5.54	8	4.19	1.35
12	Nov. 9	4.89	17 17	8.53	–
13	21	3.4	12	5.33	–
14	Dec. 13	4.98	22	8.28	–
	Jan. 20	Harv.	38	9.78	–
	totals	106.08	172	59.44	59.58
	means	7.6	12		
	mean*	4.5			

* Not counting the first irrigation, which lasted 4 days

Table 6. ON-FARM WATER BUDGET
Squash field, Farm 1, El Hammami
Date of planting Aug. 31, 1979
Date of harvest Oct. 30, 1979

Irrig. No.	Date of Irrig.	Irrig. amount cm	Time since last irrig. days	Estimated ET for interval cm	Excess application cm
1	Aug. 28, 1979	10.6		Assumed adequate	--
2	Sept. 18	3.26	18	1.66	1.60
3	29	2.82	11	2.62	0.20
4	Oct. 3	0.78	4	1.43	---
5	12	2.67	9	3.58	---
6	15	2.77	3	1.19	0.02
7	21	4.06	6	2.93	1.13
8	25	3.0	4	1.95	1.05
Harvest	Oct. 30, 1979		5	2.44	
Totals		30.0	60	17.8	4.0
Means		3.75	7.9		

Table 7. ON-FARM WATER BUDGET
Pepper field, Farm 1, El Hammami
Date of planting Sept. 7, 1979
Date of harvest June 19, 1980

Irrig. No.	Date of Irrig.	Irrig. amount cm	Time since last irrig. days	Estimated ET for interval cm	Excess application cm
1	Sept. 6, 1979	4.33			(Assuming deficit is 10 cm max.)
2	7	23.49			17.82
3	18	5.14	11	0.98	4.16
4	30	5.79	12	1.88	3.91
5	Oct. 15	4.08	15	4.56	---
6	27	4.25	12	4.88	---
7	Nov. 9	4.89	13	6.35	---
8	21	2.29	12	5.71	---
9	Dec. 12	3.67	21	8.07	---
10	Jan. 1, 1980	3.14	20	6.03	---
11	Feb. 3	4.5	33	10.81	---
12	Mar 3	3.5	29	10.23	---
13	15	6.41	12	4.58	---
14	30	8.04	15	6.27	---
15	Apr. 8	9.58	9	3.98	
16	20	10.13	12	5.26	4.07
17	30	11.62	10	4.29	7.33
18	May 12	9.88	12	5.30	4.58
19	May 23	9.90	11	4.90	5.00
20	June 7	6.67	15	6.60	0.07
21	17	6.99	10	4.30	2.69
Last Har.	19		2	0.42	
Totals		148.3	286	105.4	49.6
Means		7.1	15		

Table 8. ON-FARM WATER BUDGET
Cabbage field, Farm 1, El Hammami
Date of planting Dec. 5, 1978
Date of harvest May 23, 1979

Irrig. No.	Date of Irrig	Irrig. amount cm	Time since last irrig. days	Estimated ET for interval cm	Excess application cm
					Assume deficit is 10 cm
1	Dec. 6, 1978	13.38			3.38
2	Dec. 30	2.47	24	2.52	---
3	Feb. 5, 1979	2.42	37	12.04	---
4	Feb. 15	4.61	10	4.74	---
5	Feb. 26	4.44*	11	5.32	---
6	Mar. 9	7.0	11	5.77	---
7	Mar. 18	2.52	9	4.29	---
8	Mar. 26	1.5	8	4.00	---
9	Mar. 28	2.47	2	1.00	---
10	Apr. 2	6.86	5	2.56	---
11	Apr. 16	3.25	14	7.40	---
12	Apr. 29	6.85	13	6.42	---
Harvest	May 23		24	12.29	
Totals		57.8	168	68.35	3.38
Means		4.82	13.1		

* Missing values estimated from other data.

Table 9. TENSIOMETER READINGS AND WATER TABLE DEPTHS
Corn Field, Farm 5, Beni Magdoul, 1979
Date of planting April 24, 1979
Date of harvest August 14, 1979

Date of irrigation day-mo.-yr.	Water Applied cm	Tensiometer readings, mb				Mean depth to water table, cm	
		Before irrig.		After irrig.			
		30 cm	60 cm	30 cm	60 cm	Before irrig	After irrig.
24-4-79	7.49					135	72
13-5-79	6.62	458	105	26	16	91	72
31-5-79	12.41	182	176	70	54		
11-6-79	4.96	520	98	44	46	113	69
21-6-79	10.22	490	126	52	64	101	84
29-6-79	7.71	356	312	46	46		
7-7-79	10.32	160	232	20	80	100	57
17-7-79	11.57	112	152	150	6	98	69
27-7-79	8.86	182	10	64	46	99	77
3-8-79	10.59					94	70
Means	9.1	308	152	59	45	104	71

The last table in this group reports the irrigations on cabbage. Again the first irrigation was heavy, but only three of the subsequent eleven irrigations exceeded 5 cm. The ET estimates, when compared with the irrigation amounts, suggest some deficits accumulated, but then a larger irrigation tended to reduce or eliminate the deficit. These ET estimates from Arizona could be somewhat high for Cairo. Also, the supply in the water table comes to the rescue, so likely this crop did not suffer excessive moisture stress. Note that some irrigation intervals are less than 9 days, which suggests irrigation during the off-period.

Questions 4, 5, and 6 cannot be precisely and firmly answered from the data collected in Mansouria. However some insight can be obtained from the records of water table levels and tensiometer readings. Questions 4 and 5 are very important for good water management. For question 6, it is important that a method be found to help the farmer decide when it is time to irrigate, but it is not essential that the position of the water table be found to be a reliable guide for this decision. In the following paragraphs, the recorded data on water table position and the readings of tensiometers will be examined, separately and together, to obtain at least some partial answers.

In Table 9, the water table depths shown were measured on the same day as the selected tensiometer readings. The measurements selected for this table were made either just before irrigation or about three days after. The cup of one tensiometer was placed 30 cm below ground surface and the other 60 cm. The one at 90 cm was not included because it showed very little change in reading throughout the season. All three were the mecury-column type, and were placed between plants right in the corn row.

Looking first to question 5, it appears from the tensiometer readings that there was not excessive moisture stress except possibly before the May 13 irrigation, 19 days after planting. A tension of 458 millibars (mb) is not excessive, except that in this case the roots were mostly above the 30 cm level, where the tension was surely higher. At this stage of growth the center of the root mass may have been at 12 or 15 cm depth. Irrigation is recommended when the tension in the center of the root mass reaches about 400 mb. Usually no serious damage is done at 500, or even a bit higher. A millibar is about 1/1000 atmosphere, or equivalent to the pressure of one centimeter depth of water. It appears from the reading at 30 cm that the last three irrigations were each sooner than needed. However the 60 cm readings indicate considerable root activity there also, suggesting that there was at that time adequate capacity to store a light irrigation. The data from Table 1 shows that this was true, but that the 11.57 cm and the 10.59 cm applications were much too large. One can conclude that except possibly for the first irrigation, the timing of these irrigations was quite good, even though some of the amounts applied were excessive.

Table 10 suggests that the peppers in the sandy El Hammamy soil were not stressed as much as the corn in Beni Magdoul, and that perhaps the irrigations could have been less frequent. However, for produce harvested in a moist or wet condition, like peppers, frequent irrigations usually tend to increase production, providing the amounts applied are not excessive, and soil aeration is not impaired. At the first of the season the amounts applied were quite reasonable, but later they were excessive.

Table 10. TENSIOMETER READINGS AND WATER TABLE DEPTHS
Pepper Field, Farm 1, El Hammami
Date of planting Sept 7, 1979
Date of last harvest June 19, 1980

Date of Irrigation	Water Applied cm	Tensiometer readings at 15 cm depth, mb		Mean depth to water table, cm	
		Before irrig.	After irrig.	Before irrig.	After irrig.
Sept. 7, 79	27.82	86	50	66	38
Sept. 18	5.14	90	60	76	37
Sept. 30	5.79	86	64	73	54
Oct. 15	4.08	84	60	55	57
Oct. 27	4.25	122	72	75	56
Nov. 9	4.89	75	70	55	54
Nov. 21	2.29	89	89	49	65
Dec. 12	3.67	104	65	75	46
Jan. 1, 80	3.14	97	50	73	57
Feb. 3	4.5	75	83	51	55
Mar. 3	3.5	90	45	63	39
Mar. 15	6.41	100	44	71	46
Mar. 30	8.04	97	46	60	60
Apr. 4	9.58	150	50	71	41
Apr. 20	10.14	104	67	52	52
Apr. 30	11.62	160	30	66	47
May 12	9.88	120	60	62	39
May 23	9.90	125	60	58	50
June 7	6.67	100	70	68	77
June 17	6.99	200	75	75	52
Means	7.41	108	60.5	65	51

The conclusion is that, after the root system was well established, the interval between irrigations could have been increased somewhat. However, if the yield was limited by irrigation practice, it was not because the irrigations were too frequent, but because the amounts applied at each irrigation were too great. It is of course possible that the tensiometers were not reading quite all the tension that the roots were subjected to. One possible cause could be an energy barrier between the cup and the soil, in case the pores in the sand are much, much larger than those in the tensiometer cup.

Table 9 also shows the depths to water table just before irrigation and from one to three days after irrigation. The average rise and fall is about one-third meter, between 71 and 104 cm below ground surface. The well locations are generally around the edges of the farm, and are not immediately adjacent to the tensiometer locations, so a mean of all five wells is shown in the table. From the table it appeared that a correlation exists between tensiometer reading and water table depth, so an attempt was made to fit a curve to the set of data points. The graph of the best fit curve is shown in Figure 1. The R^2 value is not high enough to give a useful method of predicting when it is time to irrigate by measuring the depth to water. One would like to irrigate when the sum of the tensiometer values reaches about 500, or at least in the range from 400 to 600. But in that range the fluctuation of corresponding depths to water table is too great to be used as an index. This set of data thus gives a negative answer to question 6.

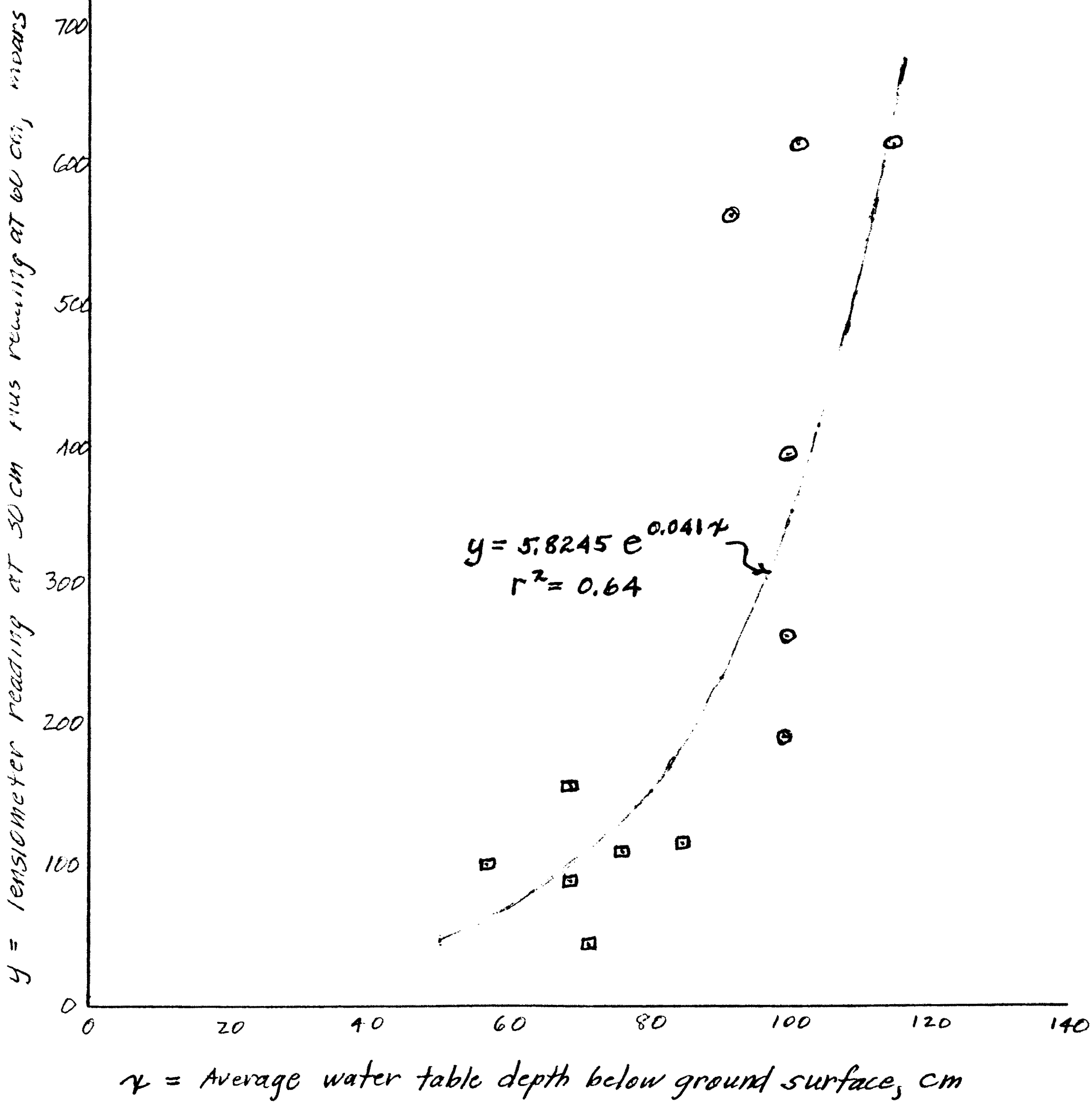
A similar attempt was made to correlate the tensiometer readings in El Hammami with water table depth, and the result was equally unsatisfactory as a method of predicting when to irrigate. Figures 2, 3, and 4 show the results. Only the tensiometer at 15 cm depth was used because the others showed little drying below field capacity. Figure 2 shows a scatter similar to that in Figure 1. The R^2 value is much too low to be useful. Only the best fit curve is shown. Figure 3 shows a much more uniformly placed set of points and a much higher R^2 value for the month of September. However, the tensiometer readings were all below 100. Figure 4 for the month of June illustrates the scatter problems when the tensiometer readings go to 200 mb. The linear curve gave as good a fit as any, but the correlation is too low to be useful. Thus we can conclude that the depth to water table is not a sufficiently accurate indicator of the need to irrigate.

From Figure 5 one can obtain a partial answer to question 4, as far as El Hammami is concerned. Three of the four wells plotted are located in the pepper field, and the other in an adjacent field. The fluctuating lines show the water levels in each of the four wells, respectively. The time and amount of each irrigation is shown by the scaled arrows pointing up from the bottom line of the graph. Amounts are in cm of water. The following features can be observed from this plot:

1. The water levels in all wells seem to fluctuate together on about a 12 day cycle, corresponding to the on-periods of the El Hammami Canal.

2. The longest recession was during the January closure period. The lowest level was about 10 cm below the usual low. A

Figure 1. Relationship between the sum of the tensiometer readings at 30 and 60 cm depths and the average depth to groundwater in a corn field, Farm 5, Beni Magdoul, 1979



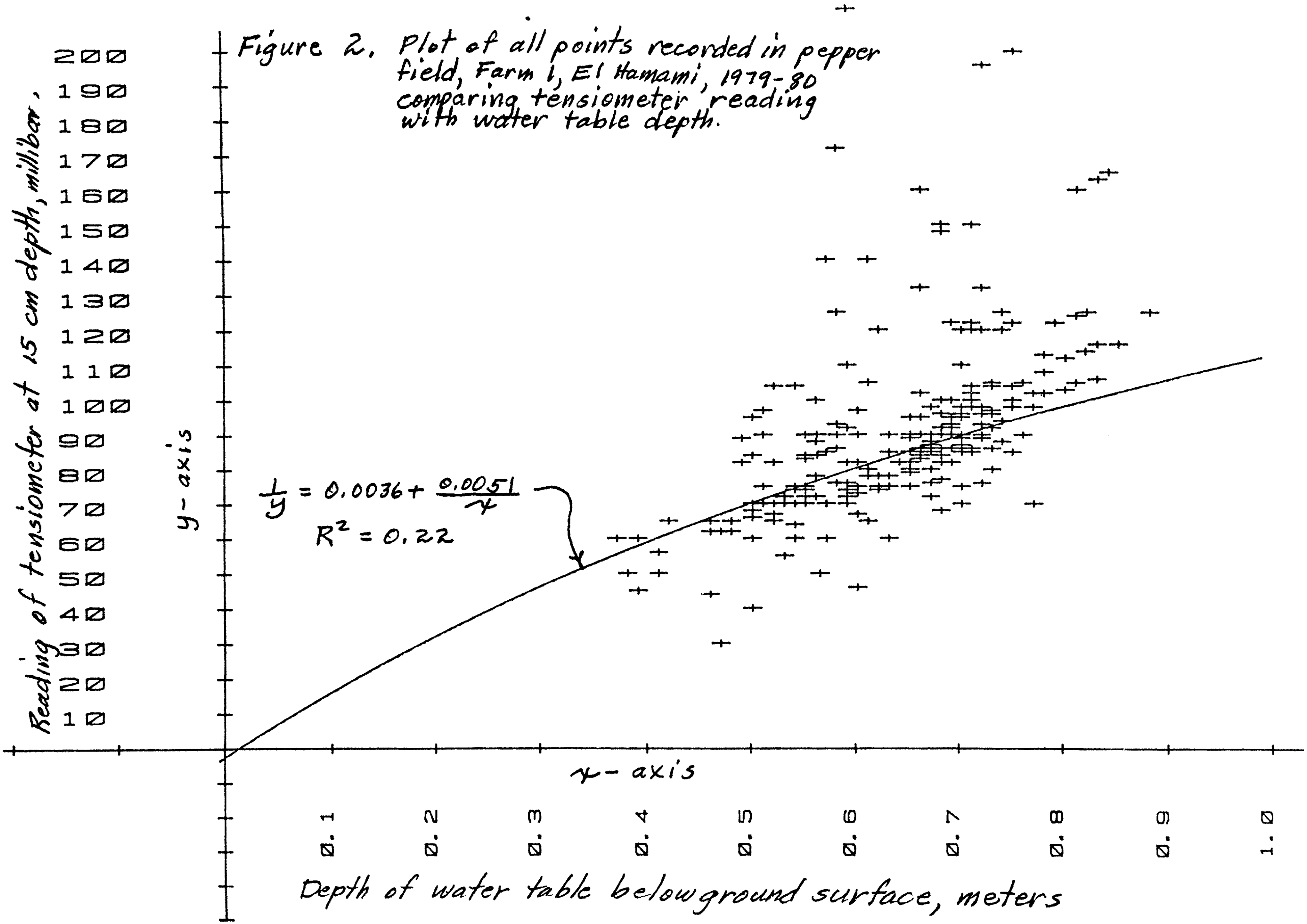


Figure 2. Plot of all points recorded in pepper field, Farm 1, El Hamami, 1979-80 comparing tensiometer reading with water table depth.

Figure 3, Tensiometer readings vs. water table depth during September, 1979 in a pepper field, Farm 1, El Hamami

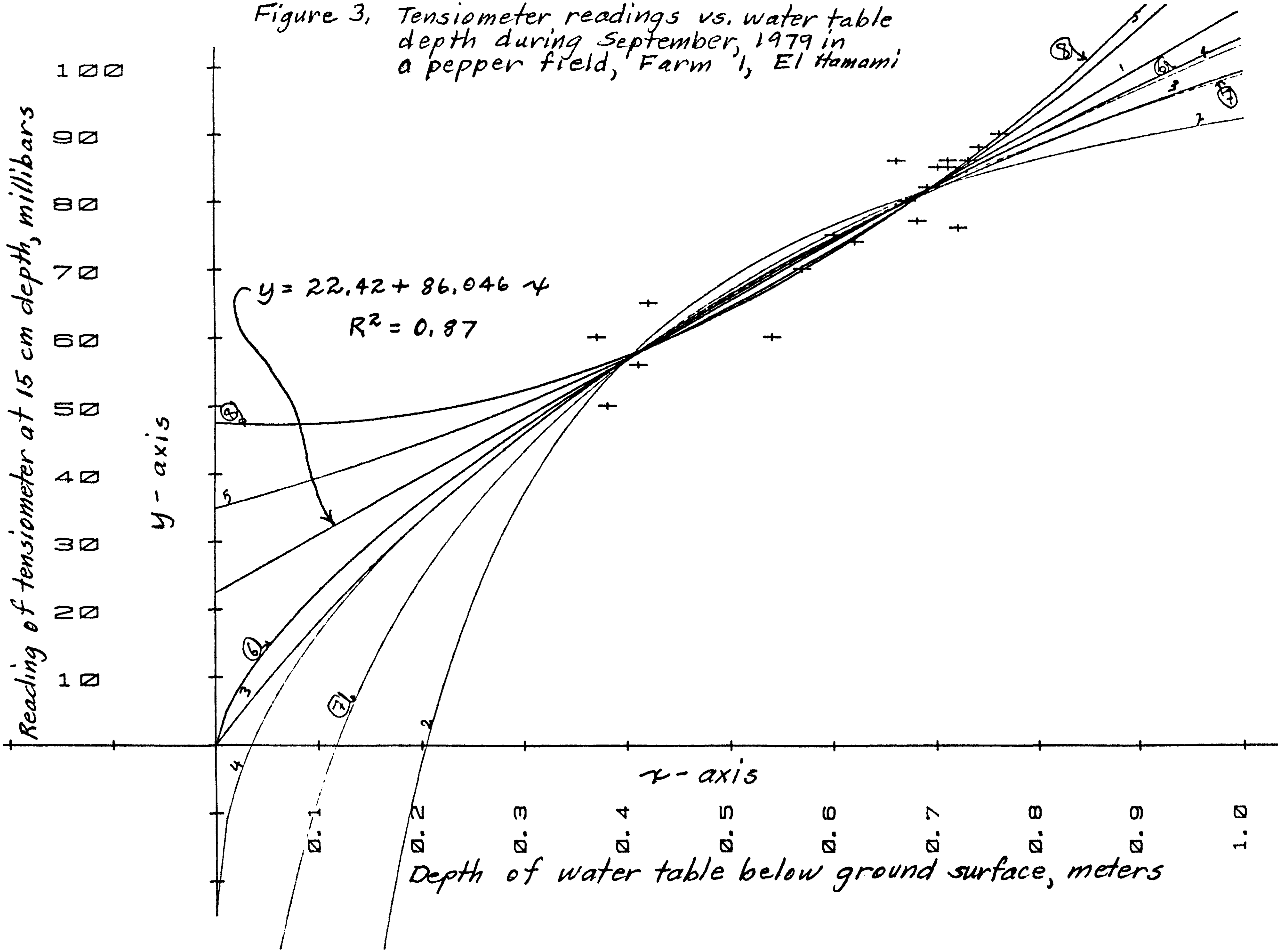
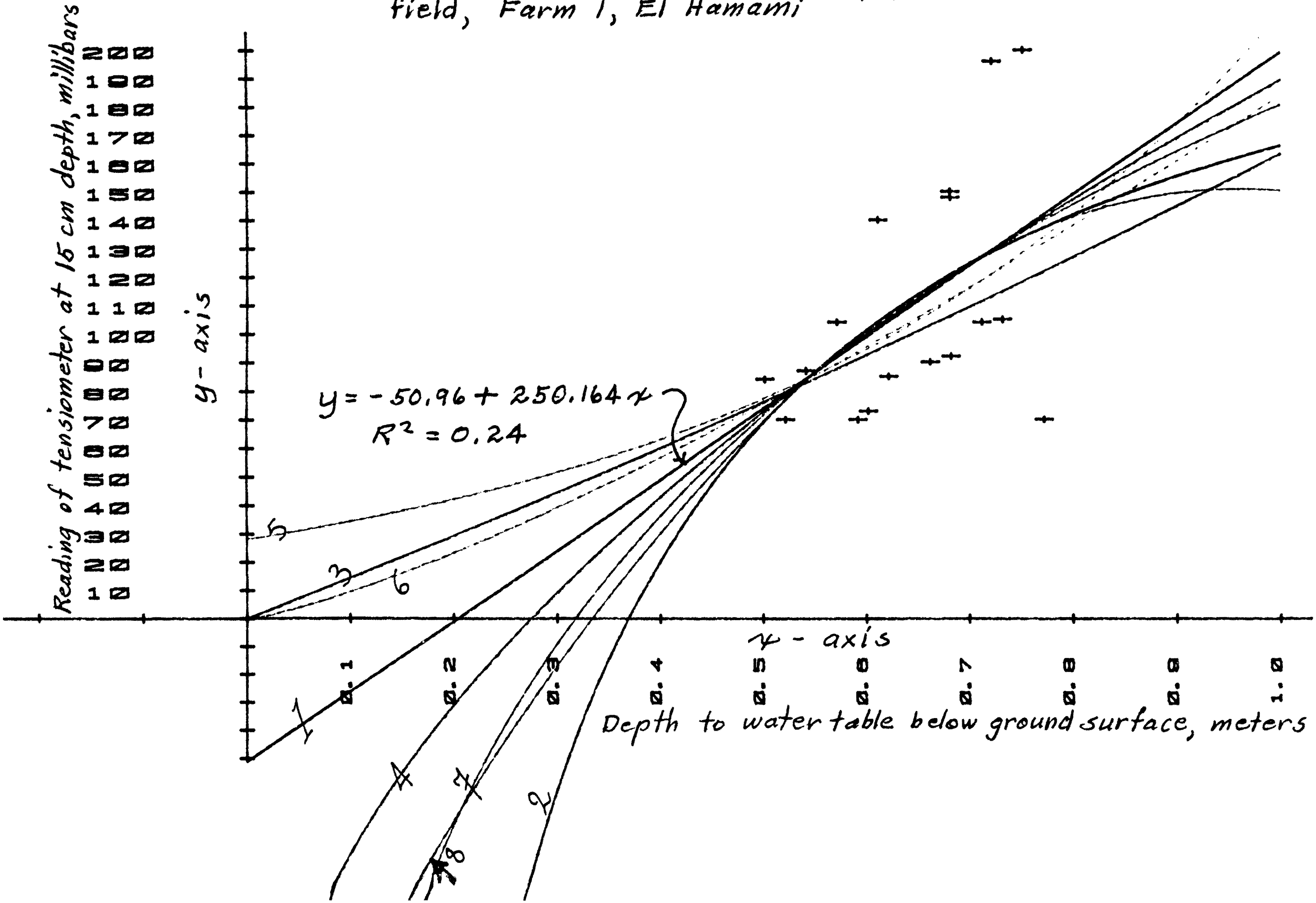


Figure 4. Tensiometer readings vs. water table depth during June, 1980 in a pepper field, Farm 1, El Hamami



$y = -50.96 + 250.164x$

$R^2 = 0.24$

mathematical projection of this recession curve predicted a level of 16.71 on Jan. 31, or about another 8 cm lower. The recession equation was $\text{Elev} = 16 + 1.11e^{-0.0145t}$, where "t" is time in days.

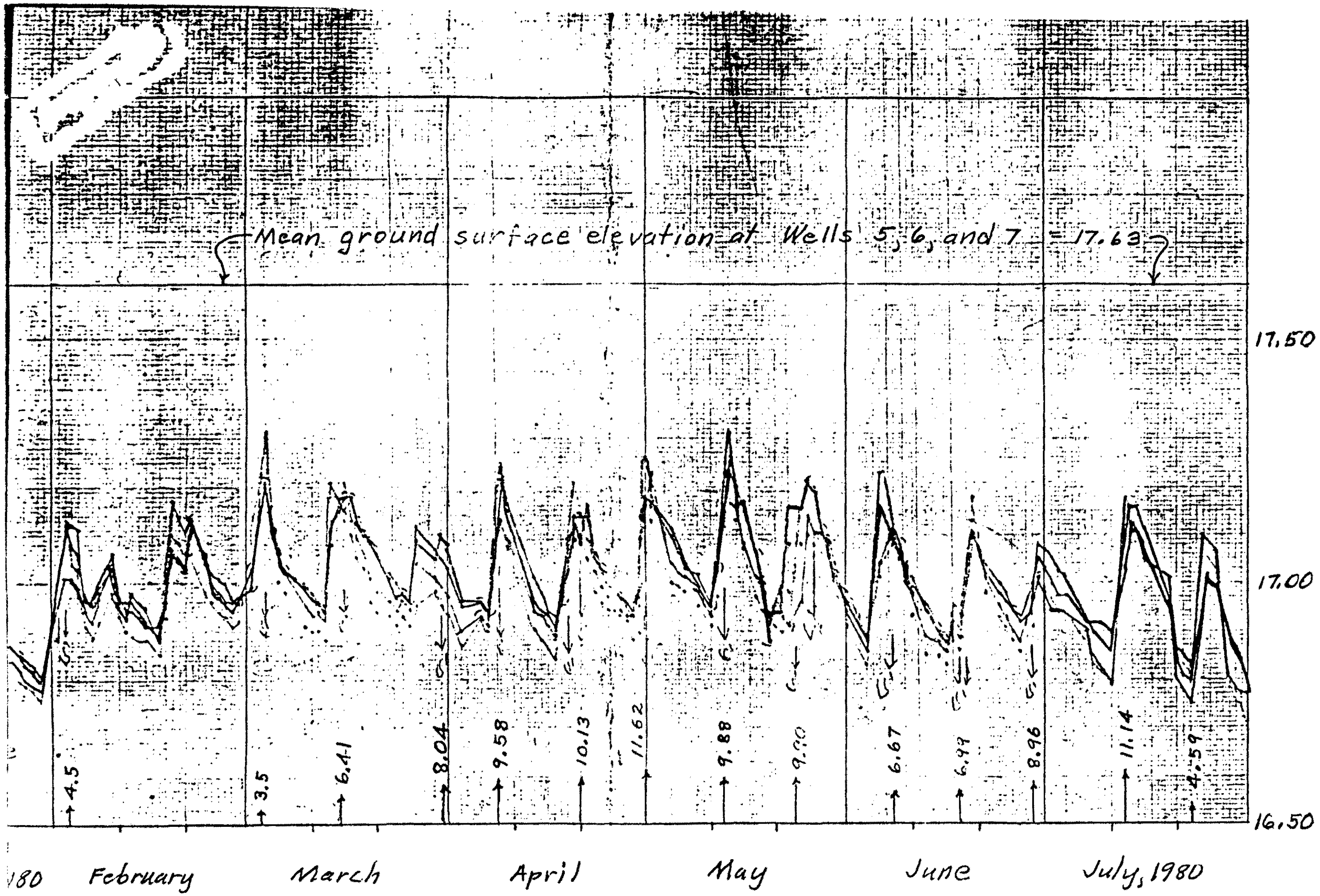
3. The water table rises during each on-period, even if there is no irrigation on this field (i.e. Dec. 1, Dec. 23, Feb. 18). However, the very heavy irrigation Sept. 7 may have been partly responsible for the high rise recorded on the 9th. Likely, however there was another greater influence which also caused the high peaks one either side.

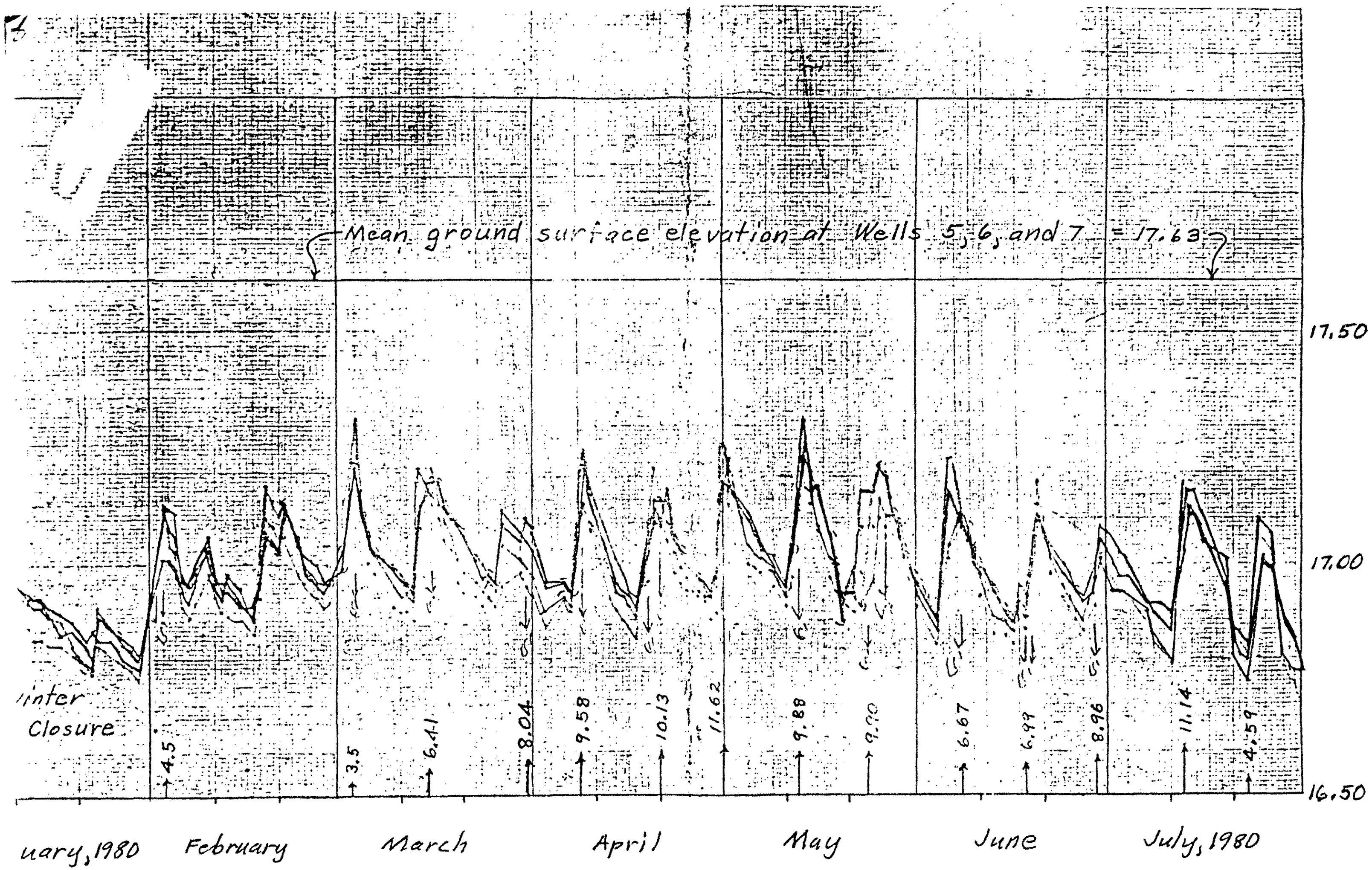
4. During the relatively steady flow period of October and November, the high's peaked about 17.5 and the lows about 16.9, for a range of 25 cm. However, during March, April, May, and part of June the highs peaked about 17.8 and the lows about 16.94, or about 3 or 4 cm higher than in October and November. Late in June and during July, both the highs and the lows dropped nearly 10 cm. The logical explanation for these changes is that the weeds increased in the spring in both the Hammami and Shimi branches, backing water to a higher level in the main Hammami Canal near Farm 1. Then the cleaning operation started in the Shimi and Hammami branches, permitting a lowering of the level in the canal (and in the groundwater level) at Farm 1.

The conclusions to be drawn from these observations is that the base level (the low points in the hydrograph) of the water table is determined by the level of water in the El Hammami Canal, its branches, and its meskas. Apparently this level is maintained mostly by seepage from the water courses. Even the high peaks, usually about 25 cm higher, are governed more by the water levels in the water courses than by the amount of irrigation application. Perhaps the same relationship exists in Beni Magdoul to a lesser degree, but because there is no rotation there, the hydrographs don't reveal it so clearly. Thus it appears that the water table in El Hammami cannot be lowered a great amount by the single effort of increasing application efficiency, although certainly this would help. What would help much more would be to decrease the conveyance loss in the El Hammami Canal and all ditches leading from it.

One could speculate that, if the proposed El Hammami pipeline could be installed with tight joints and little seepage, and if the meskas could likewise be replaced by pipelines, the water table would surely drop at least 20 cm at any farm situated like Farm 1. A greater than 20 cm drop might be expected on land closely affected by main drains.

There was one calculation made from the soil moisture data that could prove useful to the water budget calculations. Specific yield was calculated for the top 30 cm of soil in Farm 1 in El Hammami and Farm 5 in Beni Magdoul. The average moisture content measured about 3 days after irrigation was assumed to be field capacity. Bulk density was assumed to be the average measured for these respective areas, 1.68 for Farm 1, El Hammami and 1.217 for Farm 5, Beni Magdoul. Field capacity was 5.39 cm and 13.89 cm respectively. Particle density was assumed to be 2.65. From these values, specific yield was estimated as about 19% for El Hammami and about 5% for Beni Magdoul.

Mean ground surface elevation at Wells 5, 6, and 7 = 17.63
17.50
17.00
16.50
4.5
3.5
6.41
8.04
9.58
10.13
11.62
9.88
9.00
6.67
6.99
8.96
11.14
4.59
/80
February
March
April
May
June
July, 1980


Mean ground surface elevation at Wells 5, 6, and 7 = 17.63
17.50
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inter Closure
4.5
3.5
6.41
8.04
9.58
10.13
11.62
9.88
9.90
6.67
6.97
8.96
11.14
4.59
uary, 1980
February
March
April
May
June
July, 1980

Another set of interesting data recorded was the 1979-80 yield of berseem in Beni Magdoul (refer to Table 2) in terms of Egyptian pounds paid for the harvested crop. The first cutting from 6 kerat brought L.E. 42. The second and third cuttings were fed to the owner's animals. The fourth cutting sold for L.E. 30. The last cutting was primarily to clear the land for tomato cultivation, and brought only L.E. 5.

Conclusions

The following conclusions are based on the six questions adressed by this study.

1. There is over irrigation in both El Hammami and Beni Magdoul, sometimes in substantial amounts. In general, the amount is more than is needed to leach the salt contained in the irrigation water. However, not all fields measured received excessive total amounts, when you consider that some loss is inevitable. Most of the over irrigation results from too much water applied at a particular irrigation. In some crop seasons, most of the irrigations were excessive. In others there may have been one or no excessive irrigations. But usually there were several excessive and several not excessive. The planting irrigation was usually the heaviest, perhaps in part for leaching purposes.

2. The following average frequencies and amounts of irrigation were recorded:

	Beni Magdoul			El Hammami				
	Corn	Berseem	Berseem	Berseem	Tomato	Pepper	Squash	Cabbage
Number of irrigations	10	15	10	14	14	21	8	12
Frequency, days	11	14	22	14	12	15	8	13
Amount, cm	9.1	10.4	8.5	10.4	7.6	7.1	3.8	4.8

3. Soil moisture samples taken to a depth of only 30 cm before and after irrigation do not give an accurate estimate of the quantity of water extracted from the soil between irrigations. They gave a closer estimate of this quantity for short intervals, say 5 days, than for long intervals, say 21 days. The reason is believed due to the upward moisture gradient in the root zone. During the winter when ET is low, the moisture supplied from the water table apparently is almost enough to satisfy the entire ET requirement without irrigation.

4. In Farm 5, Beni Magdoul, the water table rises and falls with irrigations on that farm. The data contained in this report does not reveal the relative influence of conveyance loss on the position of the water table. However, in the sandy soil in El Hammami, the water table in Farm 1 seems to depend almost entirely on the rise and fall of water in the El Hammami Canal, during the rotation, regardless of the water applied to the farm. Therefore seepage from the water courses is the major factor.

5. The data in this report offers little evidence that either of the crops monitored with tensiometers suffered from water stress. Perhaps the first irrigation after planting on the corn field was delayed too long.

6. The measured depth to water table does not serve as an adequate index for deciding when it is time to irrigate.

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Staff Paper #32

SOCIOLOGICAL DATA OF THE PROJECT SITES: SOME CRITERIA FOR UNDERSTANDING THE IMPLEMENTATION PROCESS

The Sociology Team

September, 1980

The following report consists of a set of data which has been compiled for the purpose of (1) supplementing the two major sociological reports discussing the project areas and (2) providing a means in which crucial questions focusing on the implementation process have emerged. A general description of the areas have been presented in the following two reports:

- "Social Dimensions of Egyptian Irrigation Patterns"; and
- "Effective Extension for Egyptian Rural Development: Farmers' and Officials' Views on Alternative Strategies".

What will be presented here is more detailed data describing each project site with regard to certain crucial variables for their relationship to an implementation program. The set of variables used are organized under four categories: (1) demographic characteristics, (2) irrigation practices, (3) the farmers' level of integration with each other and (4) the farmers' receptivity toward change. These categories were chosen for their salience toward the implementation phase of the project. A few demographic characteristics were chosen in order to provide some data of the farmers in the areas and also to be used as a means to further examine some specific irrigation practices. An analysis of a few irrigation practices performed by the farmer will help delineate some activities and perceptions which will serve as an informational basis for creating specific change strategies and tactics. The last two categories provide some measures to depict the environment of the farmers with regard to how change in general may be facilitated or hindered. Again, the focus of this information will center on possible points which will serve as parameters for the work in the implementation phase of the project.

The format of the report consists mostly of tables with some introductory comments. Tables were used as the means by which data is presented in order to allow for the different disciplines involved in the project to make distinct judgements as to the meaning of the information. Such tables are supplemented with some general comments which delineate a few major questions which have to be considered in any examination of the proposed implementation programs. Hopefully through a thorough examination of the tables and comments by the different disciplines in concert with each other, some effective and meaningful procedures for implementation may evolve. What will now follow is the presentation of data divided into the four major categories of demographic characteristics, irrigation practices, farmers' integration, and farmers' receptivity to change.

DEMOGRAPHIC CHARACTERISTICS

The variables of concern in this category include the following:

- Family size
- Full time/part time operator
- Farm size
- Division of farm plots on the meska and in the villages

Such information which may evolve from these variables include a delineation of the labor force available in the area, the degree of time and commitment exhibited by the farmer concerning his operation, the degree of wealth of the farmers, and operation procedures of the farms. All of the above information has been viewed as indicators to explain the adoption of different innovations.

Table 1: Total Size of the Farmers' Household

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Number	1-5	12(52)	5(25)	11(35)
in	6-10	7(30)	13(65)	17(55)
Family	11 +	4(17)	2(10)	3(10)
	Total	23(100)	20(100)	31(100)

Table 2: Full Time/Part Time Operator

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Operator	Full Time	16(70)	20(100)	27(84)
	Part Time	7(30)	0(0)	5(16)
	Total	23(100)	20(100)	32(100)

Table 3: Total Feddans Farmed

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Number of Feddans	≤ 1.9	12(52)	1(5)	7(22)
	2.0-3.9	5(22)	7(35)	14(44)
	4.0-9.9	6(26)	9(45)	6(19)
	10≥	0(0)	3(15)	5(16)
	Total	23(100)	20(100)	32(100)

Table 4: Ownership Patterns

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Ownership	Owns All	15(65)	16(80)	27(84)
	Owns Most, Rents Some	4(17)	1(5)	0(0)
	Rents Most, Owns Some	4(17)	3(15)	0(0)
	Rents All	0(0)	0(0)	4(12)
	Uses Family Owned Land	0(0)	0(0)	1(3)
	Total	23(100)	20(100)	32(100)

Table 5: Division of Farming Plots

		Project Site		
	N (Col. %)	Mansouria	Kafr EL Sheikh	Minya
Division of Plots	Contiguous	7(30)	4(20)	5(16)
	Divided	16(70)	16(80)	27(84)
	Total	23(100)	20(100)	32(100)

Table 6: Plots Farmed in Other Villages

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Other Village Plots	None	12(52)	13(65)	28(87)
	Some	11(48)	7(35)	4(12)
	Total	23(100)	20(100)	32(100)

IRRIGATION PRACTICES/PERCEPTIONS

A number of questions were asked which measured specific aspects of the farmers' irrigation activities and their ideas pertaining to some of the conditions involved in those activities. The specific areas of concern include who irrigates, when the farmer irrigates, and the farmers' perception as to how satisfactory the irrigation system is in serving them. What is to follow is a general summation of the findings and the presentation of some questions which need to be addressed in designing an implementation project.

Concerning who irrigates, for both Mansouria and Kafr El Sheikh many members of the families participate in the irrigation of the fields (Table Minya is different in that the majority of the irrigation work is perfor only by the farmer himself (60%). When controlling for the size of farms in Minya, from less than one feddan to ten feddans, the farmers show no significant change in this pattern of work (Table 8). Thus there is no focus of farmer workers concentrating totally on the small farm plots.

The survey has shown a number of interesting findings pertaining to the time of irrigations. For the most part, the farmers in the three areas believe that the most important irrigations are during the planting and germination stages of the plant's life cycle. In Kafr El Sheikh this perception is less singular in nature with answers being distributed from pre-irrigation to irrgation at harvest time (Table 9). When controlling for the different crops in the areas, the perceptions of the farmers about the most important irrigations do change (Tables 10-12). Two irrigations were examined in more detail in the survey: pre-irrigation and the irrigation at planting. The majority of farmers did not perform a pre-irrigation, but in Mansouria the percentage of those who did is greater than in Kafr El-Sheikh or Minya (Table 13). Again, when controlling for crops the practices were different for each crop (Tables 14-15). For vegetables the farmers who did have a pre-irrigation were almost as many as those who did not while for berseem, a vast majority of farmers (75% in both Mansouria and Kafr El Sheikh) did not perform a pre-irrigation. When the size of the operation was controlled for (Tables 18-19), there may be a inverse relationship present; i.e. the larger the farm, the greater the probability of not having a pre-irrigation. The small N leaves such an inference highly questionable, but it is something which may be pursued.

Concerning the practice of irrigating at the time of planting, the majority of farmers say they do not irrigate (Table 20). However, Mansouria again shows the largest percentage of people who do irrigate. When controlling for crops (Tables 21-22) and size of holdings (Tables 25-26), the tendency of the relationships are similar to the ones for the farmers who have a pre-irriation for their fields. One additional question concerning the time of irrigation refers to whether or not the farmers irrigate at night (Tables 27-35). A majority of the farmers in Kafr El Sheikh (90%)

say they do, while a majority of the farmers are pretty well divided in half of those who do and those who do not. In looking at some possible explanations for these relationships, it was found that the position on the meska in Minya made little difference as to who does irrigate, and who does not. Other possible explanations for night irrigation may be the farmer's position of having plots in other villages and the size of the household (the greater the number the greater the probability in irrigating at night). Again, these relationships will have to be more fully analyzed in order to allow for any concrete inferences to be made. There does not seem to be any significant relationship between size of holdings and the practice of night irrigation. The major reason for night irrigation is the lack of sufficient water during the day (Table 35). The farmers were also asked how many times they irrigate their crops (Tables 36-39) and how they decide when to begin and stop the irrigation of their fields (Tables 40-41).

When asked if they believe that they receive an adequate amount of water for irrigation, the farmers on the whole stated that they did (Table 42). Kafr El Sheikh was the site which showed a more even distribution between those farmers who said they did receive an adequate amount and those who said they did not. When controlling for the location of the farmer's land on the meska, the tail end farmers in Kafr El Sheikh either said they always received enough (62%) or never received enough (38%). At the head, the majority of farmers stated that the water was generally not adequate in the summer (58%). (Table 43) Minya shows little difference between head, middle, and tail. As to the crops planted, farmers were not consistent in their belief about adequate water in any of the areas. Farmers planting the same crop; cotton in Kafr El-Sheikh, sugarcane in Minya, and wheat in Mansouria; have different ideas about receiving adequate water (Tables 44, 47, 49). Controlling for the size of farms (Tables 45, 48, 50) in the three areas shows that there might be a relationship in Kafr El Sheikh (the smaller the size, the greater the probability of having adequate water) but not in the other areas.

The farmers were then queried as to their beliefs about drainage, maintenance of ditches and the level of their land. Only in Mansouria did the farmers state their drainage was usually bad (Table 52). Regarding the maintenance of ditches and drains, the farmers in Minya and Kafr El Sheikh did not believe the private drains and ditches were maintained while in Minya the farmers also did not think the government ditches and drains were maintained (Tables 55 and 57). Finally, the farmers in all the areas generally thought that their fields were as level as they need be for irrigation purposes (Table 56).

One of the outputs of these general findings are the many questions which must be addressed when developing an implementation program; for the different strategies which may be developed in the program will depend on the circumstances permeating the area chosen to be the site of the project. The following list is an initial set of questions evolving from the data which should be taken into consideration.

To whom is the program to be directed?	– Who performs the actual irrigation of the fields? – What is the availability of labor in the area?
Upon which base will extension programs evolve?	– What is the level of knowledge of the farmer concerning the various practices in which he engages? – What is the difference of knowledge levels of the farmer throughout the area?
What are the real constraints toward changing behavior?	– What are the circumstances governing or explaining the particular activities of the farmer?
What must be addressed before programs are initiated?	– What are the perceptions of farmers as to their circumstances?

Table 7: Individuals Who Irrigate the Fields

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Irrigator	Farmer Himself	7(30)	3(15)	18(60)
	Farmer with Others (family, etc.)	12(52)	17(85)	7(23)
	Hired Help	4(17)	0(0)	5(17)
	Total	23(100)	20(100)	30(100)

Table 8: Total Feddans Farmed and the Persons Irrigating the Field - Minya

		Number of Feddans				
	N (Col. %)	< 1.9	2.0-3.9	4.0-9.9	10 +	Total
Irrigator	Farmer Himself	5(71)	10(71)	3(60)	0(0)	18(60)
	Farmer with Others	1(14)	3(21)	0(0)	3(60)	7(23)
	Hired Help	1(14)	1(7)	1(40)	2(40)	5(17)
	Total	7(100)	14(100)	4(100)	5(100)	30(100)

Table 9: Farmers' Perception of the Most Important Irrigation

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Irrigation Time	Pre-irrigation	1(4)	1(5)	0(0)
	Planting	7(31)	6(30)	23(72)
	Germination	12(52)	3(15)	3(9)
	Between Germ & Flowering	1(4)	1(5)	1(3)
	Flowering	0(0)	3(15)	0(0)
	Beginning of Seed	0(0)	4(20)	1(3)
	Later Seed & Fruit Dev.	2(8)	0(0)	2(6)
	Pre-harvest/ Harvest	0(0)	2(10)	2(6)
	Total	23(100)	20(100)	32(100)

Table 10: Cropping Pattern and Farmers' Perception of the Most Important Irrigation - Mansouria

		Crop			
	N (Col. %)	Wheat	Berseem	Vegetables	Total
Irrigation Time	Planting	0(0)	2(18)	5(72)	7(32)
	Germination	3(75)	8(73)	1(14)	12(55)
	Other	1(25)	1(9)	1(14)	3(13)
	Total	4(100)	11(100)	7(100)	22(100)

Table 11: Cropping Pattern and Farmers' Perception of the Most Important Irrigation - Kafr El Sheikh

		Crop			
	N (Col. %)	Cotton	Rice	Wheat	Total
Irrigation Time	Planting	5(56)	0(0)	1(50)	6(40)
	Germination	1(11)	0(0)	1(50)	2(13)
	Flowering	3(33)	0(0)	0(0)	3(20)
	Seed	0(0)	4(100)	0(0)	4(27)
	Total	9(100)	4(100)	2(100)	15(100)

Table 12: Cropping Pattern and Farmers' Perception of the Most Important Irrigation - Minya

		Crop				
	N (Col. %)	Cotton	Maize	Sugarcane	Other	Total
Irrigation Time	Planting	9(69)	7(100)	7(100)	0(0)	23(77)
	Germination	2(15)	0(0)	0(0)	1(33)	3(10)
	Latter Seed	2(15)	0(0)	0(0)	0(0)	2(7)
	Harvest	0(0)	0(0)	0(0)	2(67)	2(7)
	Total	13(100)	7(100)	7(100)	3(100)	30(100

Table 13: Pre-Irrigation Applied Before Plowing

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Pre-Irrigation	No	15(65)	16(80)	32(100)
	Yes	8(35)	4(20)	0(0)
	Total	23(100)	20(100)	32(100)

Table 14: Cropping Pattern and Pre-Irrigation Before Plowing - Mansouria

		Crop			
	N (Col. %)	Wheat	Berseem	Vegetables	Total
Pre-Irrigation	No	1(25)	9(82)	4(57)	14(64)
	Yes	3(75)	2(18)	3(43)	8(36)
	Total	4(100)	11(100)	7(100)	22(100)

Table 15: Cropping Pattern and Pre-Irrigation Before Plowing - Kafr El Sheikh

		Crop				
	N (Col. %)	Cotton	Rice	Wheat	Berseem	Total
Pre-Irrigation	No	11(100)	4(100)	1(25)	0(0)	16(80)
	Yes	0(0)	0(0)	3(75)	1(100)	4(20)
	Total	11(100)	4(100)	4(100)	1(100)	20(100)

Table 16: Size of Household and Pre-Irrigation Before Planting - Mansouria

		Size of Household			
N (Col. %)		1-5	6-10	11 +	Total
Pre-Irrigation	No	9(75)	4(57)	2(50)	15(65)
	Yes	3(25)	3(43)	2(50)	8(35)
	Total	12(100)	7(100)	4(100)	23(100)

Table 17: Size of Household and Pre-Irrigation Before Planting - Kafr El Sheikh

		Size of Household			
N (Col. %)		1-5	6-10	11 +	Total
Pre-Irrigation	No	3(60)	11(85)	2(100)	16(80)
	Yes	2(40)	2(15)	0(0)	4(20)
	Total	5(100)	13(100)	2(100)	20(100)

Table 18: Total Feddans Farmed and Pre-Irrigation Before Planting - Mansouria

		Number of Feddans				
N (Col. %)		< 1.9	2.0-3.9	4.0-9.9	10 +	Total
Pre-Irrigation	No	7(58)	4(80)	4(67)	0(0)	15(65)
	Yes	5(42)	1(20)	2(33)	0(0)	8(35)
	Total	12(100)	5(100)	6(100)	0(0)	23(100)

Table 19: Total Feddans Farmed and Pre-Irrigation Before Planting - Kafr El Sheikh

		Number of Feddans				
N (Col. %)		< 1.9	2.0-3.9	4.0-9.9	10 +	Total
Pre-Irrigation	No	1(100)	4(57)	9(100)	2(67)	16(80)
	Yes	0(0)	3(43)	0(0)	1(33)	4(20)
	Total	1(100)	7(100)	9(100)	3(100)	20(100)

Table 20: Fields Irrigated at Time of Planting

	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
		Project Site		
Irrigation	No	14(61)	17(85)	24(75)
	Yes	9(39)	3(15)	8(25)
	Total	23(100)	20(100)	32(100)

Table 21: Cropping Pattern and Irrigation at Time of Planting - Mansouria

	N (Col. %)	Wheat	Berseem	Vegetables	Total
		Crop			
Irrigation	No	2(50)	10(91)	1(14)	13(59)
	Yes	2(50)	1(9)	6(86)	9(41)
	Total	4(100)	11(100)	7(100)	22(100)

* Note (Kafr El Sheikh - All Rice)

Table 22: Cropping Pattern and Irrigation at Time of Planting - Minya

	N (Col. %)	Cotton	Maize	Sugarcane	Other	Total
		Crop				
Irrigation	No	11(79)	8(100)	3(43)	2(67)	24(75)
	Yes	3(21)	0(0)	4(57)	1(33)	8(25)
	Total	14(100)	8(100)	7(100)	3(100)	32(100)

Table 23: Size of Household and Irrigation at Time of Planting - Mansouria

	N (Col. %)	1-5	6-10	11 +	Total
		Size of Household			
Irrigation	No	7(58)	5(71)	2(50)	14(61)
	Yes	5(42)	2(29)	2(50)	9(39)
	Total	12(100)	7(100)	4(100)	23(100)

Table 24: Size of Household and Irrigation at Time of Planting - Minya

	N (Col. %)	Size of Household 1-5	6-10	11 +	Total
Irrigation	No	8(73)	13(76)	3(100)	24(77)
	Yes	3(27)	4(24)	0(0)	7(23)
	Total	11(100)	17(100)	3(100)	31(100)

Table 25: Total Feddans and Irrigation at Time of Planting - Mansouria

	N (Col. %)	Number of Feddans <1.9	2.0-3.9	4.0-9.9	10 +	Total
Irrigation	No	5(42)	5(100)	4(67)	0(0)	14(61)
	Yes	7(58)	0(0)	2(33)	0(0)	9(39)
	Total	12(100)	5(100)	6(100)	0(0)	23(100)

Table 26: Total Feddans Farmed and Irrigation at Time of Planting - Minya

	N (Col. %)	Number of Feddans <1.9	2.0-3.9	4.0-9.9	10 +	Total
Irrigation	No	5(71)	9(64)	5(83)	5(100)	24(75)
	Yes	2(29)	5(36)	1(17)	0(0)	8(25)
	Total	7(100)	14(100)	6(100)	5(100)	32(100)

Table 27: Farmers Irrigate at Night

	N (Col. %)	Project Site Mansouria	Kafr El Sheikh	Minya
Irrigate at Night	No	17(74)	2(10)	18(56)
	Yes	6(26)	18(90)	14(44)
	Total	23(100)	20(100)	32(100)
		Relative Frequency from 10-50%	Relative Frequency from 14-83%	Relative Frequency from 9-83%

Table 28: Farmer Meska location and Night Irrigation - Minya

		Location on Meska			
	N (Col. %)	Head	Middle	Tail	Total
Irrigate at Night	No	4(44)	8(100)	6(40)	18(56)
	Yes	5(56)	0(0)	9(60)	14(44)
	Total	9(100)	8(100)	15(100)	32(100)

Table 29: Farmer's Plots in Other Villages and Night Irrigation - Minya

		Plots in Other Villages		
	N (Col. %)	None	Some	Total
Irrigate at Night	No	18(64)	0(0)	18(56)
	Yes	10(36)	4(100)	14(44)
	Total	28(100)	4(100)	32(100)

Table 30: Size of Household and Night Irrigation - Minya

		Size of Household			
	N (Col. %)	1-5	6-10	11 +	Total
Irrigate at Night	No	7(64)	9(53)	1(33)	17(55)
	Yes	4(36)	8(47)	2(67)	14(45)
	Total	11(100)	17(100)	3(100)	31(100)

Table 31: Total Feddans Farmed and Night Irrigation - Minya

		Feddans Farmed				
	N (Col. %)	<1.9	2.0-3.9	4.0-9.9	10+	Total
Irrigate at Night	No	4(57)	8(57)	4(67)	2(40)	18(56)
	Yes	3(43)	6(43)	2(33)	3(60)	14(44)
	Total	7(100)	14(100)	6(100)	5(100)	32(100)

Table 32: Farmer's Plots in Other Villages and Night Irrigation - Mansouria

	N (Col. %)	Plots in Other Villages None	Some	Total
Irrigate at Night	No	9(75)	8(73)	17(74)
	Yes	3(25)	3(27)	6(26)
	Total	12(100)	11(100)	23(100)

Table 33: Size of Household and Night Irrigation - Mansouria

	N (Col. %)	Size of Household 1-5	6-10	11 +	Total
Irrigate at Night	No	9(75)	5(71)	3(75)	17(74)
	Yes	3(25)	2(29)	1(25)	6(26)
	Total	12(100)	7(100)	4(100)	23(100)

Table 34: Total Feddans Farmed and Night Irrigation - Mansouria

	N (Col. %)	Feddans Farmed <1.9	2.0-3.9	4.0-9.9	10+	Total
Irrigate at Night	No	9(75)	4(80)	4(67)	0(0)	17(74)
	Yes	3(25)	1(20)	2(33)	0(0)	6(26)
	Total	12(100)	5(100)	6(100)	0(0)	23(100)

Table 35: Circumstances When Night Irrigation is Performed

		Project Site Mansouria	Kafr El Sheikh	Minya
Irrigation Circumstances	Water not sufficient during day	5(63)	12(44)	14(100)
	Busy during day with other activities	1(12)	2(7)	0(0)
	Better for crop	1(12)	12(44)	0(0)
	Neighbors irrigate at night	1(12)	1(4)	0(0)
	Total	8(100)	27(100)	14(100)

Table 36: Number of Times Crops Will be Irrigated

		Project Site		
		Mansouria	Kafr El Sheikh	Minya
Number of Irrigations	4-8	2(9)	12(75)	6(19)
	9-11	8(36)	4(25)	14(44)
	12-15	5(23)	0(0)	9(28)
	14 +	7(32)	0(0)	3(9)
	Total	22(100)	16(100)	32(100)

Table 37: Cropping Pattern and Number of Times Crop is to be Irrigated - Mansouria

		Crop			
	N (Col. %)	Wheat	Berseem	Vegetables	Total
Number of Irrigations	4-8	1(25)	0(0)	0(0)	1(5)
	9-11	1(25)	7(64)	0(0)	8(38)
	12-13	1(25)	3(27)	1(17)	5(24)
	14 +	1(25)	1(9)	5(83)	7(33)
	Total	4(100)	11(100)	6(100)	21(100)

Table 38: Cropping Pattern and Number of Times Crop is to be Irrigated - Kafr El Sheikh

		Crop			
	N (Col. %)	Cotton	Wheat	Berseem	Total
Number of Irrigations	4-8	8(73)	4(100)	0(0)	12(75)
	9-11	3(27)	0(0)	1(100)	4(25)
	12-13	0(0)	0(0)	0(0)	0(0)
	14 +	0(0)	0(0)	0(0)	0(0)
	Total	11(100)	4(100)	1(100)	16(100)

Table 39: Cropping Pattern and Number of Times Crop is to be Irrigated - Minya

	N(Col. %)	Crop				
		Cotton	Maize	Sugarcane	Other	Total
Number of Irrigations	4-8	0(0)	3(38)	0(0)	3(100)	6(19)
	9-11	8(57)	5(62)	1(14)	0(0)	14(44)
	12-13	6(43)	0(0)	3(43)	0(0)	9(28)
	14 +	0(0)	0(0)	3(43)	0(0)	3(9)
	Total	14(100)	8(100)	7(100)	3(100)	32(100)

Table 40: Farmer's Deicision on When to Begin an Irrigation

	N (Col. %)	Project Site		
		Mansouria	Kafr El Sheikh	Minya
Decision Making Method	Time interval since last irrigation	9(13)	11(28)	29(73)
	Top soil appearance	22(33)	8(20)	3(7)
	Subsoil moisture inspection	0(0)	19(49)	1(2)
	Plant Appearance	23(35)	0(0)	6(15)
	Water Availability in Ditch	1(2)	0(0)	1(2)
	Access to Lifting Equip.	0(0)	1(3)	0(0)
	Hardness of Soil	10(20)	0(0)	0(0)
	Total	65(100)	39(100)	40(100)

Table 41: Farmer's Decision on When to Stop an Irrigation

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Decision Making Method	The total ground is covered	13(32)	6(24)	32(84)
	Water reaches a certain point in field	10(25)	14(56)	1(3)
	Depth of water in field	17(43)	4(16)	4(10)
	After a specified time period	0(0)	1(4)	1(3)
	Total	40(100)	25(100)	38(100)

Table 42: Farmer's Perception on Receiving Adequate Amount of Water

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Receives Adequate Water	Never	4(17)	3(15)	3(9)
	Usually not in summer	1(5)	7(35)	4(13)
	Usually always	18(78)	10(50)	25(78)
	Total	23(100)	20(100)	32(100)

Table 43: Farmer Meska Location and Adequacy of Irrigation Water - Kafr El Sheikh

		Location on Meska		
	N (Col. %)	Head	Tail	Total
Receives Adequate Water	Never	0(0)	3(38)	3(15)
	Usually not in summer	7(58)	0(0)	7(35)
	Usually always	5(42)	5(62)	10(50)
	Total	12(100)	8(100)	20(100)

Table 44: Cropping Pattern and Adequacy of Irrigation Water - Kafr El Sheikh

		Crop			
	N (Col. %)	Cotton	Rice	Wheat	Total
Receives Adequate Irrigation	Never	2(18)	0(0)	0(0)	2(11)
	Usually not in summer	6(54)	0(0)	1(25)	7(36)
	Usually always	3(28)	4(100)	3(75)	10(53)
	Total	11(100)	4(100)	4(100)	19(100)

Table 45: Total Feddans Farmed and Adequacy of Irrigation Water - Kafr El Sheikh

		Feddans Farmed				
	N (Col. %)	< 1.9	2.0-3.9	4.0-9.9	10 +	Total
Receives Adequate Water	Never	0(0)	1(14)	0(0)	2(67)	3(15)
	Usually not in summer	0(0)	2(29)	5(56)	0(0)	7(35)
	Usually always	1(100)	4(57)	4(44)	1(33)	10(50)
	Total	1(100)	7(100)	9(100)	3(100)	20(100)

Table 46: Farmer Meska Location and Adequacy of Irrigation Water - Minya

		Location on Meska			
	N (Col. %)	Head	Middle	Tail	Total
Receives Adequate Water	Never	0(0)	0(0)	3(20)	3(9)
	Usually not in summer	2(22)	1(12)	1(7)	4(13)
	Usually always	7(78)	7(88)	11(73)	25(78)
	Total	9(100)	8(100)	15(100)	32(100)

Table 47: Cropping Pattern and Adequacy of Irrigation Water - Minya

		Crop				
	N (Col. %)	Cotton	Maize	Sugarcane	Other	Total
Receives Adequate Water	Never	1(7)	1(12)	1(14)	0(0)	3(9)
	Usually not in summer	1(7)	0(0)	3(43)	0(0)	4(13)
	Usually always	12(86)	7(88)	3(43)	3(100)	25(78)
	Total	14(100)	8(100)	7(100)	3(100)	32(100)

Table 48: Total Feddans Farmed and Adequacy of Irrigation Water - Minya

		Feddans Farmed				
	N (Col. %)	<1.9	2.0-3.9	4.0-9.9	10 +	Total
Receives Adequate Water	Never	0(0)	3(21)	0(0)	0(0)	3(9)
	Usually not in summer	0(0)	2(14)	1(17)	1(20)	4(13)
	Usually always	7(100)	9(65)	5(83)	4(80)	25(78)
	Total	7(100)	14(100)	6(100)	5(100)	32(100)

Table 49: Cropping Pattern and Adequacy of Irrigation Water - Mansouria

		Crop			
	N (Col. %)	Wheat	Berseem	Vegetables	Total
Receives Adequate Water	Never	1(25)	2(18)	1(14)	4(18)
	Usually not in summer	1(25)	0(0)	0(0)	1(4)
	Usually always	2(50)	9(82)	6(86)	17(78)
	Total	4(100)	11(100)	7(100)	22(100)

Table 50: Total Feddans Farmed and Adequacy of Irrigation Water - Mansouria

		Feddans Farmed				
	N (Col. %)	< 1.9	2.0-3.9	4.0-9.9	10 +	Total
Receives Adequate Water	Never	1(8)	0(0)	3(50)	0(0)	4(17)
	Usually not in summer	0(0)	0(0)	1(17)	0(0)	1(4)
	Usually always	11(92)	5(100)	2(33)	0(0)	18(79)
	Total	12(100)	5(100)	6(100)	0(0)	23(100)

Table 51: Farmer's Perception on Adequate Timing of Water Delivery

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Adequate Timing	Not adequate	3(13)	2(10)	0(0)
	Adequate in winter only	7(30)	2(10)	2(6)
	Usually adequate	13(57)	16(80)	30(94)
	Total	23(100)	20(100)	32(100)

Table 52: Farmer's Perception of Adequate Drainage

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Drainage	Usually bad	14(61)	0(0)	8(25)
	Sometimes bad	2(9)	6(30)	3(9)
	Not bad	7(30)	14(70)	21(66)
	Total	23(100)	20(100)	32(100)
		Estimate of Water Table: 60-300 cm	Estimate of Water Table: 20-200 cm	Estimate of Water Table: 50-500 cm

Table 53: Farmer Meska Location and Perception of Adequate Drainage - Kafr El Sheikh

		Location on Meska		
	N (Col. %)	Head	Tail	Total
	Usually bad	0(0)	0(0)	0(0)
Drainage	Sometimes bad	6(50)	0(0)	6(30)
	Not bad	6(50)	8(100)	14(70)
	Total	12(100)	8(100)	20(100)

Table 54: Farmer Meska Location and Perception of Adequate Drainage - Minya

		Location on Meska			
	N (Col. %)	Head	Middle	Tail	Total
	Usually bad	1(11)	3(38)	4(26)	8(25)
Drainage	Sometimes bad	2(22)	1(12)	0(0)	3(9)
	Not bad	6(67)	4(50)	11(74)	21(66)
	Total	9(100)	8(100)	15(100)	32(100)

Table 55: Farmers' Perception: Adequacy of Maintenance of Private Ditches and Drains

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Ditches Adequately Maintained	Yes	19(83)	6(30)	1(3)
	No	4(17)	14(70)	31(97)
	Total	23(100)	20(100)	32(100)

Table 56: Farmers' Perception: Fields Are as Level as They Should Be for Good Irrigation

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Level of Field Adequate	Yes	18(78)	20(100)	18(56)
	No	5(22)	0(0)	14(44)
	Total	23(100)	20(100)	32(100)

Table 57: Farmers' Perception: Adequacy of Maintenance of Government Ditches and Drains

	N (Col. %)	Project Site Mansouria	Kafr El Sheikh	Minya
Ditches Adequately Maintained	Yes	16(70)	19(95)	0(0)
	No	7(30)	1(5)	32(100)
	Total	23(100)	20(100)	32(100)

INTEGRATION OF FARMERS AMONG THEMSELVES AND THEIR RECEPTIVITY TO CHANGE

One of the major components of the pilot programs is that of the organization of farmers for some collective action pertaining to the irrigation of their fields. Questions were asked of the farmers to initally see if any type of cooperation existed and how they viewed change. Knowledge of both conditions is necessary to develop strategies pertaining to the changing of a particular type of behavior, especially when that behavior will require a collective change. The results of survey show that there is a distinct predisposition for collective action and change in the areas of study. How this predisposition can be positively exploited will need to be examined as the pilot programs develop. Tables 58-70 present some of the findings pertaining to farmer cooperation and receptively to change.

Table 58: Number of Families (Related) Visited by Respondent

	N (Col. %)	Project Site Mansouria	Kafr El Sheikh	Minya
Number of Families	0-3	4(17)	4(20)	11(34)
	4-6	8(35)	8(40)	5(16)
	7-15	6(26)	7(35)	8(25)
	16 +	5(22)	1(5)	8(25)
	Total	23(100)	20(100)	32(100)

Table 59: Number of Families (Not Related) Visited by Respondent

Project Site

	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Number of Families	0-3	11(48)	8(40)	9(28)
	4-6	6(26)	6(30)	12(38)
	7-15	4(17)	2(10)	7(22)
	16 +	2(9)	4(20)	4(12)
	Total	23(100)	20(100)	32(100)

Table 60: Number of Families (Related) Which the Respondent Exchanged Animals, Tools, etc.

Project Site

	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Number of Families	None	3(12)	1(5)	13(41)
	1-3	10(44)	5(25)	9(28)
	4-9	5(22)	12(60)	7(22)
	10 +	5(22)	2(10)	3(9)
	Total	23(100)	20(100)	32(100)

Table 61: Number of Families (Not Related) Which the Respondent Exchanged Animals, Tools, etc.

Project Site

	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Number of Families	None	10(44)	4(20)	11(34)
	1-3	4(17)	10(50)	12(38)
	4-9	6(26)	3(15)	6(19)
	10 +	3(13)	3(15)	3(9)
	Total	23(100)	20(100)	32(100)

Table 62: Number of Families (Related) Which the Respondent Exchanged Work

			Project Site	
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
	None	16(69)	4(20)	9(28)
Number of Families	1-2	3(13)	3(15)	7(22)
	3-4	2(9)	5(25)	10(31)
	5 +	2(9)	8(40)	6(19)
	Total	23(100)	20(100)	32(100)

Table 63: Number of Families (Not Related) Which the Respondent Exchanged Work

			Project Site	
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
	None	16(69)	6(30)	11(34)
Number of Families	1-2	2(9)	4(20)	7(22)
	3-4	2(9)	6(30)	8(25)
	5 +	3(13)	4(20)	6(19)
	Total	23(100)	20(100)	32(100)

Table 64: Respondents' Answers to the Statement: "On Important Things, People Line Up on Opposite Sides"

			Project Site	
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Respondent's Answer	Agree	5(22)	5(25)	0(0)
	Not sure	0(0)	0(0)	7(22)
	Disagree	18(78)	15(75)	25(78)
	Total	23(100)	20(100)	32(100)

Table 65: Respondents' Answers to the Statement: "Even When Something Seems Like a Good Idea, People Will Not Move"

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Respondent's Answer	Agree	5(22)	5(25)	6(19)
	Not sure	0(0)	0(0)	3(9)
	Disagree	18(78)	15(75)	23(72)
	Total	23(100)	20(100)	32(100)

Table 66: Respondents' Answers to the Statement: "People Often Change Sides of an Issue as it Develops"

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Respondent's Answer	Agree	23(100)	19(95)	29(91)
	Disagree	0(0)	1(5)	3(9)
	Total	23(100)	20(100)	32(100)

Table 67: Respondents' Answers to the Statement: "The Effect Required to Change Things is Often Greater than the Benefit"

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Respondent's Answer	Agree	2(9)	1(5)	4(12)
	Not sure	0(0)	0(0)	2(6)
	Disagree	21(91)	19(95)	26(81)
	Total	23(100)	20(100)	32(100)

Table 68: Respondents' Answers to the Statement: "There is More Profit in Farming by Following the Newest Recommendations"

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Respondent's Answer	Agree	23(100)	20(100)	32(100)
	Not sure	0(0)	0(0)	0(0)
	Disagree	0(0)	0(0)	0(0)
	Total	23(100)	20(100)	32(100)

Table 69: Respondents' Answers to the Statement: "Accept Life Around Us as God's Will - Do Not Try to Change It"

		Project Site		
	N (Col. %)	Mansouria	Kafr El Shiekh	Minya
Respondent's Answer	Agree	6(26)	2(10)	4(12)
	Not sure	0(0)	1(5)	10(31)
	Disagree	17(74)	17(85)	18(56)
	Total	23(100)	20(100)	32(100)

Table 70: Respondents' Answers to the Statement: "Old Ways are Generally the Best Ways"

		Project Site		
	N (Col. %)	Mansouria	Kafr El Sheikh	Minya
Respondent's Answer	Agree	3(13)	3(15)	0(0)
	Not sure	0(0)	0(0)	0(0)
	Disagree	20(87)	17(85)	32(100)
	Total	23(100)	20(100)	32(100)

The previous set of data is to serve as an initial picture of the social situation of the farmer in the sites where the pilot programs are to be established. There are other types of information which have to be collected in order to complete the picture; yet the data in this staff paper, supplementing the two major papers previously addressed, presents to the sociological team a set of parameters which can be used in helping to design the pilot programs.

Staff Paper #33

ANALYSIS OF SOIL WATER DATA COLLECTED FROM WINTER CROPS IN EL MINYA 1979-80

Agronomy Discipline of El Minya and
Main Office Cairo
Abdel Sattar, A. Taher & R. Tinsley

This report presents 20 tables reviewing the soil water data collected in El Minya during winter season 1979-80 for four crops. The report is submitted to illustrate what soil water data is currently being collected, how it is being analyzed, and some interpretations of the analysis. This report also serves as a first approximation for developing a standard procedure of soil water analysis, most of which could be done at the site location. For this reason we solicit any comments on how helpful these tables are and what additional tables and interpretations would be more useful for each discipline.

The first set of tables (Table 1-4) is a record for each crop of the irrigations starting with planting as 1st and continuing to harvest. the tables show the volume of soil water to 90 cm depth in the soil one day before and three days after each irrigation. The three days after irrigation represent the usual time allowed for a wetting front to become distributed through the soil profile. The tables continue to show the volume of water applied, the volume of water stored after three days for each irrigation and then a calculation of irrigation application efficiency. This is based on the water stored after three days and the water applied. It does not account for the water used during the four days between samplings. Thus the actual efficiency is somewhat greater than shown. The irrigation application efficiency shows more variation than would be desirable. They also are substantially higher than expected even going over 100% on a couple occasions. This contrast with the usual surface irrigation application efficiency which will range around 60%. The high values are not completely impossible. There are several possible sources of reasonable error that can have a multiplicative compounding effect. Some of this will be discussed later.

The final portion of the main body of Tables 1-4 relates to soil water depletion between irrigations. This value is calculated as a difference between soil water after one irrigation and before the next irrigation. The value should represent the "consumptive use" of plants plus any continual deep percolation. This is finally expressed as daily soil water depletion value. The numerical value of the daily soil water depletion appears reasonable close to expected "consumptive use". This would indicate that the deep percolation after three days was relatively small. However, the values are considerably less than the Blanney-Criddle values used for calculated consumptive use at other project locations, with less evaporation energy than in Minya.

.../...

At the bottom of the tables are some summary information on the total water depletion which is the sum of the soil depletion values plus a correction to account for the unaccounted four days between sampling. This is then used to calculate a water production index that shows the production per unit of water lost.

Table 5 is a brief summary of the daily soil water depletion for all crops studied. The values are mostly taken from Tables 1-4 assigned to the month that most nearly corresponds to the irrigation interval involved. The maximum value obtained for any crop is shown at the left along with a letter indicating which crop. This value may be useful in water budget determinations, as the value to use that will accommodate all crop requirements. Likewise they may be useful in an initial estimate of the total water needed in a given month, and coupled with the amount of water released into the canal, provide the first crude approximation of excessive water use. This could than become an realistic initial target for improvement.

Tables 6 to 9, are a closer look at soil water depletion values for each crop. These tables show how much of the water depletion is coming from the upper 30 cm of the soil. This is the area with the highest concentration of roots and from which most of the water is extracted by the plants. As expected this shows that most of the water loss is coming from this zone. The range is from slightly under 50% all the way to the upper 80 or 90 percent. Most values were between 50 and 75% of total water loss. All the water depleted was not consumptive use as the value of 111% indicates (Table 7). In this case some water continued to percolate from the upper horizons and accumulated in the lower horizons during the inter-irrigation period. These tables illustrate the need to concentrate on the upper 30 cm, but not to the exclusion of the lower horizons.

Table 10 and 11 show the changes in soil water from irrigation to irrigation. The tables illustrate a general but not conclusive trend toward wetter conditions as the season progresses. This could indicate a certain degree of over irrigation. It is interesting to observe that the soil water in the 60-90 cm depth does not change appreciably after the first irrigation, and is not affected by irrigation during the crop season. Also the average moisture of the 30-60 cm depth is usually higher than the soil water in the 60-90 cm depth. This could be attributed to the tendency of increasing alkalinity and bulk density with depth. Table 10 shows the data in terms of percent dry weight while Table 11 has this converted to % by volume and summed for the 90 cm of soil to give cm H_2O/90 cm soil. This table also shows only a general non-conclusive trend for wetter soil profiles both before and after the different irrigations.

Table 12 and Fig. 1 show the soil water characteristics of soils in El Minya as measured with pressure plates. The values represent an average of 6 represenive profiles. The determinations were made using disturbed samples. This would effect the values obtained from the lower tensions. The samples were originally taken at 30 cm intervals, but the similarity in values for the lower three justified the lumping together into a 0-30 cm and 30-120 cm fractions. From the data it is observed that there is only a slight decrease in soil moisture content by increasing suction from 0.33 to 1 bar i.e., from field capacity to maximum irrometer reading.

Table 12 is really to be used in connection with Tables 13 to 16 to illustrate the moisture tension range over which the systems were operating. This shows that irrigation was usually applied when the soil in the upper 15 cm was between 3 and 15 atmosphere, and after irrigation the soil was between 0.1 and 0.33 atmosphere which is above "field capacity". Lower horizons were generally wetter usually staying wetter than 0.33 to 1 atmosphere tension even just prior to irrigation. This is generally wetter than may be desired and indicates a need to consider longer intervals between irrigation. Unless the increasing alkalinity and bulk density problems hinder water uptake.

The generally wet conditions raise the question of possible aeration problems. Tables 13 to 16 attempt to show this by looking at the percent of the soil which is mineral adding the percent water by volume and substracting from 100. This showed the possibility of saturated condition frequently occuring even in the 15-30 cm depth, and almost continuous saturation below this. This is surprising because the water table is supposed to be 1.5 to 2.0 m below ground level. If this is the case the data indicates either a very large capillary fringe or a perched water table within the first meter, that is not being picked up by the 3 m observation wells. These possible saturated conditions in the sub-soil 1 meter above the water table could be associated with the dispersion and compaction of the alkaline clay. If the soils are indeed saturated below 30 cm there could be a severe aeration problems. This should be examined with some root samples for each crop, and observing influence of irrigation on the water table.

One problem with the aeration data is that frequently the sum of mineral plus water would exceed 100% to even reach almost 120%. This would indicate a systematic error. The most likely place would be in bulk density determinations. The bulk density values particularly at lower depths were actually higher than expected with values of 1.20 at the top and 1.47 at the bottom. Errors under these conditions may be due to either sampling procedure or problems in getting a constant weight in drying these hydrated clays. Also, determination of bulk density could change depending on soil moisture content at sampling time.

Table 17 is a puttering around table looking for some consistency upon which long range project strategy could be developed. None of the parameters examined showed any real promise. It would be very convenient if there was some consistency in the water applied. However, this may improve in other areas where lift irrigation is required. The farmers may then either run their animals or pumps for a relatively stable time period and in the process apply water in uniform increments. The other value of real potential for planning is the intervals between irrigations. But consistency here was also lacking. The other parameters really have little practical potential for use.

.../...

The last three tables are intended to review some of the problems in soil water measurements and analysis. Tables 18 and 19 review the reliability of soil moisture measurements. This is an outgrowth of the concern for irrigation application efficiency data and the contribution soil moisture measurements would have. To look at this, nine replicates of soil moisture were taken from two recently planted cotton fields both before and after irrigation. The results were averaged, along with the standard deviation and coefficient of variation. Table 18 shows this with the soil moisture expressed on a dry weight basis. The data looks about as reliable as you can expect from a biological or natural physical setting. Most of the standard deviation are in the order of 2 percentage points with an overall C.V. of 5 percent. However, there can be some compounding effect by which a small error when summed through the entire profile could still contribute to substantial error in application efficiency. Thus Table 19 was made to show the water on a volumetric bases and the effect on the entire profile was examined. As expected there was some within profile compensation between different levels, so that the C.V. for the total volume of water in the profile was usually considerable less than the different depths taken separately. The C.V. were thus in the order of 2 to 3% and the S.D. in order to 1 to 1.25 cm. However, when the applied water is of the order of 10 cm this could cause an error of 10 to 12 percent.

Other sources of error in measuring water application efficiency could be in use of flumes. This is particularly a problem when flumes are temporary and reinstalled for each irrigation. Bill Ree reviewed this problem and developed an HP 67 program to determining the flow error for different errors in h_b. This indicated that for a flume with 20 cm throat, and 10 cm h_a near submergence the error of ½ cm in h_b, as would occur in reasonable misalignment of a temporary flume due to settling after placement, would be 10 or 20% depending on which way the error was. This added to the 10% error in soil water could bring the error to the 20-30% range.

The last table shows some of the inconsistency in using tensiometers for measuring soil water. This simply shows that tensiometers are not a vigerous research tool, and never were intended to be such. They are subject to good deal of systematic error, particularly in a hydrated clay soil that cracks and heaves with wetting and drying. Also as indicated in Table 12 for the El Minya soils the full range of the tensiometer remains in neighborhood of "field capacity". This data is not intended to indicate tensiometers should not be used, but only the appropriate amount of skepticism that is required when relying on them.

This concludes the report. There are no conclusions to be drawn at this time other than the commentary presented. Again it is requested that any comments or ideas for improvement be forwarded to us. This will assist us in formalizing a standard procedure for soil water evaluation.

Table 1. Irrigation and Soil Water Depletion Summary for Wheat in El Minya Winter 1979-1980

Irrigation	Sample date	Soil water before/ after	Soil water change	Water applied	Irrigation application efficiency	Soil water depletion between Irrigations	Days between readings	Soil water Depletion per day
		--cm H_2O/90 cm--		cm	%	cm/90 cm		cm
1st	Before:Dec. 3, 1979	37.80						
	After:Dec. 6, 1979	46.60	8.75	11.69	74.8			
						5.16	21	0.25
2nd	Before:Dec. 27, 1979	41.44						
	After:Jan. 1, 1980	52.28	10.84	7.02	154.4			
						4.88	32	0.15
3rd	Before:Feb. 2, 1980	47.40						
	After:Feb. 7, 1980	54.11	6.71	7.67	87.5			
						7.35	31	0.35
4th	Before:Feb. 28, 1980	46.76						
	After:Mar. 2, 1980	52.94	6.18	---	---			
						7.78	17	0.46
5th	Before:Mar. 19, 1980	45.16						
	After:Mar. 23, 1980	52.23	7.07	13.58	52.1			
						2.97	12	0.25
6th	Before:April 4, 1980	49.26						
	After:April 9, 1980	53.42	4.16	9.55	43.5			
						10.38	33	0.31
	Harvest May 12, 1980	43.04						

Total water loss 38.51 = 7.1[1/] = 45.61

[1/] To account for water used during irrigation period calculated by taking daily soil depletion for previous period x 4 for days between before and after irrigation measurement.

Total growing season 161 days

Total water loss 45.62 cm = 1915.6 m^3/f

Yield: 13.26 ± 2.03 Ardab/F. grain c.v. 15% plus
5.8 ± 0.61 T/F straw c.v. 10%

$$\text{Water production index} = \frac{\text{Yield}}{\text{Water loss}} = \frac{13.26 + 5.8}{1915.6} = .069 \text{ Ardebs grain} + 3.0 \text{ kg straw/m}^3\text{H}_2\text{0}$$

Table 2. Irrigation and Soil Water Depletion for Broadbeans in El Minya Winter 1979-80

Irrigation	Sample date	Soil water Before/after	Soil water change	Water applied	Irrigation application efficiency	Soil water depletion between Irrigations	Days between readings	Soil water Depletion per day
		--cm H_2O/90 cm--		cm	%	cm		cm
1st	Before:Nov. 9, 1979	37.89						
	After:Nov. 13, 1979	50.98	13.09	--	--			
						7.67	43	0.18
2nd	Before:Dec. 29, 1979	43.31						
	After:Jan. 2, 1980	48.24	4.93	5,61	88			
						2.65	44	0.06
3rd	Before:Feb. 15, 1980	45.59						
	After:Feb. 19, 1980	50.95	5.36	5,39	99			
						6,42	30	0.21
4th	Before:Mar. 20, 1980	44.53						
	After:Mar. 23, 1980	49.84	5.31	--	--			
						5.11	26	0.20
	Harvest Apr. 18, 1980	44.73						
					Total soil water depletion	21.85 = 2.60[1/]		

1/ To account for water use during irrigation period calculated by taking the daily soil depletion of the previous period x 4 for the days between before and after irrigation sampling.

Total growing period 151 days Total water loss 24.45 cm = 1027 m^3/F

Yield: 9.68 ± 0.76 Ardabs/F seed c.v. 7.9%
3.56 ± 0.07 T/F stran c.v. 1.9%

$$\text{Water production index} = \frac{\text{Yield}}{\text{water loss}} = \frac{9.68 + 3.56}{1027} = 0{,}0094 \text{ Ardabs seed} + 3.5 \text{ kg straw/m}^3$$

Table 3. Irrigation and Soil Water Depletion Summary for Onions in El Minya - Winter 1979-80

Irrigation	Sample date	Soil water Before/after	Soil water change	Water applied	Irrigation application efficiency	Soil water depletion between Irrigations	Days between readings	Soil water Depletion per day
		--cm H_2O/90 cm--		cm	%	cm		cm
1st	Before:Nov. 25, 1979	46.43						
	After:Nov. 29, 1979	53.78	7.35	9.71	76			
						4.26	37	0.12
2nd	Before:Jan. 2, 1980	49.52						
	After:Jan. 5, 1980	58.33	8.81	10.86	81			
						7.95	33	0.24
3rd	Before:Feb. 7, 1980	50.38						
	After:Feb. 10, 1980	54.90	4.51	5.21	86			
						4.58	15	0.31
4th	Before:Feb. 27, 1980	50.32						
	After:Mar. 1, 1980	54.61	4.29	5.13	83			
						8.92	45	0.20
	Harvest Apr. 15, 1980	45.69						

Total soil water depletion 25.70 + 3.48[1/] = 29.18

1/ To account for water used during irrigation period calculated by taking the daily soil depletion of previous period x 4 for days between before and after irrigation sampling.

Total growing period 142 days Total water loss 29.18 = 1226 m^3/F

Yield: 13.04 ± 0.77 T/F c.v. 5.89 n = 4 10% Discount for channels = 12.06 T/F

$$\text{Water production index} = \frac{\text{Yield}}{\text{Water loss}} = \frac{12.060}{1226} = 9.84 \text{ kg onions/m}^3\ H_2O$$

Table 4. Irrigation and Water Loss Summary for Broad bean/Sugarcane in El Minya Winger 1979-80

Irrigation	Sample date	Soil water Before/after	Soil water change	Water applied	Irrigation application efficiency	Soil water depletion between Irrigations	Days between readings	Soil water Depletion per day
		--cm H_2O/90 cm--		cm	%	cm		cm
1st	Before:Oct. 22, 1979	32.51						
	After:Oct. 31, 1979	49.01	16.50	15.0	110			
						4.94	17	0.29
2nd	Before:Nov. 17, 1979	44.07						
	After: Nov. 23, 1979	49.14	5.07	9.0	57			
						6.21	37	0.17
3rd	Before:Dec. 30, 1979	42.93						
	After:Jan. 4, 1980	50.59	7.66	8.0	95			
						4.86	40	0.12
4th	Before:Feb. 12, 1980	45.73						
	After:Feb. 15, 1980	52.63	6.90	9.0	77			
						7.78	27	0.29
5th	Before:Mar. 13, 1980	44.85						
	After:Mar. 18, 1980	50.76	5.91	14.0	43			
						8.90	28	0.32
	Harvest Apr. 15, 1980	41.86						
					Total soil depletion	32.69 + 4.76[1] = 37.45		

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[1] To account for water use during irrigation period, calculated by taking the daily soil depletion of the previous period x 4 for the days between the before and after irrigation sampling.

Total growing period for broad bean 171 days Total water loss 37.45 cm = 1572.0 m^3/f

Yield: 7.11 to 0.72 Ardabs/F seed c.v. 10% + 2.64 ± 0.45 T/F straw c.v. 17%

$$\text{Water production index} = \frac{\text{Yield}}{\text{water loss}} = \frac{7.11 + 2.64 \text{ x sugar}}{1572} = 0.0045 \text{ Ardabs seed} + 1.7 \text{ kg straw} + \text{sugarcane}/m^3 H_2O$$

Table 5. Daily Soil Water Depletion for Winter Crops in El Minya 1979-1980

Approx. months	Sugarcane/ Broadbean	Wheat	Broadbean	Onions	Max
	------------------------cm/day------------------------				
November	0.29				
December	0.17	0.25	0.18	0.13	0.25 W
January	0.12	0.15	0.06	0.24	0.24 O
February	0.29	0.35	--	0.31	0.35 W
March	0.32	0.37*	0.21	0.20	0.37 W
April		0.31	0.20		
Gross Ave.	0.24	0.29	0.16	0.22	

* Weighted average of water depletion between 4th and 6th irrigation

Table 6. El Minya Soil Water Depletion from Upper 30 cm - Wheat During Winter 1979-80

Soil Depth	Volume of Soil Water After previous	 Before Current	Water Depletion Specific Horizon	 Total Profile (90cm)	% of Total
	------------------------------	------------------------------	cm	------------------------------	------------------------------
		From 1st to 2nd Irrigation			
0-15	8.86	4.97	3.89	5.16	75
15-30	7.95	6.79	1.16		22
		Total	5.05		97
		From 2nd to 3rd Irrigation			
0-15	8.54	6.15	2.39	4.88	49
15-30	8.76	7.08	1.68		34
		Total	4.07		83
		From 3rd to 4th Irrigation			
0-15	9.91	6.21	3.70	7.35	50
15-30	9.24	8.18	1.06		14
		Total	4.76		65
		From 4th to 5th Irrigation			
0-15	8.96	6.18	2.78	7.78	36
15-30	8.91	8.02	0.89		11
		Total	3.67		47
		From 5th to 6th Irrigation			
0-15	8.80	6.66	2.14	2.97	72
15-30	8.17	7.71	0.46		15
		Total	2.60		88
		From 6th Irrigation to Harvest			
0-15	8.99	4.94	4.05	10.38	39
15-30	8.60	6.50	2.10		20
		Total	6.15		59

Table 7. El Minya Soil Water Depletion from Upper 30 cm - Broad Beans During Winter 1979-80

Soil Depth	Volume of Soil Water		Water Depletion		% of Total
	After previous	Before Current	Specific Horizon	Total Profile (90cm)	
	--------------	--------------	cm	--------------	--------------
		From 1st to 2nd Irrigation			
0-15	8.77	6.44	2.33	7.67	30
15-30	7.94	7.08	0.86		11
		Total	3.19		41
		From 2nd to 3rd Irrigation			
0-15	8.46	6.44	2.02	2.65	76
15-30	8.31	7.40	0.91		34
		Total	2.93		111
		From 3rd to 4th Irrigation			
0-15	8.90	5.83	3.07	6.42	48
15-30	8.60	7.06	1.54		24
		Total	4.61		72
		From 4th Irrigation to Harvest			
0-15	8.87	6.17	2.70	5.11	53
15-30	7.93	6.20	1.03		20
		Total	3.73		73

Table 8. Minya Soil Water Depletion from Upper 30 cm - Onions During Winter 1980

Soil Depth	Volume of Soil Water		Water Depletion		% of Total
	After previous	Before current	Specific Horizon	Total Profile (90 cm)	
cm	----------------------	---------------------- cm	----------------------	----------------------	
		From 1st to 2nd Irrigation			
0-15	8.27	6.55	1.72	4.26	40
15-30	9.04	8.03	1.01		24
		Total	2.73		64
		From 2nd to 3rd Irrigation			
0-15	9.86	9.54	3.32	7.94	42
15-30	9.67	8.87	0.80		10
		Total	4.12		52
		From 3rd to 4th Irrigation			
0-15	9.56	9.83	2.73	4.58	60
15-30	9.37	8.05	1.32		29
		Total	4.05		88
		From 4th Irrigation to Harvest			
0-15	9.33	5.10	4.23	8.92	47
15-30	8.98	6.98	2.00		22
		Total	6.23		70

Table 9. Minya Soil Water Depletion from Upper 30 cm - Broadbean/sugarcane Intercropped During Winter 1979-9180

Soil Depth	Volume of Soil Water		Water Depletion		% of Total
	After previous	Before current	Specific Horizon	Total Profile (90 cm)	
cm	cm				
	From Planting to 1st Irrigation				
0-15	7.88	6.73	1.15	4.93	23
15-30	7.99	7.14	0.85		17
			Total 2.00		40
	From 1st to 2nd Irrigation				
0-15	8.16	4.84	3.32	6.22	53
15-30	8.14	6.85	1.29		21
			Total 4.61		74
	From 2nd to 3rd Irrigation				
0-15	8.58	6.13	2.45	4.86	50
15-30	8.44	6.80	1.64		34
			Total 4.09		84
	From 3rd to 4th Irrigation				
0-15	8.72	5.99	2.73	7.78	35
15-30	8.95	7.41	1.51		19
			Total 42.4		54
	From 4th Irrigation to Harvest				
0-15	8.76	5.04	3.72	8.90	42
15-30	8.50	7.23	1.27		14
			Total 4.99		56

Table 10. Trend Toward Progressively Wetter Soils as Winter Season Advanced in El Minya 1979-1980

Soil Depth	Day Before Irrigation						Harvest	Three Days After Irrigation					
	1	2	3	4	5	6		1	2	3	4	5	6
cm	% dry wt.												
							Wheat						
0-15	23.65	27.16	33.61	33.97	33.68	36.40	26.98	48.42	46.68	54.18	48.97	48.12	49.11
15-30	25.15	34.31	35.80	41.34	40.52	38.98	32.82	40.17	44.25	46.66	45.05	41.29	43.43
30-60	30.16	32.25	38.43	38.99	36.45	46.34	35.76	32.59	40.49	40.86	41.73	41.09	41.56
60-90	34.67	35.21	39.28	34.79	34.04	39.11	36.14	35.11	39.13	38.72	38.17	39.22	40.00
							Broadbean						
0-15	22.48	34.34	34.34	31.12			32.93	46.79	45.11	47.45	47.32		
15-30	34.07	36.28	37.94	36.21			35.41	40.69	42.62	44.10	40.68		
30-60	30.96	34.57	38.27	35.37			36.23	38.33	37.03	40.07	37.73		
60-90	31.59	34.41	35.32	37.83			37.04	38.92	35.85	37.44	38.71		
							Onions						
0-15	34.05	33.88	33.78	35.31			26.35	42.75	51.05	49.43	48.25		
15-30	32.52	37.99	41.94	38.11			33.01	42.79	45.75	44.35	42.47		
30-60	36.13	40.29	38.28	41.00			37.13	42.77	42.09	40.48	41.91		
60-90	37.51	38.46	40.48	38.89			38.55	39.47	45.27	40.54	39.90		
							Broadbean/Sugarcane						
0-15	18.93	37.07	26.66	33.78	33.01		27.76	43.40	44.96	47.28	48.03	48.31	
15-30	26.19	36.07	34.59	34.33	37.44		36.50	40.34	41.11	42.65	45.22	42.94	
30-60	28.28	40.39	37.64	38.32	37.65		35.49	40.58	39.64	41.11	43.75	40.92	
60-90	29.20	32.40	37.55	40.61	38.04		35.71	39.20	39.41	39.68	40.43	39.76	

Table 11. Changes in Total Soil Water Content With Subsequent Irrigation for Winter Crops in El Minya, 1979-1980

Crop	1 Day Before Irrigation						Harvest	3 Days After Irrigation					
	1	2	3	4	5	6		1	2	3	4	5	6
	cm H_2O/90 cm soil												
Wheat	37.85	41.44	47.40	46.76	45.16	49.26	43.03	46.60	52.28	54.11	52.94	52.23	53.42
Broadbean	37.89	43.31	45.59	44.53			44.73	50.98	48.24	50.95	49.84		
Onions	46.43	49.52	50.39	50.32			45.69	53.78	58.33	54.90	54.61		
Broadbean/ Sugarcane	32.51	44.07	42.93	45.73	44.85		41.86	49.01	49.14	50.59	52.63	50.76	

Table 12. Soil Moisture Characteristics of Soil in El Minya

Depth	Moisture Content at Specific Atmosphere Tens.					
	0.10	0.33	0.66	1.00	3.00	15.00
	% volume					
0-30	67.16	53.60	49.19	49.94	40.71	31.72
30-120	67.16	59.74	57.38	57.51	45.88	33.72

Table 13. Changes in Soil Water Volume and Aeration for Wheat - Winter 1979-80 - El Minya

Soil Depth	Bulk Density	% Mineral[1]	Water air	1st irr. 11-12-79		2nd irr. 28-12-79		3rd irr. 3-2-80		4th irr. 29-2-80		5th irr. 19-3-80		6th Irr 4-4-80		Harvest 12-5-80
				Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
cm	g/cc			% by volume												
0-15	1.22	46	water	29	59	33	57	41	66	41	60	41	58	44	60	33
			air	25	sat	21	sat	14	sat	13	sat	13	sat	10	sat	21
15-30	1.32	50	water	33	53	45	58	47	62	55	59	53	54	51	57	43
			air	17	sat	5	sat	3	saturated							7
30-60	1.43	54	water	43	47	46	58	54	58	56	69	52	59	58	54	51
			air	3	saturated											
60-90	1.50	57	water	52	53	53	59	59	58	52	57	51	59	58	60	54
			air	saturated												

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[1] Calculated from bulk density assuming a particle density of 2.65 g/cc

Table 14. Changes in Soil Water Volume and Aeration for Broadbeans Winter 1979-80

Soil Depth	Bulk Density	% Mineral 1/	Water air	1st irr. 9-11-79		2nd irr 29-12-79		3rd irr. 15-2-80		4th irr 20-3-80		Harvest 18-4-80
				Before	After	Before	After	Before	After	Before	After	
cm	g/cc			% by volume								
0-15	1.25	47	water	28	48	43	56	43	59	39	60	41
			air	25	5	10	sat	10	sat	14	sat	12
15-30	1.30	49	water	44	52	47	55	49	57	47	53	46
			air	7	sat	4	sat	2	sat	4	sat	5
30-60	1.40	53	water	43	54	48	52	53	56	50	53	51
			air	4	saturated							
60-90	1.48	56	water	47	50	51	53	52	55	56	57	56
			air	saturated								

1/ Calculated from bulk density assuming a practicle density of 2.65 g/cc.

Table 15. Changes in Soil Water Volume and Aeration for Onions - Winter 1979-80 - El Minya

Soil Depth	Bulk Density	% Mineral 1/	Water air	Planting 25-11-79		1st Irr. 2-1-80		2nd Irr. 7-2-80		3rd Irr. 27-2-80		Harvest 15-4-80
				Before	After	Before	After	Before	After	Before	After	
cm	g/cc			% by volume								
0-15	1.29	49	water	44	55	44	66	44	64	46	62	34
			air	7	sat	7	sat	7	sat	5	sat	17
15-30	1.41	53	water	46	60	54	64	59	63	54	60	47
			air	1	saturated							
30-60	1.45	55	water	52	62	58	61	56	59	59	61	54
			air	saturated								
60-90	1.51	57	water	57	59	58	68	61	61	59	60	58
			air	saturated								

1/ Calculated from bulk density assuming a particle density of 2.65 g/cc.

Table 16. Changes in Soil Water Volume and Aeration for Borad Bean/sugarcane - Winter 1979-80 - El Minya

Soil Depth	Bulk density	% Mineral 1/	Water air	1st Irri. 4-12-79		2nd irr. 19-11-79		3rd irr. 1-1-80		4th irr 12-2-80		5th irr 13-3-80		Harvest 15-4-80
				Before	After	Before	after	Before	after	Before	after	Before	After	
cm	g/cc													
0-15	1.21	46	water	23	53	45	54	32	57	41	58	40	58	34
			air	31	1	9	sat	22	sat	13	sat	14	sat	20
15-30	1.32	50	water	34	53	48	54	46	56	45	60	49	57	48
			air	16	sat	2	sat	4	sat	5	sat	1	sat	2
30-60	1.37	52	water	39	56	55	54	52	56	52	60	52	56	49
			air	13	..................saturated...									
60-90	1.40	53	water	41	55	45	55	53	56	56	57	53	56	50
			air	6	sat	2	......................saturated......................							

1/ Calculated from bulk density assuming a particle density of 2.65 g/cc

Table 17. Variation in Possible Irrigation Planning Parameters From Minya During Winter 1979-80

	Wheat				Broadbean				Broadbean/sugarcane				Onions			
Irrig.	Water applied	Water stored	Days between irrig.	Profile soil moisture	Water applied	Water stored	Days between irrig.	Profile soil moisture	Water applied	Water stored	Days between irrig.	Profile soil moisture	Water applied	Water stored	Days bet. irr.	Profile soil mois
	cm	cm		%	cm	cm		%	cm	cm		%	cm	cm		%
1	11.69	8.75	25	37.80	---	13.09	46	37.89	15.0	16.5	20	32.51	9.71	7.35	40	46.43
2	7.02	10.84	35	41.44	5.61	4.93	47	43.31	9.0	5.07	40	44.07	10.86	8.81	36	49.54
3	7.67	6.71	24	47.40	5.39	5.36	33	45.59	8.0	7.66	43	42.93	5.20	4.51	18	50.38
4	---	6.18	20	46.76	---	5.31		44.53	9.0	6.90	30	45.73	5.13	4.29		50.32
5	13.58	7.07	15	45.16					14.0	5.91		44.85				
6	9.55	4.16		49.26					---	---						
$\bar{x}$	10.62	7.29	23.8	44.64	---	7.17	43.7	42.82	11.00	8.41	33.25	42.02	7.73	6.24	3.17	49.16
SD	2.22	2.29	8.4	4.29	---	3.95	8.50	3.45	3.24	4.63	10.44	5.42	2.98	2.21	11.15	1.86
CV	21	31	31	10	---	55	19	8	29	55	31	12	3.9	3.5	35	4
$\bar{x}$[1]	10.37	6.99		46.00	---	5.20		44.48	10.0	6.39		44.40	70.7	58.7		50.07
SD[1]	2.47	2.43		2.94	---	0.24		1.14	2.71	1.13		1.19	32.8	25.5		0.48
CV[1]	24	34		6	---	5		3	27	18		3	46	43		1

---

[1] Prior values were calculated omitting the 1st irrigation at planting which tended to be unusually heavy

Table 18. Soil Moisture Variability from Nine Replicated Samples Taken From Two Field Meskas Before & After Irrigation In El Minya.

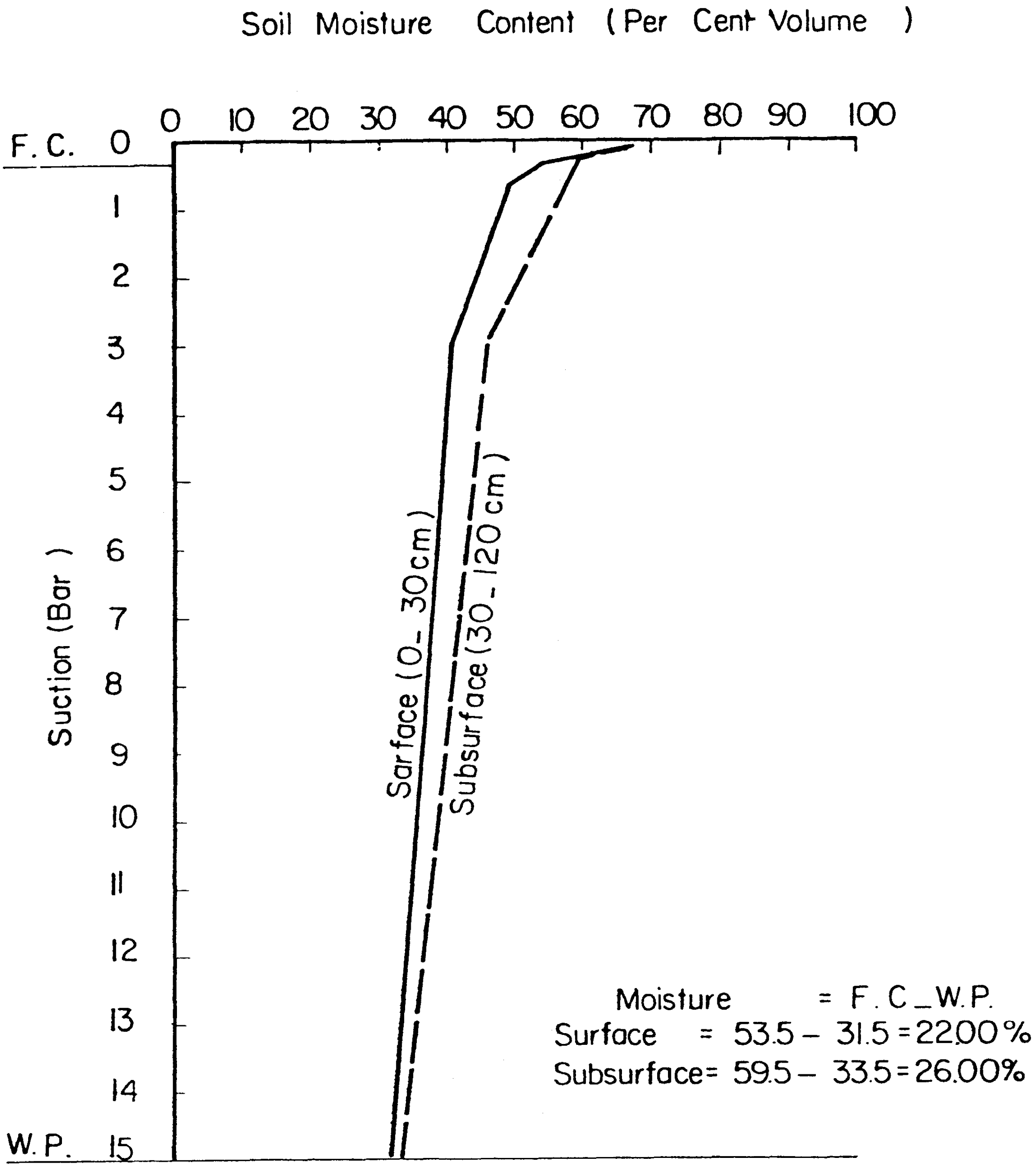
	Meska 13								Meska 30							
	Before				After				Before				After			
	0/15	15/30	30/60	60/90	0/15	15/30	30/60	60/90	0/15	15/30	30/60	60/90	0/15	15/30	30/60	60/90
	% Dry WT															
	36.75	40.88	40.66	39.08	45.60	48.76	43.29	40.53	32.59	33.24	36.98	34.69	44.31	42.21	36.94	35.02
	34.55	40.22	38.29	38.60	48.73	46.59	41.01	41.00	27.52	31.27	36.67	34.09	36.13	36.93	33.59	35.58
	38.22	39.10	39.10	37.06	46.46	44.10	40.00	41.34	31.78	33.73	28.13	38.63	39.92	37.84	33.84	34.80
	38.53	38.94	38.06	43.15	53.58	48.35	41.43	40.02		29.70	35.10	32.41	43.59	34.02	36.52	35.22
	39.48	40.90	41.13	38.38	46.87	43.52	42.27	39.56	31.77	35.56	40.88	38.64	44.66	40.82	35.52	36.00
	38.90	43.53	40.38	37.38	50.95	46.62	40.39	39.51	25.44	33.76	29.97	35.52	41.94	41.34	36.64	34.85
	36.17	41.99	39.02	38.98	47.54	44.32	41.32	42.92	30.83	37.75	37.43	38.54	41.61	39.02	38.74	36.03
	37.44	39.55	36.29	39.74	49.95	41.79	42.16	36.67	28.13	35.55	36.29	38.23	40.00	38.51	37.03	37.90
	36.37	42.65	39.79	37.52	52.11	45.62	42.97	39.37	33.11	37.93	34.08	34.24	37.60	40.39	35.79	36.49
x̄	37.38	40.86	39.19	38.88	49.09	45.52	41.65	40.10	30.15	34.28	35.06	36.11	41.08	39.01	36.07	35.56
D	1.57	1.60	1.51	1.93	2.74	2.23	1.12	1.71	2.77	2.59	3.91	2.42	2.95	2.54	1.61	0.99
V	4.19	3.92	3.85	4.70	5.58	5.05	2.68	4.27	9.18	8.01	11.15	6.70	7.18	6.52	4.47	2.77

Table 19. Soil Moisture Variability by Volume For Nine Replicated Samples Taken Before and After Irrigation in El Minya

	Meska 13										Meska 30									
	Before					After					Before					After				
	0/15	15/30	30/60	60/90	Σ	0/15	15/30	30/60	60/90	Σ	0/15	15/30	30/60	60/90	Σ	0/15	15/30	30/60	60/90	Σ
	--------% volume----------				cm H2O	--------% volume----------				cm H2O	----------% volume---------				cm H2O	-----------% volume-----				cm H20
	45.57	54.78	57.33	57.45	49.49	56.54	65.34	61.04	59.58	54.47	40.44	49.54	52.14	50.99	44.44	54.94	56.56	52.08	51.48	47.7
	42.84	53.83	53.99	56.74	47.72	60.43	62.43	57.82	60.27	53.86	34.12	41.90	51.70	50.11	41.95	44.80	49.49	47.36	52.30	44.0
	47.39	52.39	55.13	54.48	47.85	57.61	59.09	56.40	60.77	52.66	34.41	45.20	39.66	56.79	41.63	49.50	50.71	47.71	51.16	44.6
	47.78	52.18	53.60	63.43	50.10	66.44	64.79	58.41	58.83	54.86		39.80	49.49	47.64	40.72	54.05	45.59	51.49	51.77	45.9
	48.96	54.81	57.99	56.42	49.89	58.12	58.32	59.83	58.15	52.85	34.39	47.65	57.64	56.80	47.39	55.38	54.70	50.68	52.92	47.5
	48.24	58.33	56.94	54.95	49.55	63.18	62.47	56.95	58.08	53.36	31.55	45.24	42.26	52.21	39.86	52.01	55.40	51.66	51.23	46.9
	44.85	56.27	55.02	57.30	48.86	58.95	59.39	58.26	63.09	54.16	38.23	50.58	52.78	56.65	46.15	51.60	52.29	54.62	52.96	47.8
	46.43	53.00	51.17	58.42	47.79	61.94	56.00	59.45	53.90	51.70	34.88	47.64	51.17	56.20	44.59	44.60	51.60	52.21	55.71	46.5
	45.10	57.15	56.10	55.15	48.71	64.62	61.13	60.59	57.87	54.40	41.06	50.83	48.65	50.33	43.48	46.62	54.12	50.46	53.64	46.3
x̄	46.35	54.76	55.25	57.15	48.88	60.87	61.00	58.75	58.95	53.59	37.38	45.93	49.43	53.08	43.36	50.94	52.27	50.86	52.58	46.4
S.D	1.94	2.15	2.13	2.69	0.93	3.40	3.08	1.59	2.52	1.03	3.43	3.68	5.51	3.55	2.52	3.66	3.41	2.28	1.46	1.3
CV.	4.19	3.92	3.86	4.70	1.91	5.58	5.05	2.71	4.27	1.92	9.18	8.01	11.15	6.69	5.82	7.19	6.52	4.47	2.77	2.9

Table 20. Inconsistant Tensiometer Reading in El Minya

Date	30 cm			60 cm			90 cm		
	1	2	3	1	2	3	1	2	3
Jan. 23	--	30	33	58	38	64	--	20	48
26	--	30	33	58	38	64	--	20	48
31	12	38	58	61	48	64	--	20	52
Feb. 2	59	38	63	60	52	64	--	26	52
3	70	38	64	60	59	64	--	28	52
	Irrigated Feb. 3, 1980								
Feb. 10	4	0	16	26	24	20	--	29	20
11	10	0	5	26	21	62	--	28	24
13	18	0	8	27	26	62	--	29	28



Moisture = F. C _ W. P.
Surface = 53.5 − 31.5 = 22.00 %
Subsurface = 59.5 − 33.5 = 26.00%

Fig (1) Soil Moisture Characteristic Curves For Menia Soils Surface

Staff Paper #34

USE OF CHEMICAL FERTILIZERS IN MANSOURIA LOCATION

M. Zanati, M. Lotfy, & G. Ayad

July 1980

Chemical fertilizers is one of the important factors in crop production. Its kind, rate and time of application should be based on the soil characteristics, plant varieties and water application. Recommendations for Egyptian farmers are based on the results obtained from experimental stations located throughout the country.

The EWUP policy is to identify the problems facing crop production in three pilot areas in order to look for reasonable solutions to be implemented. In this concern, the agronomists are dealing with fertilizer situation as an effective factor in crop production.

Mansouria area is one of the three selected pilot areas where no fixed rotation is followed. Farmers in this area decide by themselves how to make use of their land. Moreover, the farmers get their fertilizers from the cooperative and also from the black market in order to meet the crop requirements. The EWUP economists are keeping eye on recording all the items of crop production. For instance, twelve farms from both Beni Magdoul and El Hammami were taken into consideration. Every farm has different strips where every strip was subjected to be grown with different crops for a period of one agricultural year. This gave us an opportunity to have 72 study cases in these two locations. The amount of nitrogen and phosphorus applied were recorded as shown in the following tables in kgs of pure nutrients/fed.

The data collected could be discussed under the following subheadings:

1. Fertilizers applied to different crops
    a. Berseem
    b. Maize for seed production
    c. Maize for forage production
    d. Cabbage
    e. Wheat

2. Total amount of fertilizers applied to every strip during one year.

It is worthy to mention that the two locations under study (Beni Magdoul and Hammami) differ greatly in their texture, where Hammami location could be considered as sandy loam for the depth of 0-30 cm then, the rest of profile till 150 cm is completely sandy. Moreover, the clay content of the surface layer is around 10% while it is 4% in the subsurface layers.

In case of Beni Magdoul, the surface layers contain higher amounts of clay up till 40% in some areas. The subsurface layers contain less clay as this location is considered as an interference zone between the desert and the valley. The difference in clay content goes in harmony with leaching losses of applied nutrients.

1. Fertilizers applied to different crops
   a. Berseem

Berseem is considered as the main forage crop in Egypt during the period of November till May. According to its capability for fixing atmospheric nitorgen to meet its needs, the rate of recommended nitrogen is so low and is applied only as a start to encourage the plant at its early stages of growth. This rate is 7.5 kgs N/fed, where phosphorus is recommended to be applied at a rate of 15.5 kgs P_2O_5/fed. The following table indicates that the farmers in the studied locations usually apply excessive amounts of phosphorus. Often twice or three times the recommended rate was used. The average rate of application in Beni Magdoul area is approximately twice the recommended rate and none of these farmers applied less than the recommended rate. In the case of El Hammami area, the variation in rates of application ranges between 8.84 and 100 kgs P_2O_5/fed. with an average of 28.35.

Those aforementioned rates of application increased the amounts of available phosphorus in the two areas. Data obtained through the soil fertility survey revealed that the soil contained ample amounts of available P_2O_5

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even in case of the sandy soils at El Hammami. Accordingly, phosphorus deficiency was not considered as a problem.

Table 1: Rate of Phosphorus Application in Kgs P_2O_5/fed. to Berseem in Case of Beni Magdoul and El Hammami Areas

Beni Magdoul			Hammami		
40.76	36.89	28.50	41.23	68.80	9.30
40.76	36.89	26.66	41.23	68.80	100.00
40.76	19.84	28.83	44.49	31.00	43.40
40.76	19.84	15.50	39.99	45.50	60.00
30.54	80.14	15.50	36.89	31.00	60.40
31.00	16.90	28.37	47.12	9.30	8.84
34.72	16.90	18.60	35.34	15.50	
17.36	23.56	36.89	31.00	14.42	
			35.34	10.00	

$\bar{x}$ = 32.70 Kgs P_2O_5/fed
s = 12.73
cv = 39%

$\bar{x}$ = 38.42 Kgs P_2O_5/fed
s = 28.35
cv = 72%

b. Maize for seed production

Maize is grown in Mansouria area generally as a grain crop. It does however supply both grain for human consumption and green forage for feeding cattle during summer season.

It is known that nitrogen is a key element in maize production. Voluminous studies have been conducted in Egypt where N rate, time, kind and method of application were considered. According to the wide use of high yielding corn varieties instead of the local varieties, it is recommended to apply

.../...

high doses of nitrogen to meet the plant requirements. In this concern, 60 Kgs of N plus 7.5 Kgs of P_2O_5/fed were recommended to be applied to corn grown in delta governorates. In case of Upper Egypt, the recommended rate is increased to 70 Kgs of N plus 7.5 Kgs P_2O_5/fed.

Data tabulated in the following table reveal that there is a great difference in nitrogen rates applied to corn. Moreover, the average rate of application in case of Beni Magdoul area was 105.74 Kgs N/fed., whereas some farmers apply nitrogen up to 165 Kgs.

Mostly, berseem is followed by corn in those areas. In this case, nitrogen rates should be decreased as a result of berseem effect on increasing the soil nitrogen content. Most of the case studies indicate that the previous crop was berseem and at the same time twice or three folds of the recommended nitrogen rate was applied to corn.

Tabel 2: Rate of Nitrogen Rate Application in Kgs/Fed to Corn at Beni Magdoul and El Hammami Areas

Beni Magdoul		El Hammami	
95.37	133.74	158.24	194.58
149.17	104.88	158.24	89.00
53.48	92.00	99.00	67.30
33.00		36.89	
125.00		85.10	
165.00		95.33	

$\bar{x}$ = 105.74
s = 50.46
cv = 46%

$\bar{x}$ = 84.80
s = 80.77
cv = 95%

c. Maize for forage production

Table 3: Rate of Nitrogen Application in Kgs N/Fed. to Maize (Forage Crop) in Case of Beni Magdoul and El Hammami Areas

Beni Magdoul		El Hammami	
43.56	0.00	73.14	139.36
0.00	68.36	310.96	54.25
0.00	0.00	66.00	59.40
132.00	16.50	31.00	44.22
4.65	0.00	23.43	66.00
116.16	0.00	65.01	0.00

$\bar{x}$ = 38.12 $\bar{x}$ = 84.80

s = 50.82 s = 80.77

cv = 1.33 cv = 0.95

Farmers usually grow maize for forage production in Summer. It is known that the suitable date of planting extends from late in April till September and it is recommended not to use the same land to produce two maize crops in the same year to minimize the soil exhaustion resulting from the high seed rate. Ten Kgs of pure N/feddan is recommended to be applied to maize before the second irrigation. Usually, it could be used for feeding cattle starting from 45 days after planting. In case of Beni Magdoul area, it is noticed that the farmers used to apply more nitrogen than recommended. In some cases, the applied nitrogen exceeds that recommended for maize seed production, where four cases out of ten did not receive any nitrogen.

In case of El Hammami area, ample amounts of nitrogen were used for forage production with a range of 23.43 up to 310.94 kgs N/fed. with an average of 84.80.

.../...

d. Cabbage

Four cases from every area indicate a high inconsistency in nitrogen applications. For instance, those rates range between 109.48 to 375.54 Kgs N/Fed in case of Beni Magdoul with an average of 212.57. Those rates range between 56.12 to 250 Kgs N/fed in case of El Hammami area with an average of 123.95. Leaching losses are great in the coarse textured soils prevailing this area. Thus rates of N application should be higher if compared with the clay soils of Beni Magdoul area.

Table 4: Rate of Nitrogen Application in Kgs N/fed to Cabbage in Case of Beni Magdoul and El Hammami Areas

Beni Magdoul	El Hammami
135.24	250.00
375.54	104.60
109.48	85.10
230.00	56.12

$\bar{x}$ = 212.57
s = 120.38
cv = 57%

$\bar{x}$ = 123.95
s = 86.36
cv = 70%

e. Wheat

Wheat is not widespread in the Mansouria area where berseem and vegetables are the major winter crops.

The data of eleven cases in the two areas reveal that a great variation in rates of nitrogen application exists within farms. But, it is obvious that the rates used in case of Beni Magdoul area are not largely different than the recommended rate, where the average rate of application is 61.79 Kgs N/fed. On the other hand, the variation in nitrogen rates is greater in case of El Hammami, ranging from 19.78 upto 115.50 Kgs N/fed. with an average of 67.51.

.../...

Table 5: Rate of Nitrogen Application in Kgs N/fed. to Wheat in Case of Beni Magdoul and El Hammami Areas

Beni Magdoul	El Hammami	
60.72	102.30	69.00
54.74	115.50	39.60
69.92	100.28	66.00
	19.78	27.60

$\bar{x} = 61.79$ $\bar{x} = 67.51$

$s = 7.65$ $s = 36.34$

$cv = 12\%$ $cv = 54\%$

2. Total amount of fertilizers applied to every strip of land during one year.

Data shown in table 6 indicate that the application of fertilizer varies within the studied strips. The variation in amounts could be attributed to the cropping pattern itself, but if we consider this contribution to a certain extent, we will still have a distinct variation in the applied amounts. In other words, let us assume that those strips are subjected to an intensive cropping system/year where approximately 150 kgs N/fed is needed. Then we'll find about 45% of the strips in Beni Magdoul are still subjected to nitrogen over-fertilization, while this percentage goes up to 68% in case of El Hammami area. In addition to the previous findings, there is no relationship between phosphorus and nitrogen, in other words, the ratio between those two nutrients varies greatly within strips.

The following figure 1 indicates that the average amount of nitrogen application is 173.79 Kgs N/fed., where 29% of the strips receive an amount of nitrogen more than 183 Kgs up to 1085.70. Moreover, 13% of them receive nitrogen starting from none up to 45.83 Kgs N/fed. It is worthy to mention that the strip receiving no nitrogen produced berseem followed by maize for forage. The farmer did not apply nitrogen for either berseem or maize.

.../...

In case of El Hammami area, the situation is quite different (Fig. 2). The data reveal that the average amount of application is 249.66 Kgs N/fed. Ten percent of all studied cases receive an amount of nitrogen ranging from 30 to 74.38 Kgs N/fed, where about 50% of those cases receive more than the average.

In addition to the previous findings, it is obvious from the data that there is no relationship between the total amounts of both nitrogen and phosphorus. In other words, the ratio between those nutrients differ greatly within the studied cases. It could be said that phosphorus was added in conjunction with nitrogen for nearly all the studied cases in Beni Magdoul area. On the contrary, nitrogen was added without any phosphorus application in case of about 45% of the studied cases at El Hammami. The ratio between the nitrogen and phosphorus amounts of application differs within areas, i.e. 3.59 and 13.50 for Beni Magdoul and El Hammami areas, respectively.

Discussions

The farm records from the study cases in Beni Magdoul and El Hammami areas describe the situation of fertilizers used in those areas. There is no doubt that what was kept in those farm records is valuable and can help a lot in describing the existing system or at least give us an idea about the farmers ways of handling the chemical fertilizers.

The data presented in the previous tables and histograms clearly indicate that a severe variation in rates of fertilizers application exists. In this concern, the values of c.v are large and it exceeds more than 90% in most of the cases. Generally, it could be said that the majority apply more fertilizers than needed. For instance, 43 farmers out of 48 farmers in the two areas applied more phosphorus to berseem than recommended. The same situation

.../...

was clear in case of nitrogen, where 83%, 76% and 73% of the farmers applied more nitrogen than recommended in case of corn for seed production, corn for forage and wheat, respectively. At the same time, the cultivated land in those areas received ample amounts of chemical fertilizer per year with different salt indexes which create salinity problems afterwards. The present situation could be considered as an identified problem which should be tackled by all disciplines, but we have to throw some light on the reasons which lead to this situation. First of all, lack of extension services in those areas is well known and it should be considered. All of us feel that with minimum guidance of those farmers can increase the crop production. For eg. what was accomplished with insect control is a good example for solving a problem by extension services.

At the same time we have to ask the farmers why they do apply less or more fertilizers. In other words we have to show them that every crop has a nutrient-yield relationship and the yields obtained as a result of different rates of application follow the law of diminishing returns. So, why does the farmer add more than recommended? Does he get more yield? Secondly, is this situation due to farmers way of living? They are considered as part-time farmers. In this case they do not devote all their time of farming. Thirdly, is it due to the availability of fertilizers in Mansouria area? A lot of orchards are located there and their owners receive large amounts of subsidized fertilizers.

Table (6): Shows the rate of nitrogen and phosphorus applications in kgs/fed to every farm (selected to represent Beni Magdoul and Hammami Location) during one agricultural year Oct. 1978 - Oct. 1979.

Case No.	P_2O_5	N	Case No.	P_2O_5	N	Case No.	P_2O_5	N	Case No.	P_2O_5	N
	kgs/fed.			kgs/fed			kgs/fed			kgs/fed	
	Beni Magdoul Location						El Hammami Location				
1	81.52	138.93	20	46.50	429.00	1	12.40	1095.14	21	5.12	184.00
2	40.76	–	21	18.60	109.48	2	–	524.10	22	38.50	70.75
3	70.52	135.24	22	73.78	39.27	3	–	158.24	23	23.57	305.36
4	61.23	70.95	23	31.00	196.00	4	–	158.24	24	22.79	334.96
5	71.30	30.36	24	41.23	108.50	5	–	300.16	25	–	57.50
6	31.00	132.00	25	41.23	64.15	6	–	373.36	26	–	252.52
7	34.72	153.82	26	44.49	230.00	7	–	229.00	27	–	126.00
8	17.36	34.50	27	39.99	175.72	8	31.00	66.00	28	–	284.25
9	73.78	274.89	28	55.49	188.94	9	45.50	116.49	29	–	232.27
10	36.89	164.22	29	94.24	154.38	10	15.50	396.00	30	–	194.58
11	19.84	53.48	30	35.34	174.80	11	31.00	132.00	31	–	261.00
12	99.98	53.48	31	62.00	276.00	12	–	684.00	32	–	308.22
13	50.70	124.66				13	–	539.33	33	–	199.90
14	47.12	50.16				14	–	259.41	34	–	138.50
15	59.50	259.20				15			35	–	169.41
16	82.15	56.76				16	–	180.41	36	–	116.70
17	15.50	99.00				17	18.60	95.09	37	–	138.63
18	–	1085.70				18	9.30	33.97	38	–	312.44
19	22.79	323.79				19	24.80	244.00	39	–	198.00
						20	14.42	255.30	40	–	247.50
									41	–	143.51

Figure (1): Frequency distribution of total nitorgen applied/feddan in Beni Magdoul Area.

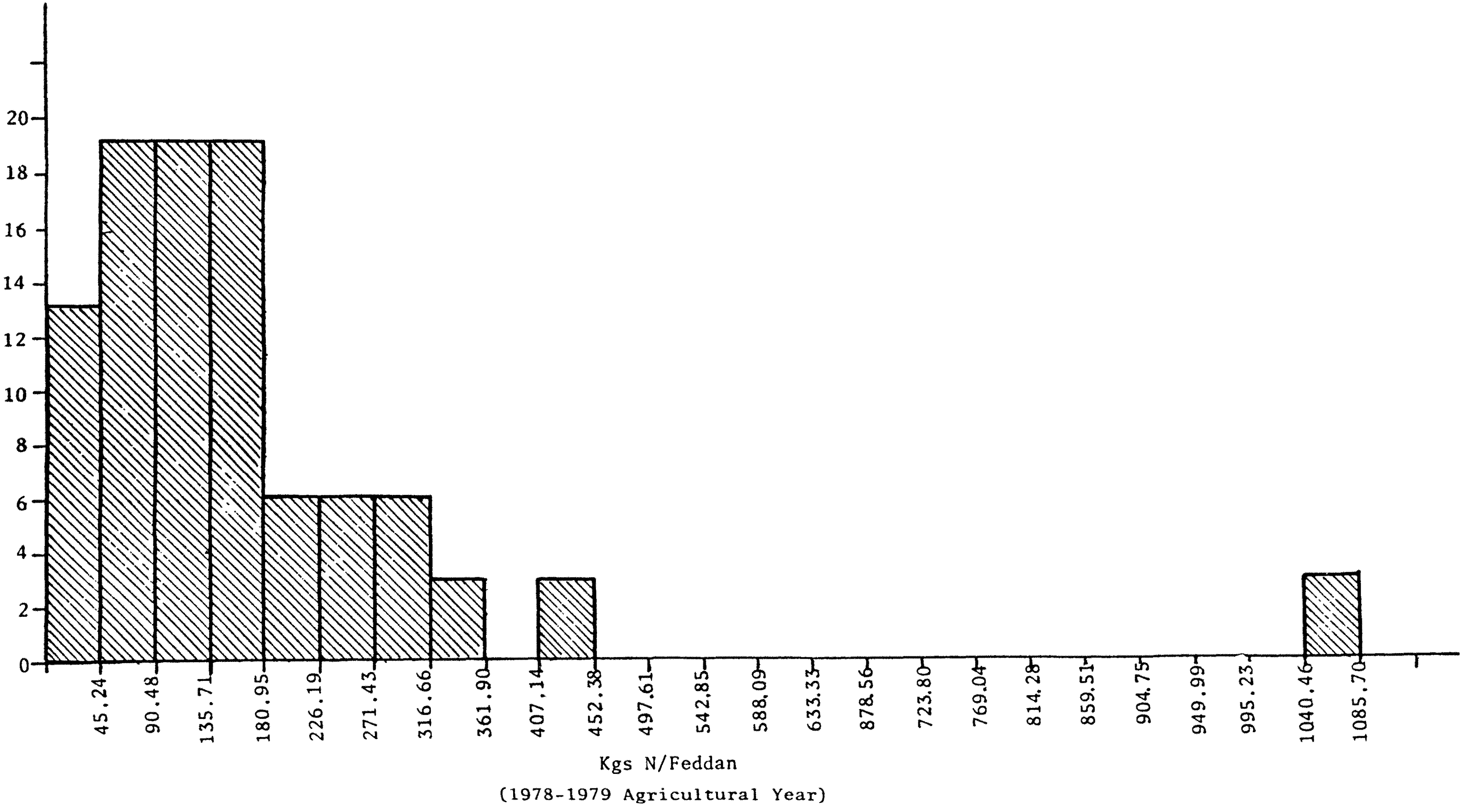
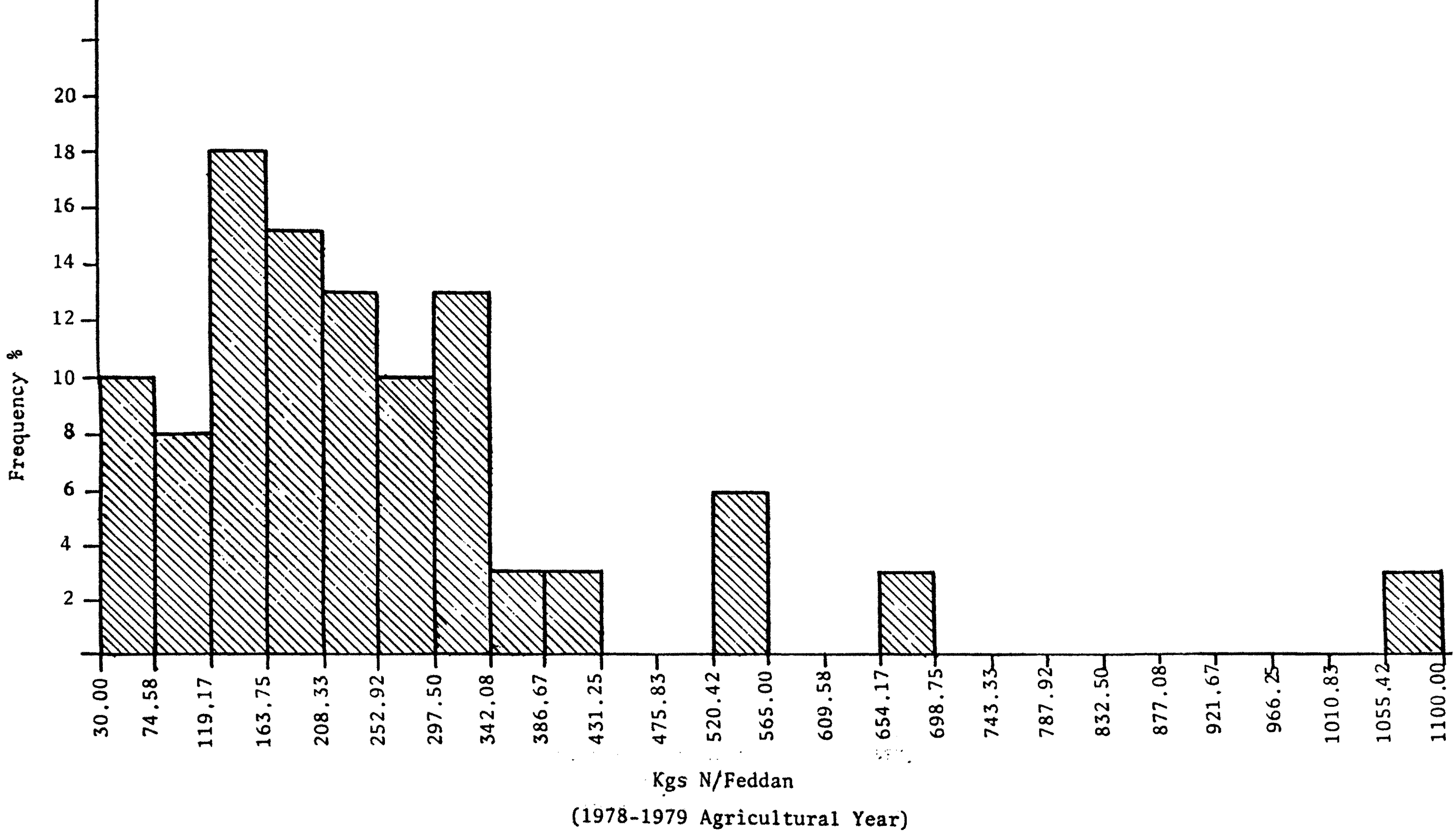


Figure (2): Frequency distribution of total nitrogen applied/feddan in El Hammami Area.



Staff Paper #35

AGRICULTURAL PESTS AND THEIR CONTROL
GENERAL CONCEPTS

Dr. E. A. R. Atalla

INTRODUCTION

Insects were present and well established on earth long before man established himself. By the time he started to practice agriculture, he was - and still is -faced with the problem of protecting his crops from pest attacks. The basis for man's problem is that both he and insects are competing for the same resources needed for food, clothing, shelter, and other requirements. Pests reduce the yield, lower the quality, increase the cost of production and require cash outlays for material and equipment for control measures. Besides, chemical pesticides used for their control are blamed for a good part of environmental pollution.

Different general estimations of the economic loss caused by pests have been suggested. Generally, it is estimated that world agriculture suffers a loss caused by pests amounting to about 10% in field crops, 20-40% in fruits crops, 20% in vegetable crops, and about 20% in grain and other stored products. In Egypt it is estimated that the annual loss caused by insects and plant diseases to major crops amounts to more than L.E. 60 million. With all the control measures taken, cotton yield in Egypt suffers a reduction of about 7-10% as a result of infestation by cotton bollworms alone. Several cases are known in the world where cotton production was terminated in whole countries or regions because of the fact that costs of pest control made it impossible to continue producing the crop economically.

Furthermore, with the explosive increase of the human population the the social and economic progress of man, his requirements increased both in quantity and in quality. On the other hand, the intensive and extensive agriculture he is practicing and the continuous alteration of the environment with more favoured conditions for increase of insects and related groups and pathogens are leading to a gradually increasing grave critical situation in the confrontation between man and pests. Man is continuously facing an increase in the abundence and distribution of pests and the fight is growing more and more intense.

With all the above-mentioned actual and potential hazards and losses, it is becoming obvious that if man is to continue his civilization and social progress, if not even his mere existence, he has to win his fight against pests and to use the least injurious and most enlightened methods of control in that fight.

PESTS AND THEIR TYPES

A pest is a species of organisms that has increased in numbers to exceed the economic injury level. This means that a species cannot be always condemned to be a pest everywhere in the world since it can be an injurious pest in one area and an existing organism with no significant economic consequences in another area depending on its population densities. This is also an important factor that should be considered in pest control programmes since generally control measures, especially application of chemical pesticides, should not be used unless the numbers attain the economic threshold.

In general pest injurious to plant crops may be divided into the following categories:

I. Pests belonging to the plant kingdom:

1. Weeds: These are higher plants which grow where they are not desired and, among other injuries, often compete with economic crops.

2. Parasitic plants: These are also higher plants which live totally or pratially as parasites on economic crops.

3. Some species of algae

4. Parasitic fungi.

5. Bacteria

II <u>Pests Belonging to the Animal Kingdom</u>:

1. Vertebrates: Such as rodents, bats, injurious birds and certain other animals.

2. Invertebrates: The main group of invertebrates which is of immense economic importance as plant pests are the Asthropoda which include insects, ticks and mites. Insects have the highest number of species within the animal kingdom with an estimated over 5 million species, out of which only about one million species already known and identified. At least about 10,000 species of insects are known to be injurious as pests to agriculture in different areas of the world. Within this category the groups with more important economic significance are insects and mites.

3. Nematodes

4. Parasitic protozoa.

III <u>Viruses</u>:

In the present paper, however, we shall be more restricted to problems of pests belonging to class insects and other related classes.

METHODS OF PEST CONTROL

Before trying to control any pest, a thorough study of the factors creating favourable conditions for an explosive increase in its numbers should be conducted. Such a study should include the biology and life history of the pest, its behaviour, seasonal history, reaction to different environmental factors, and certain other aspects. The knowledge gained from such studies is essential for formulating the most efficient control programme with the least short and long term hazards. Furthermore, such knowledge helps in forecasting with a reasonable accuracy the time and degree of future infestations so that adequate control measures may be appropriately prepared beforehand.

An important point to be considered is the fact that most present major agricultural pests in the world are of foreign origin which gained entry either before the establishment of plant quarantine services or accidentally after that establishment. This is true in Egypt where almost all pests and diseases of crop plants have gained entry from abroad. This fact emphasises the importance of plant quarantine regulations in plant protection systems. The economic basis for quarantine is that it is better to undergo considerable inconvenience and initial expense in an effort to exclude, or at least delay, a pest rather than to submit to its damages and control expenses for an indefinite period if it gained entry. Nevertheless, it has to be realized that the increasing volume of foreign exchange of agricultural commodities, the more and more rapid transport and the growing need for imports make it almost impossible to totally and permanently prohibit the introduction of foreign pests and diseases. All that is hoped by enforcing strict plant quarantine regulations is to reduce the number and rate of foreign pest introductions to a minimum.

Several methods of pest control are being practiced. Among the most important of these methods are the following:

I Cultural Control

This is a cheaper, less demanding, method of control. Some of its practices are the following:

1) Early production of crops: In many cases this procedure helps in reducing the rate of infestation, even to the point of totally escaping infestation in some cases. It also helps in preventing the late generations from finding adequate and appropriate food supplies, which leads to a sharp decrease of the numbers of the hibernating individuals and consequently to weak generations in the new season.

   Early production can be achieved by general planting, using early producing varieties and practicing certain agricultural processes that accelerate ripening. In general early production helps to reduce infestation in several cases such as the leaf-worms and bollworms in cotton, corn borers in maize, late season infestations by aphids and spider mites in several crops, and many other cases.

2) Following an appropriate crop rotation to stop the increase of the population densities of pests which occur due to the continuous availability of their host plants. Such rotations help to control several well known pests such as the corn borers, sugar-cane mealybug, several vegetable insects and many others. Generally a good rotation should include, whenever possible, occasional following.

3) Crop arrangement: Crops should be arranged in such a way that common hosts of important pests should be separated as much as possible. An example of the problem is the high infestation by the Med-bly, Ceratitis capitata, in orchards with mixed host trees. It is more advisable that different hosts of the Med-fly should not be grown together in the same orchard.

4) Growing of certain plants to serve as traps to protect the main crops. The idea is to grow some less important and more attractive plants to take the infestation out of the main crop,

these trap plants should be destroyed before they serve as breeding grounds to spread the infestation to other plants. For example, growing few corn plants in sugar-cane fields reduce the infestation of the canes with borers. Few ratoon cotton plants in a cotton field help reducing the infestation by bollworms in the main crop.

5) Development of more tolerant or less susceptible varieties of plants: This procedure can be worked out with the help of plant breeders and through hybridization and selection. This procedure is more applied in case of plant diseases, but there are several successful examples in the world in case of plant pests such as corn borers, bollworms, alfalfa aphids and others.

6) Soil management: Different procedures of soil management have important effects on pest control. Some examples are:

   a. Deep ploughing and hoeing result in killing many soil inhabiting insect larvae and pupae, either by deeply burying them, exposing them to natural enemies or exposing them to unfavourable physical factors. It was proved in Egypt that larvae and pupae of the cotton leafworm, _Spodoptera littoralis_, are reduced drastically in clover fields after ploughing than before it.

   b. Infestation by _Thrips tabaci_ in cotton can be reduced by hoeing and weeding, and by repeated irrigation of the infested cotton field at short intervals.

   c. Infestation of the potato tuber-moth, _Phthorimaea opercubella_, is reduced by burying the sown tubers at about 12-15 cm. deep. On hoeing, exposed tubers should be covered and cracks should be filled so that tubers may not be exposed to infestation.

d. With the woolly apple aphid, Eriosoma lanigela, surrounding the apple trees with a layer of sand about 8 cm. deep and filling the soil cracks reduce the infestation by preventing the aphids from crawling into the subterranean parts of the tree for infestation or hibernation.

7) Water management: Irrigation and water management affect both plant and pest. Excessive irrigation more than needed may encourage the vegetative growth and accordingly increase infestation by certain pests, especially leaf feeding insects. In Egypt it is observed that heavily irrigated cotton leafworm moths and accordingly infestation is increased. Many farmers refrain from irrigating their cotton fields during the peak of moth abundance and in this way successfully reduce egg depositing in their fields. Irrigation of clover fields is prohibited after the first week of May in an attempt that low humidity and high temperature reduce percentage of emerging cotton leafworm moths. Repeated irrigation of cotton fields infested with cotton thrips is said to reduce infestation or even control it. In case of infestation by the bean fly, Agromyza phaseoli, the first hoeing should be manipulated as early as possible. Irrigation helps forming more side roots to replace the main root when affected by the infestation.

8) Sanitation: Removal of weeds and crop residuals, especially in the pest hibernation period, helps reducing the infestation. Examples are cleaning stores to reduce infestations by stored product insects, removal of maize stalks for corn borers, removal of wheat residues for saw-fly, burning the cotton-bolls for bollworms, burying or burning infested and fallen fruits flies. Removing post-season growths of host plants prevents the occurance of an appropriate host plants prevents the occurance of an appropriate host early in the season for an overbridging generation.

9) Manures and fertilizers: All of the fertilizing elements must be used with caution and in proper balance. Applications of nitrogen beyond the amount normally needed on a particular soil type will result in vegetative growth that is attractive to some insect pests. Nitrogen in particular must be used in proper balance to have a plant less attractive to many pests such as boll weevil, plant bugs, bollworms, and other pests in case of cotton plants. In general, it is shown that pest damage increases when excessive nitrogenous fertilizers are applied. On the other hand, several studies have shown that phosphorous and potash fertilizers may help in resisting infestation by several insects.

   In Egypt, it is known that nitrogen fertilizers in excess in cotton fields are positively correlated with infestations of leafworms, bollworms, and possibly other pests. On the other hand, strengthening the fruit trees by fertilizers helps controlling infestations by shoot borers and bark bettles.

10) Host free period: In some cases, especially if the pest is more or less monophagous, an establishment of a host free period may help reducing the infestation.

   Closely related to this point is the separation of different types of host required by an insect to complete its annual life-history. For instance, the peach aphid, *Myzus persicae*, spends part of its annual genrations mainly on potatoes and another part mainly on peaches and related fruits. Separation of these different seasonal hosts helps in reducing the infestation.

II Mechanical Control

These methods of control include the mechanical killing of insects at different stages, preventing them from reaching appropriate host plant or appropriate part of the host, mechanical trapping, mechanical removal of the pest, and several other procedures.

Some examples of this control method are:

1) Hand picking of the egg-masses of the cotton leafworm, Spodoptera littoralis, in Egypt. If properly carried out, cotton crop can be economically saved the ravages of this pest.

2) Preventing ditches filled with water and dusted on both sides with lime, calcium oxide, prevent cotton leafworm from migrating from one field to invade another field.

3) Desert locusts are swept into ditches and destroyed by buying or burning.

4) Pomegranate butterfly is controlled by screening the fruits on the trees with paper, cloth or plastic bags, so preventing the females fromoviposting on such fruits.

5) Tin or wooden traps set around the apiaries, next to bee-hives, or as upper or side compartments of the hives, help control the oriental hornet, Vespa orientalis.

6) Different kinds of traps could be set in fields to catch a certain proportion of concerned insects and consequently reduce their numbers in the fields.

7) Certain other mechanical means are used in several cases, including plant quarantine stations, for de-infestation of commodities. Among these methods are grinding, sieving, mechanical removal by brushing or air pressure and several others.

III Physical Control:

These methods include the application of physical factors, mainly temperature, in controlling pests. Main measures include heating of plants or their parts up to degrees affecting the insects. Examples of such methods of control are:

1. For controlling the pink bollworm, Pectinophora gossypiella, picked cotton is required by law to be ginned before spring and the produced seeds should be heated at 55-58° for five minutes to kill any hibernating larvae without affecting the viability of the seeds.

2. Cold storage for several days, down to 0°C, of appropriate fruits may kill eggs and young larvae of fruit flies within those fruits.

3. Tests have indicated that covering of land by tarpaulin during summer time for some days causes a considerable increase in the soil temperature leading to higher mortality of certain insects, such as the cotton leafworm in the larval and pupal stages, and to destruction of some fungus spores.

4. It was previously mentioned that irrigation of clover fields is prohibited in Egypt after the first week of May. This is based on the results obtained that this procedure leads to an increase in temperature accompanied by a decrease in humidity leading to higher mortality of the pupae of the cotton leafworm or to malformation and failure to emergence of moths.

5. In plant quarantine stations, heating and boiling of commodities are frequently used for disinfection.

IV. Biological Control:

Biological control is the action of parasites, predators and pathogens on a host or a prey population which produces a general lower equilibrium that would prevail in the absence of these agents.

Sometimes biological control is used alone, or at least without the application of pesticides. However, as will be discussed later, this method of control is now used in a compatible manner with chemical control. Several successful cases of application of parasites and predators are recorded in the world. Among the recorded cases in Egypt of successful biological control caused by imported natural enemies are the following:

a) Control of the fluted mealybug, *Icerya purchasi*, by the coeinellid ladybird bettle *Rodolia cardinalis*.

b) Control of lebek and hibiscus mealybugs by encyrtid parasites.

c) Control of the woolly apple aphid, *Eriosoma lanigera*, by the aphelinid parasite, *Aphelinus mali*.

Microbial pesticides, containing pathogens and their toxins as active ingredients, are now commercially produced and on sale. They are used either alone or in combination with chemical pesticides.

V. Chemical Control

This method refers to the application of poisonous chemicals (pesticides) for control of pest and disease populations. It is still the only method available in our hands to be used when populations exceed the economic injury level and accordingly economic loss is inevitable. However, this method of control should be kept as a last resort for controlling a destructive pest because its application leads to the interference of main in established ecosystems and in the natural balance and consequently to the creation of incalculable problems. These will be discussed in more detail later in this paper.

VI. New Approaches in Pest Control

There are several recent non-conventional approaches for pest control that are being worked out, mostly still on comparatively small scale levels. Among these methods are applications of the following:

Attractants (including sexual attractants), repellents, antifeedants, chemosterilants, sterilization by irradiation, hormones (such as juvenile hormones), including a lethal or inferior mutations, and several others.

The enthusiasm towards experimenting with such methods reflects the feeling that fight between man and pests requires all his ingenuity to win, though it is still very doubtful that he can exclusively win such a war.

INTEGRATED CONTROL:

Towards the end of the last world war, a new era in pest control started with the discovery and application of synthetic organic insecticides. Within a short period, these chemicals were in wide use in pest control programmes. It is to be admitted that the rapid and widespread adoption of organic pesticides has brought incalculable benefits to mankind. However, through their general and mostly indiscriminate use, the components and complicated interrelations of the agrecosystems have been drastically changed and accordingly a number of problems have resulted. Among these problem are the following:

1) There are many recorded cases of resistance to insecticides, leading to their reduced effect on pests. In many cases resistance is already drastic enough to have eliminated certain insecticides from important pest control programmes.

2) The resurgence of treated species necessitating repeated pesticide applications. Such repeated outbreaks occur from individuals surviving treatment or migrating into the treated area where they can reproduce unregulated because of the elimination of their natural enemies.

3) Outbreaks of non-target arthropods. Among other reasons, these outbreaks usually result from destruction of the natural enemies which otherwise hold the populations of these arthropods in check. The more common examples are the increase of mites, aphids, white flies and others in fields treated with certain pesticides.

4) Environmental disruption outside the pesticide treated area resulting in the build-up of pest problems on adjacent crops or the creation of a pest problem where none existed before.

5) Hazards to pesticide handlers and to persons, livestock and wildlife subjected to contamination by drift.

6) Toxic pesticide residues on food and forage crops and accumulation of harmful pesticide residues within most elements of the environment including man, domestic animals, wildlife, plants, soil, water and others.

With all these problems caused by chemical control, it is more and more appreciated now that chemical control is not, and cannot be, the only and final means of control of all pests. On the contrary, it is more realized now that we need an integrated approach, utilizing all possible means of control in a harmonial way in what is called the "integrated control" concept.

Integrated control is defined as a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible a manner as possible to maintain the pest population at levels below those causing economic injury.

To practice the integrated control system thorough and deep research work on pests and other related elements of the environment should be conducted. These studies should aim at obtained as many information as possible of the biology, ecology, phenology of the pest and of its population dynamics and the biotic and abiotic natural factors affecting its distribution and abundance. A forecasting system of the outbreak numbers of the pests should be developed and economic injury levels of each pest at different conditions should be determined. In general "protective treatments" should not be used and whenever possible "selective pesticides" should have more consideration to be applied.

The effect of pesticides on beneficial forms and on other elements of the environment should always be considered. Accordingly, chemical pesticides are to be used only when nothing else can be done, and in this case the most appropriate pesticide at the lowest possible dose and at a minimum number of applications should be used. A proper timing and place of pesticidal application can also be of benefit. Disease pathogens, used as microbial pesticides, should also be considered for application either alone or combined with a lower dosage of chemical pesticide than normal.

In general it should always be kept in mind that the ideal chemical pesticide is not one that kills the highest proportion of pest numbers regardless of what happens to the natural enemies, but is one that helps reducing the pest numbers so that the balance is shifted back in favour of the natural enemies and hence the pest numbers could be favourable regulated again.

INTEGRATED CONTROL OF COTTON PESTS IN EGYPT:

To illustrate an ongoing programme of integrated pest control in action, control programme of cotton pests in Egypt is summarized here.

The main cotton pests occurrign in Egypt are the following:

Mole crickets, Gryllotalpa spp.; cotton thrips, Thrips tabaci; cotton aphid, Aphis gossypii; cutworm, Agrotis ipsilon; cotton leafworm, Spodoptera littoralis, lesser cotton leafworm, S. exigua; pink bollworm, Pectinophora gossypiella; spiny bollworm, Earias insulana; and mites, Tetranychus spp.

Two of the above mentioned pests; the cotton leafworm and the pink bollworm, are considered as key pests of cotton in this country. An integrated control programme is devised with the aim of attaining an acceptable economic control of cotton pests while restricting as much as possible the use of pesticides and maintaining the natural balance. The main control procedures of cotton pests currently applied in Egypt are summerized here:

1) The cotton leafworm is active all the year round and attacks mainly cotton, maize, clover and many vegetable crops. It overwinters almost exclusively in clover fields. More than 90% of the moths ovipositing in cotton fields for the first brood in May and June emerge from pupae in the soil of adjacent clover fields. In order to minimize infestation in neighboring cotton fields, it is required of law that the last irrigation of clover fields should not exceed 1-10 May. The resulting high soil temperature and low humidity reduces moth emergence and consequently reduces the initial population of the pest in cotton fields, apparently with no harmful effects on natural enemies.

2) In late spring, if clover still harbours heavy cotton leafworm infestations, solar oil (a derivative of crude petroleum oil) rather than persistent pesticides, is applied with irrigation water at the rate of 30 lt. per acre. This measure helps reduce the population of the pest with no harmful effects on beneficial insects. Pesticidal treatments are limited to

fields where infestation actually warrants control and no general spray is applied as used to be the case.

3) No general protective spray is used against thrips infestation early in the season. An economic injury level (8-12 indivduals per seedling) was determined and it is generally used for determining treatments of fields reducing the acreage of treated fields from about one million acres in the early sixties to about 100,000 acres in recent years. Chemical treatment early in the season has a drastic effect on natural enemies.

4) For control of cotton leafworm in cotton fields, hand picking of egg masses still proves to be an efficient control measure. Up to about 85% of the egg masses could be picked and destroyed leading o effective control. The current general recommendation for control comprises concentration on hand picking of egg masses for as long a period as possible. If chemical control has to be applied, usually it comes after the predator peak of abundance in cotton fields which normally takes place in early July.

   Hence, through proper timing of chemical treatment, integration of mechanical, biological and chemical methods of control is accomplished.

5) An economic injury level has been established for infestation of the cotton bolls by bollworms, at 10% infestation of green bolls in fields close to the villages. Since early July each season, trained teams of the Ministry of Agriculture periodically inspect cotton fields for level of bollworms infestation. Chemical control is not allowed in any village unless the economic injury level is attained. This procedure has helped minimizing unduly spraying, delaying unnecessary earlier spraying, and in general reducing the total cotton acreage treated with pesticides.

At least partially due to the practice of the above mentioned procedures, several encouraging phenomena in cotton agro-ecosystem in Egypt have been observed in the last few years. Among these phenomena are the following:

(1) Cotton leafworm infestations are becoming more and more under control.

(2) Early season infestations have been in most cases gradually declining within the last few years.

(3) Loss of cotton yield caused by bollworm infestations declined from about 20% in the fifties to about 5-8% only since the late sixties.

(4) The average yield per acre is fluctuating but generally following a higher level. It has reached a record yield of 334 kg. of baled cotton per acre in 1969.

Finally it should be emphasized that the integrated method of control has worked so satisfactory in many situations and in many areas of the world that there is no doubt as to its advantages and potentialities in many other cases in the future. Necessary information, through research work, should be obtained and whenever possible the method should be tried and short and long term results evaluated.

In all cases it must be well understood that application of chemical pesticides in agriculture is here to stay, still we should also understand that what is actually needed is the "wise" application of pesticides rather than the "wide" application of pesticide.

Staff Paper #36

CONVEYANCE LOSSES IN CANALS

Farouk Shahin, M. Saif Issa,
Bushara Essac and Wadie Fahim

1. INTRODUCTION

In a world where water is such a precious resource, where, water wasted or lost means loss of another man's or land's need. Efficient use of irrigation water is the aim and hope of the irrigation engineer.

The earliest irrigation efficiency concept for evaluating water losses was water conveyance efficiency. Losses which occured while conveying water were often excessive.

In Egypt where precipitation is scarce with increasing population; an optimistic agricultural development plan is laid. Each drop of the River Nile water will be needed to add new cultivated lands.

The huge canals up to 1000 m^3/sec with very long pathes are the symptoms of the irrigation system in Egypt "where the River Nile is the main source of irrigation".

In the system design practical water duties were used for maximum and minimum requirements and calculated according to the cropping pattern, the climate and the soils to insure adequacy of irrigation water to the plants. The adequacy of the irrigation water delivery system doesn't depend only upon the system capacity but, also upon the system efficiency that evaluated whether it is a successful one or not.

* This work has been carried out within the activities of the "Egypt On Farm Management Project" under the guidance of Dr. M. Abu-Zeid the Project Director.

Water that is lost through delivery to fields may become unavailable to the farm. However, part of seepage water may eventually return to the ground water and become harmful by raising the watertable and consequently causes water logging and salinity problems. Some water may also find its way through the outlets and intakes that supposed to be closed and doesn't find its way to the appointed reaches. If such conditions happen system operation problems and low irrigation efficiencies will take place.

2. GENERAL SURVEY

Conveyance losses are still unknown field because of the complex variables that rules it. These losses were considered as a problem since the perennial irrigation was first practiced in Egypt. Many engineers and authors wrote about the direct feeding to the ground water from the system. Willcocks in 1913 said, "When the water levels of the canals throughout winter and summer is maintained above the surface of the ground, the spring level is high and all but the high land salted at the surface, when in contrary the water level of the canals throughout winter and summer maintained below the surface of the ground, the soil is not salted. To prevent the water logging of the soil and to keep the spring level well below the level of the country, it has been found convenient in certain localities to run the canals in alternate weeks...". Many engineers since that time related the high water table directly to the high water levels in the canal system due to the seepage losses along its course.

Therefore, for the system design som imperical values for the conveyance losses in canals specific values are estimated for each case.

For main and secondary canals the following figures had been recommended:

. 10% of the designated flow on Nov., Dec. and Jan.
. 15% " " " " " Feb., Mar., Apr., Sep., and Oct.
. 20% " " " " " May, June, July, and Aug.

Many individual studies were completed for some canals for specific problem evaluation. A study was carried out for the Ismailia Canal. The conveyance losses that estimated for the proposed enlarge showed excessive losses between 10-30%. Other studies for individual canals showed losses that range between 10% and 40% of its flow discharges.

3. THE FIELD OF STUDY

The system losses and efficiencies are one of Egypt's Water Use and Management Project fields of interest which are under study in the project areas.

3.1 TYPES OF WATER LOSSES FROM CANALS

The types of losses from canals are:

1. Seepage losses
2. Evaporation from the water surface
3. Transpiration of the acquatic weeds
4. Outlets and intakes' leaks

3.1.1 Seepage Losses

The factors affecting the quantity of the seepage losses from canals and ditches are:

a. Beds

b. Water levels

c. Ground water table and boundary conditions

3.1.2 Evaporation From the Water Surface

Evaporation from canals depends on the following factors:

a. Canal cross section

b. Meteorological factors

c. Water depth

3.1.3 Evapotranspiration from Acquatic Weeds

Evapotranspiration from acquatic weeds depends on the following factors:

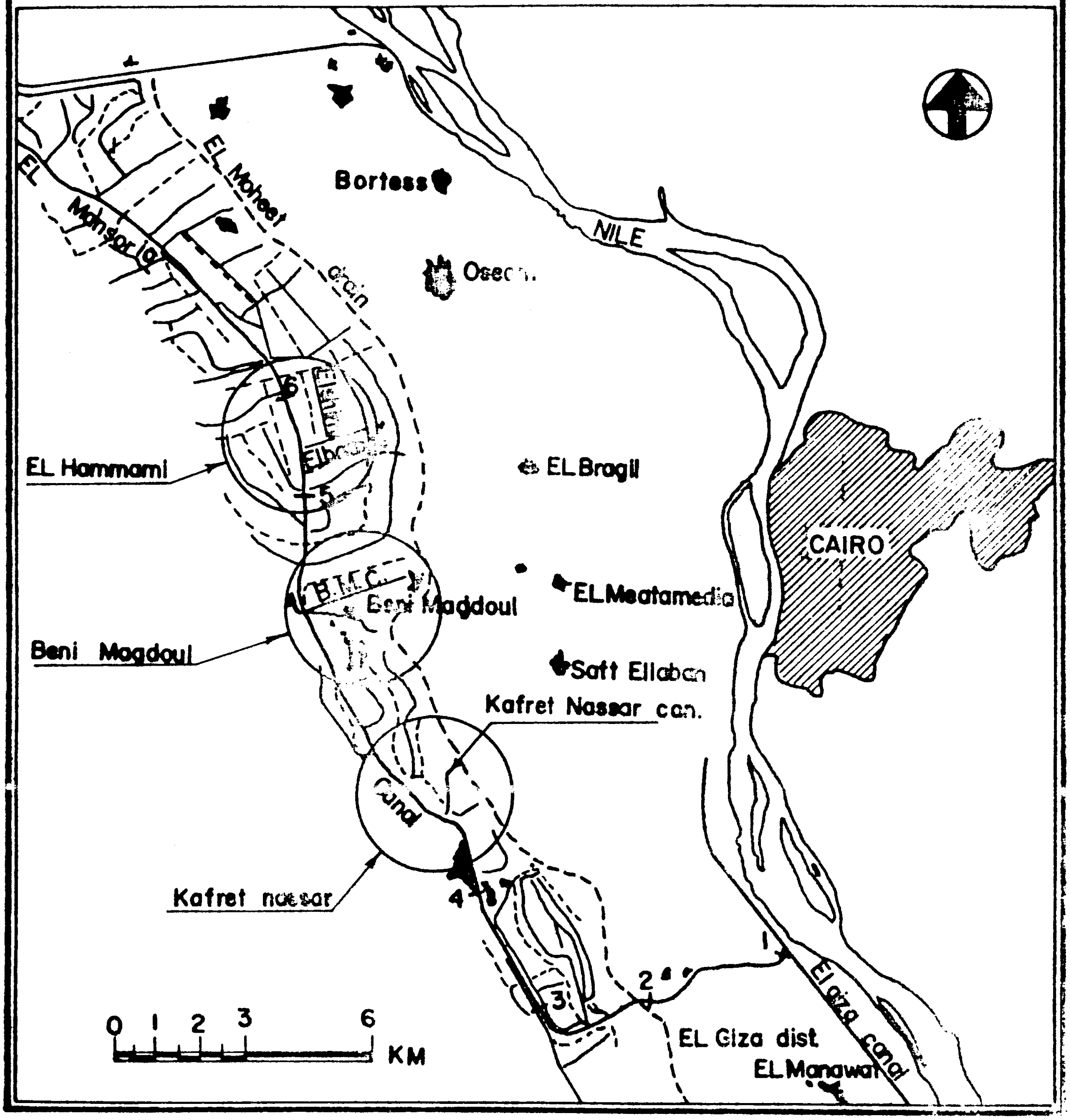
a. Intensity of weeds

b. Kind of weeds

c. Adequacy of water

d. Agrometeorological conditions

General lay out of Mansoria District



3.1.4 Outlets and Intakes' Leaks

The water lost from the leaking and uncontrolled intakes and outlets depend upon:

a. Number and size of the leaky points

b. Hydraulic head

c. The downstream conditions

The conveyance losses as the sum of the prementioned items make a complex interrelations that can't be easily seperated.

As the beds change with depth and distance along the canals, the boundary conditions change randomnly in space and time with the irrigators. Evaporation and evapotranspiration change with time and also between day and night and at last the leaks change with number and size of outlets and its tightness, effective hydraulic heads beside its downstream conditions.

In this study, the conveyance losses are studied as a whole without identifying each kind of loss seperately.

3.2 GENERAL DESCRIPTION

The study area (see map) is fed by Mansouria Main Canal 37 kms long and serves 24000 feddans and of about 650,000 m^3 daily discharge. The canal works as a carrier in its first reach of 12.46 kilometers. The canal inlet is a 2 vent sluice gate 3.0 m wide each. It is also supplied by three regulators, first at kilometer 16.274, second at kilometer 28,545 and the last at kilometer 37. A three rotational system is mainly applied with 4 days on and 8 days off.

Mansouria Canal supplies 24 secondary canals of an average length of 3.00 kilometers besides 121 direct on farm intakes. The secondary canals' intakes are of one vent intakes, that are controlled by timber blocks or relatively leaky sluice metalic gates. The direct intakes are mostly supplied with old unmaintained gates that are open all the time.

3.3 SITES OF MEASUREMENTS

3.3.1 Sites of Measurements in Mansouria Canal

The study was accomplished in the canal at three reaches. The reaches are:

1st Reach: Between site (1) km 0.200 and site (2) km 4.700

2nd Reach: Between site (2) km 4.700 and site (4) km 11,980

3rd Reach: Between site (5) km 24.700 and site (6) km 27.400

3.3.2 Sites of Measurements in Kaffret Nassar Canal

Kaffret Nassar secondary canal was chosen to represent canals with clay beds. The reach of the study was between site (1) at km 0.050 and site (2) at km 1.180. The rotation in this canal is 4 days on and 8 days off.

3.3.3 Sites of Measurements in El Hammami Canal

The measurements were carried out between site (1) km 0.085 and site (2) at km 0.600.

3.3.4 Meska No. 6 in Beni Magdoul Area

This meska was chosen as a model for the study of losses from meskas. Its intake is at the left side of Beni Magdoul canal at km 1.428. The type of soil in this meska is clay. The meska is about 500 m in length. Losses were measured in a reach of about 100 m.

Note: During the discharge measurements the irrigation within each reach under consideration was stopped. The engineers were assuring that no one is irrigating from the reach.

4. FIELD MEASUREMENTS OF CONVEYANCE LOSSES

4.1 INFLOW OUTFLOW METHOD

This method was used on large water courses. The measurements were carried out as follows:

1. The reach of measurements is chosen between two suitable sites.
2. Cross sections between the two sites in the chosen reach have been traced to obtain the mean cross section for the reach. The wetted perimeter was also estimated.
3. The discharges were measured in the same time at the chosen sites at the beginning and at the end of the reach. Different discharges were made at different levels.
4. The soil was classified visually for different reaches.

This method was applied in three chosen reaches in Mansouria canal, the chosen reach in Kaffret Nassar and El Hammami branch canals.

On Kaffret Nassar and El Hammami canals, it was not allowable for the farmers to irrigate during measurements. The technicians were taken care for keeping the farmers not irrigating in the time of measurements.

4.2 POND AREA METHOD

The Pond area method was made for small ditches. These steps were followed for the measurements of the losses on Meska No. 6 left side of Beni Magdoul Canal.

1. The mean cross section of the meska and wetted perimeter were obtained.
2. Earth dams were erected at two sites. The distance between the two earth dams was chosen between 100 m and 70 m, according to the case of irrigation on the meska.
3. Four observation wells were drilled at mid site of the ditch, at 3,10 m from the meska axis.
4. The water levels were controlled at each time of measurement by lifting up-stream the first earth dam.
5. The time of measuring was ranged between 5 hours to 24 hours.
6. The drop in the water level in the pond was recorded just after totally closed the read at its end, by the earth dams. The hook-gauge in stilling well was used for recording the drop in the water levels.
7. The ground water table and the water level in the ditch, the width of the water surface were recorded.

5. ANALYSIS AND RESULTS

5.1 LOSSES FROM MESKAS

From table (1) and fig (2), it is noticed that the total losses were affected by the evaporation rate and the ground water table, it increases also with the difference in head between the ditch water level and the ground water table and vise versa.

Table (1): Rate of drop in the water level in ditch No. 6 Beni Magdoul Canal (mm/day)

Ser. No.	Date	Total drop in the water level mm	Meas. Time hrs.	Rate of drop in the water level in 1 day mm/day	Water level in ditch (m.)	Ground Water table	Ground water Potential
1	9/16/78	5.21	3.7	34.10	16.52	15.96	56
2	9/20/78	5.02	3.0	40.16	16.50	15.86	64
3	10/4/78	3.54	5.2	16.44	16.47	16.62	-15
4	10/18/78	5.45	4.1	32.03	16.61	16.23	38
5	12/5/78	5.13	4.3	28.97	16.64	16.59	5
6	3/14/79	32.54	24.0	32.54	16.59	16.60	- 1

FIG. 2) RELATION SHIP BETWEEN LOSSES FROM DITCH & DIFERENCE IN HEAD BETWEEN THE DITCH & WATER TABLE

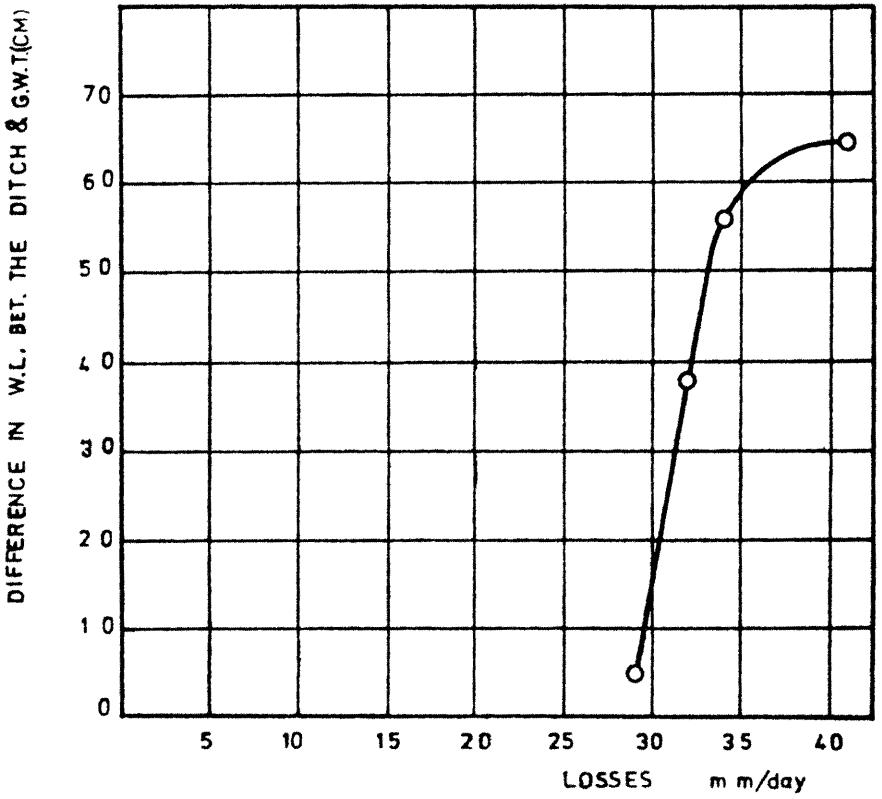


FIG. 3) GAIN AND LOSSES IN MANSURIA M. C. BET. SITES 1 & 2

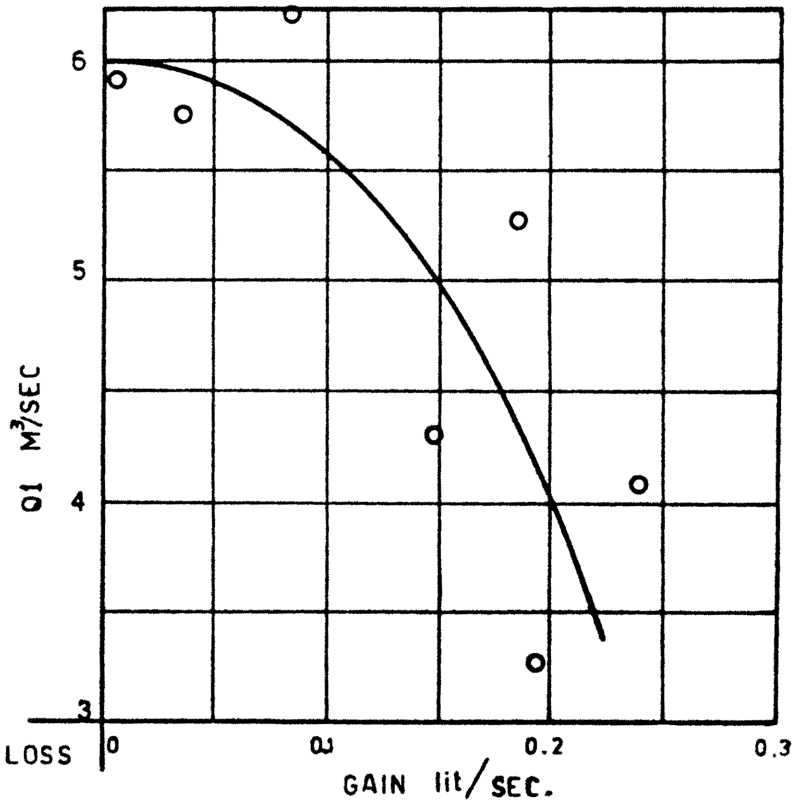


Fig. 4: LOSSES FROM MANSURIA CANAL BETWEEN SITES 2 & 4 K. M. 4.700 & K.M. 11,980

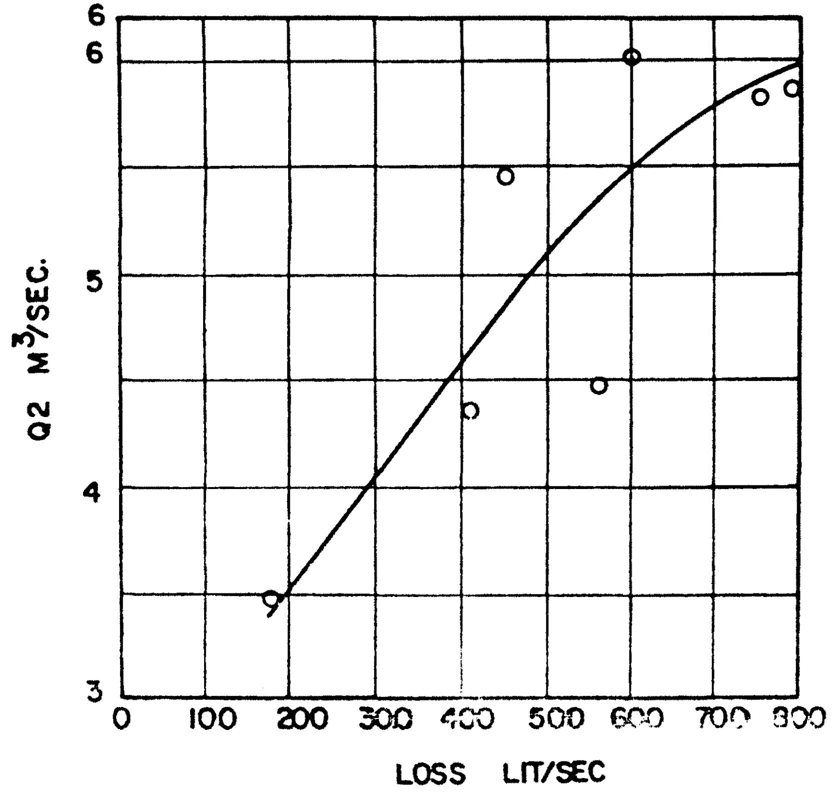
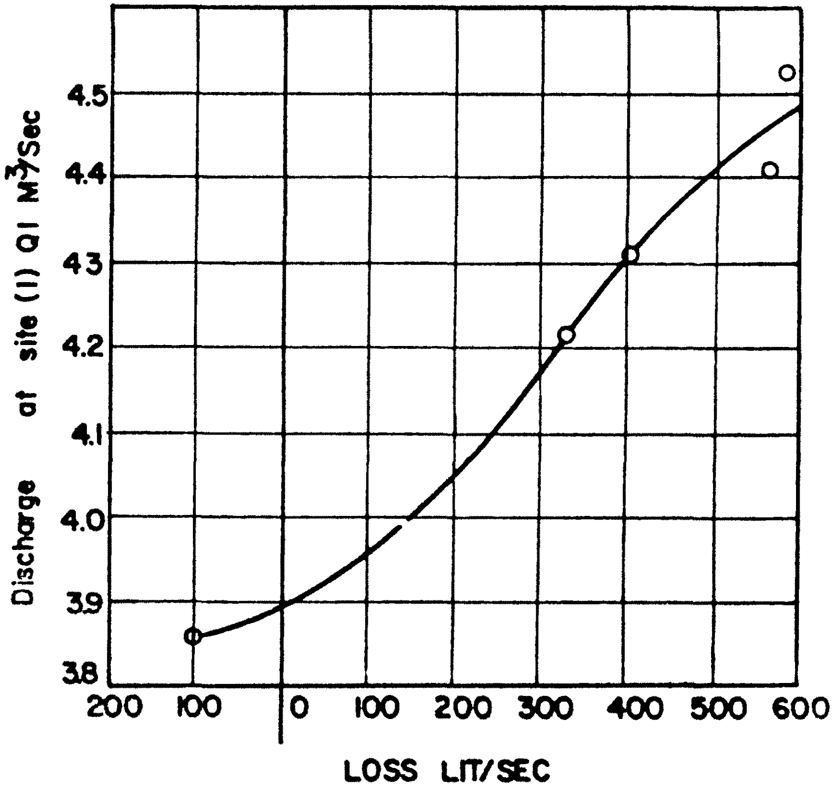


Fig 5: LOSSES FROM MANSURIA CANAL BETWEEN SITES 5 K.M. 24.890 & SITE 6 K. M. 27.450



5.2 MAIN MANSOURIA CANAL

In the first reach between sites (1) and (2), (fig 3) there was mostly gain with slight losses at the higher discharges. The gain increases with a decrease of canal flow. It appears to begin at zero at a flow of about 6m^3 /sec and increases to about 6% at a flow of 3.5m^3/sec. That gain is almost certainly due to seepage from the surroundings.

- In the rest of the first reach, losses were dominant. Between sites 2 & 4, (fig 4) a total length of 7.280 km, the losses increased with an increase in flow, and ranged between 5% and 13%, with an average of 9.73%, of the entering discharge at site 2. This loss represents a loss of 1.34% per each km length. These results may be representative of all losses in that first reach.

- The second reach is near the Hammami area. It may be representative of the middle reach of the canal where the canal bed is of coarse texture and soils. It is between sites 5 and 6 (fig 5). The measured discharges show a higher rate of loss than appeared in the first reach. They also show an increase in water losses with an increase in flow. From the limited number of readings it appears that the loss ranges between 7.9% at a flow of about 4.2 m^3/sec and 12.9% at 4.41 m^3/sec, with an average of about 10.1%. That represents a loss of about 3.93% for each km.

5.3 KAFFRET NASSAR CANAL

In the reach from the intake and km 1.180 there were mostly losses that increase appreciably with the increased flow, while decreases with flow and tends to zero at low flows of about 90 lit/sec, slight gain may happen at flows lower than 90 lit/sec. In this canal irrigation is mostly by gravity where water levels are higher than the ground. (fig 6)

5.4 HAMMAMI CANAL

In this canal it was available to measure only the losses at the first 850 m where no outlets exist. It still shows losses that increase with the increase of flow and canal water levels, the losses are about 20% in that reach where the bed is sandy and the water levels are slightly below ground surface (fig 7).

Fig. 7 LOSSES FROM ELHAMAMI CANAL BETWEEN KM. 0.085 & KM. 0.850

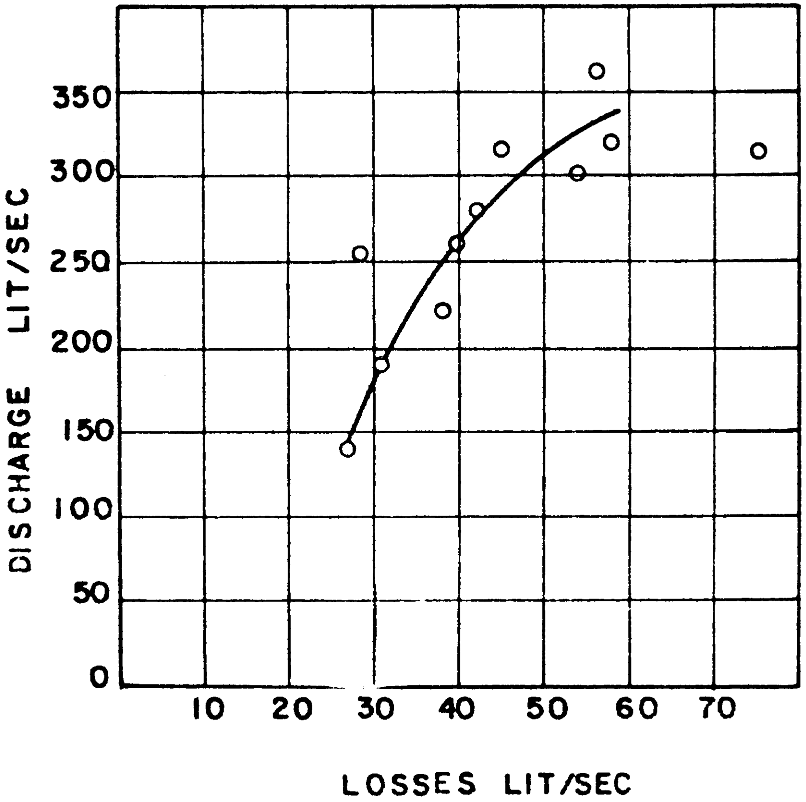
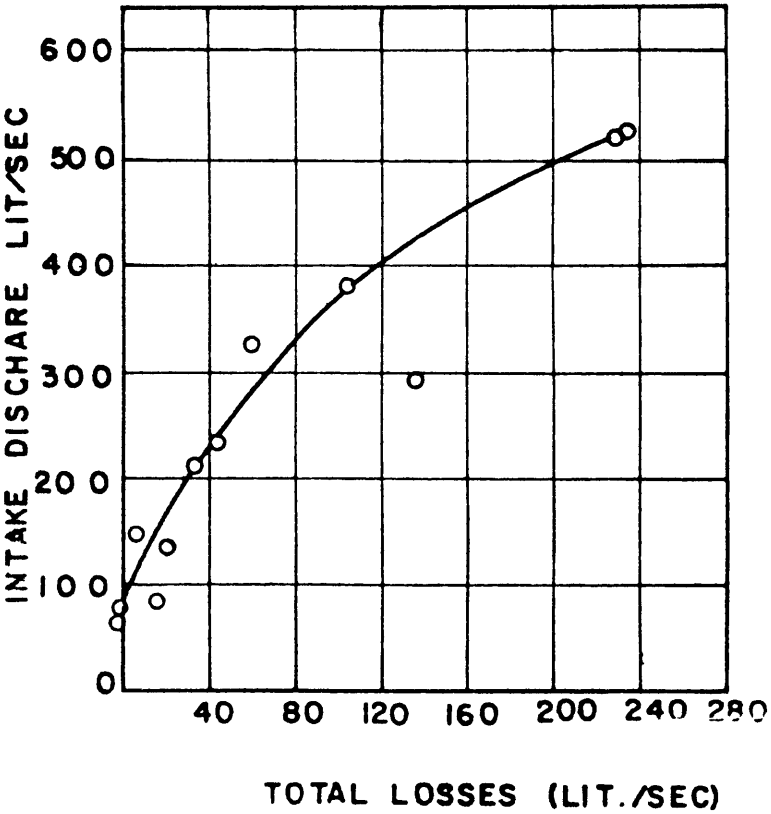


Fig. 6 LOSSES FROM KAFERET NASSAR CANAL BETWEEN INTAKE AND K.M. 1.180



6. THE CONCLUSION

The collected information and analysis indicate or suggest the occurence of appreciable losses in Mansouria Canal and its branches more than expected.

- The losses increase appreciably with the increase of water elevation in the water courses, and decreases and may deminish as the water levels go more below the ground surface.

- An appreciable part of those losses is due to the excessive uncontrolled direct intakes besides the leaky intakes of the branches.

.1 RECOMMENDATIONS

- The application system is needed to be better managed and controlled.
- Direct uncontrolled intakes to be minimized or even prohibited.
- More controlled and less leaky gated intakes have to be developed.
- To lower the design water levels in the canals as possible to minimize the conveyance losses.
- A national program is needed for measuring the conveyance losses in representative water courses and hopefully with the help of the universities.

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Staff Paper #37

A SYSTEMATIC FRAMEWORK FOR DEVELOPMENT OF SOLUTIONS

Max K. Lowdermilk

April, 1980

There is no <u>one</u> way to solve priority problems or to develop solutions for those problems. There are, however, several flexible approaches which can be used within the context of a team operation which will save time and other resources. The systematic framework presented here has been developed by an economist, a sociologist, an agronomist, and two engineers who have written a development of solutions manual under the Pakistan Water Management Project.

The purpose of this paper is to present a framework for development of solutions and to ask each of you to improve it by utilizing your own knowledge and experience. This paper will focus on several key aspects of the process and utilize a few examples.

While reading, keep in mind the key concepts and major emphasis which guide the Research-Development process. As shown in Figure 1 we still have an <u>on-farm approach</u> which is <u>management oriented</u> and requires a <u>systems perspective</u> using a <u>team</u> of workers from <u>relevant disciplines</u>. We still stress the importance of knowing and making explicit your <u>basic assumptions</u> or <u>valuations</u>. Also, <u>training</u> is important for <u>host country personnel</u>. <u>Communication</u> among <u>team members</u> and between <u>team members</u>, and <u>farmers</u> is as important for DOS as at any stage of the process. <u>Setting objectives</u> to know where we are going and building in a <u>continuous monitoring</u> and <u>evaluation process</u> is also vital to DOS. Additionally, a basic emphasis is that the team which identifies the farmer's priority problems must be the same team which develops the alternative solutions for the final stage of the process, project implementation.

The remainder of this paper will be organized in the following manner:

I. A Systematic Framework for DOS and Key Concepts

  A. Identification and ranking of potential solutions

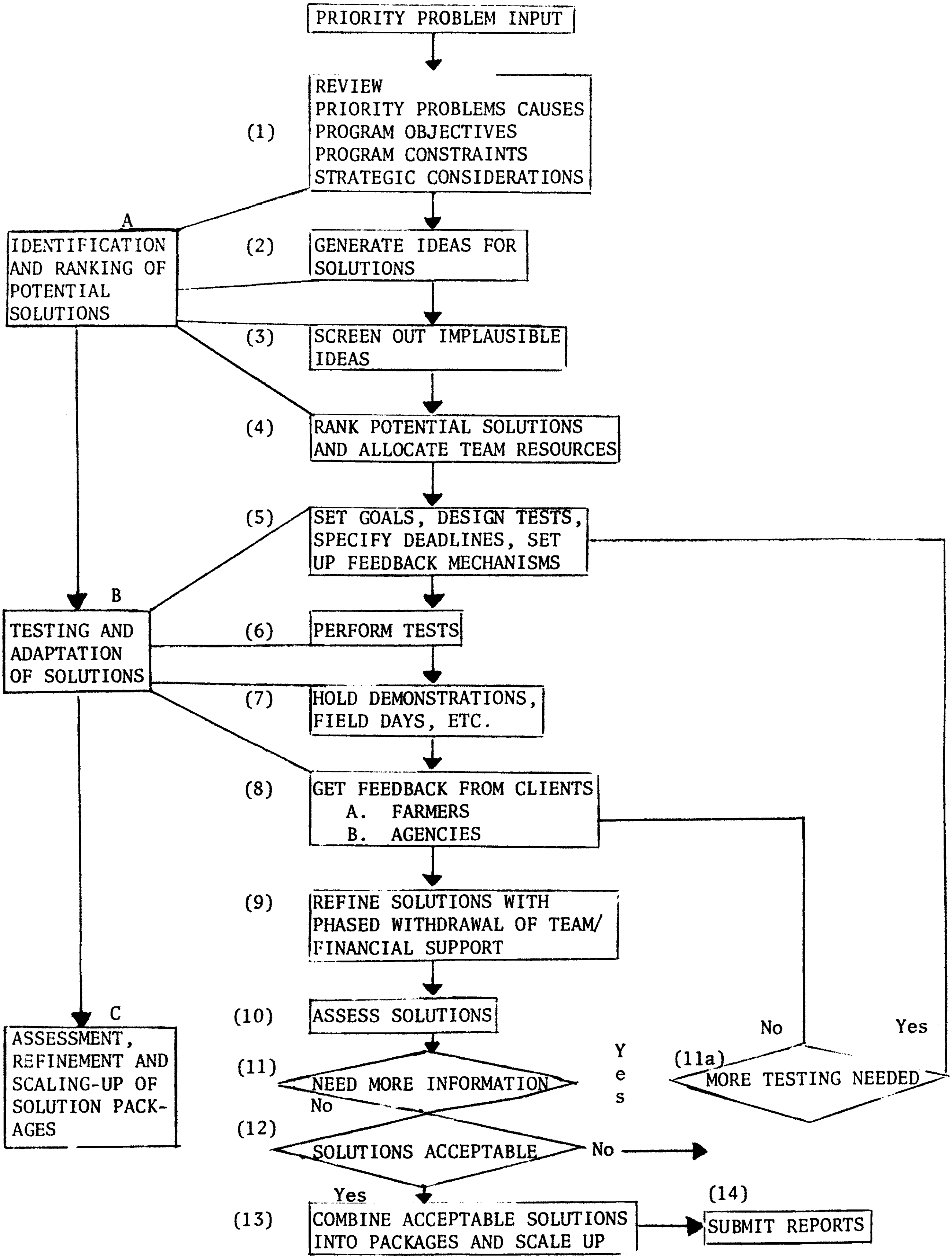

Figure 1. Systematic Framework for Development of Solutions

Source: Development of Solutions Manual by Sparling, Lowdermilk, Skogerboe, Steward, Lattimore. Pakistan Water Management Project, CSU Fort Collins 1980

   B. Testing and adaptation of solutions
   C. Assessment, refinement, and scaling-up of solution packages

II. A note on the importance of performance objectives as tools in developing solutions

III. A method for productive team output in decisions about performance objectives: Brainstorming

I. Systematic Framework for DOS and Key Concepts

Time will permit only a brief description of the framework. This is shown in Figure 1 and discussed below.

A. Identification and Ranking of Potential Solutions

The input for DOS is the experience, knowledge, and the data from OI. Remember that in PI you first develop hypotheses after the Reconnaissance, then test the hypotheses with quantitative and qualitative data, and finally are able to identify some of the major causes in contrast to the symptoms of these problems. As a team, you established criteria for ranking these problems. These criteria could have been increased crop production, income distribution, and resource maintenance.

Utilizing the input from PI you will need to review the causes of the high priority problems. Experience shows that you should stress a few key problems rather than many. Also, as A(1) in Figure 1 indicates, as a team you need to be sure of where you are going. Therefore, you should carefully look at your objectives. Some will be provided by Government policy and some the team may evolve. Again, depending on the particular policy of a Government, the objectives may be increased agricultural production, improved income distribution, resource maintenance or others. Table 1 provides a long list of possible ways to meet these three objectives, but it is by no means complete. Use this table only for ideas.

TABLE 1. PROGRAM OBJECTIVES

- Increasing Crop Production
- Optimizing Use of Plant Environment
    - Identification of best crops and varieties for environment
    - Breeding new varieties
    - Improving practices
- Complementing Plant Environment
    - Reduce costs of agri-chemicals
    - Add organic matter to soil
    - Add tillable acreage by modifying terrain
- Optimizing Labor Use
    - Change cropping patterns to reduce labor bottlenecks
    - Education of farmers
    - Improved nutrition
    - Improved health
- Complementing Labor Use
    - Introduction of labor-saving machines
    - Facilitate mobility of seasonal laborers
- Optimizing Use of Current Water Supply and Removal System
    - Land leveling
    - Bunding
    - Maintenance of delivery and removal systems
    - Improved application efficiency
    - Improvement of scheduling
- Complementing Water Supply and Removal System
    - Modification of supply and removal systems
    - Addition of storage capacity
    - Addition of wells
- Optimizing Use of Current Organizational, Institutional and Legal Infrastructure
    - Rationalization of prices with national priorities
    - Rationalization of organizational incentive structures
    - Develop incentives for Water User Associations
    - Education and training of agency staff
- Changing Existing Infrastructure
    - Add new organizations to service farmers
    - Development of marketing services for inputs and outputs
    - Develop new organization to manage interregional water allocation
    - Change laws to allocate water rights to individuals
    - Land consolidation
    - Land reform
    - Organize cooperatives or Water User Associations
- Income Distribution
- Increase Productivity of Resources Belonging to Poorer Farmers and Laborers:
    - Labor: education, extension, nutrition, health, machinery, chemical inputs, new varieties with shorter duration
    - Land: consolidation, leveling, increased water supply, complementing nutrients, higher yielding varieties
    - Water: increase application efficiency, increase delivery efficiency, introduce crop varieties better adapted to water

Increase Access to Productive Resources
    Land: reform, consolidation and cooperative use
    Water: redistribution and enforcement of water rights
    Capital: credit, collective ownership of indivisible capital equipment (tubewells, tractors, etc.)
    Information: Extension, education, mass media
Direct Redistribution of Income
    Tax relief
    Subsidies
    Food programs
    Free medical care
    Direct transfer payments (social security, welfare, etc.)
Increase Demand for Farm Products
    Transportation, storage, and other marketing systems
    Development of overseas markets
    Development of domestic processing industries
Reduce Uncertainty for Smaller Farmers
    Disease and pest control
    Regulation of water supply
    Regulation of prices
    Crop insurance
    Organize credit cooperatives
    Establish dependable marketing for inputs and outputs
Increase Access of Small Farmers to Government Agencies
    Organize small farmers into politically-effective groups
    Furnish small farmers with advocates to plead cases with agencies

<u>Resource Conservation</u>

Water
    Maintenance of quality of water supplies
    Maintenance of sustainable yield from water supplies
    Increasing sustainable yields through storage
Soil
    Maintenance of "optimal" levels of erosion
    Reclamation of degraded soils
    Maintenance of acceptable levels of soil salinity
Air
    Maintain safe quality
    Maintain aesthetic quality
Forests
    Maintenance of sustainable yields from forests
    Extend acreage of forests to increase sustainable yields
    Introduce substitutes for wood as fuel and construction materials
Fisheries
    Maintenance of quality of water
    Maintenance of sustainable yields or
    Increasing sustainable yields
Rangeland
    Maintain sustainable yield
    Increase nutritional value of yield
    Increase efficiency of animals

Source: <u>Development of Solutions Manual</u> by Sparling, Lowdermilk, Skogerboe, and Stewart. Pakistan Water Management Project, Colorado State University, Fort Collins, Colorado, 1980

The specific context of your team work in DOS will likely provide other ways of meeting objectives. A(1) in Figure 1 also indicates that you, as a team, need to carefully consider constraints which limit what can be done in DOS. In the real world you will have many constraints. If you assume that there are none, you will run into conflicts between "the idea" and "the real" situations. For example, Table 2 provides a checklist of Program Resources which can pose constraints to DOS. These include personnel available, budget, equipment, access to agencies and authorities, and available information. Remember Murphy's Law that "if anything can go wrong, it will," and Lowdermilk's modified collary that "you can't win completely," "you often can't break even," and "you certainly can't quit the game of DOS."[*]

Another consideration under A(1) in Figure 1, is that the team should look at strategic considerations. Again return to the objectives. If your objectives are increased agricultural production, improved income distribution with a focus on small farmers and tenants, plus resource conservation, then these are criteria which guide and delimit your work with DOS.

Figures 2 and 3 provide a matrix approach which also helps to focus the DOS process. Note in Figure 2 the constraints of <u>program priorities</u>, <u>program constraints</u>, <u>time requirements</u>, and <u>resource requirements</u>. The <u>target interest groups</u> also need to be identified. Elite farmers, politicians can be a real constraint. There are many potential <u>uncertainties</u> as well as <u>complementarities</u>. You may want to reduce <u>uncertainties</u> by particular solutions and maximize complementary solutions

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[*] See Adams, Jones L. <u>Conceptual Blockbusting</u>, A Guide to Better Ideas, W. M. Freeman and Company, San Francisco, 1974

TABLE 2. PROGRAM RESOURCES CHECKLIST

Project Personnel

- Agronomists
- Engineers
  - Civil
  - Agricultural
- Hydrologists
- Economists
- Sociologists
- Lawyers
- Managers

Research and Development Budget

- Transportation
- Clerical
- Computational
- Laboratory Equipment
- Field Equipment
- Field Assistants

Equipment

- Lab equipment
- Field testing equipment
- Tractors
- Earthmovers
- Levelers, etc.

Access to Agencies Resources

- Personnel
  - Agronomists, etc.
- Facilities
  - Laboratories
  - Experiment Station
  - Field Equipment, etc.

Access to Authority

- Irrigation Department
  - National
  - Regional
  - Local
- Agricultural Ministry
  - National
  - Regional
  - Local
- Transportation Ministry
  - National
  - Regional
  - Local
- Ministry of Finance
  - National
  - Regional
  - Local

Information (Local/Regional (National/International)

- Climatic Data
- Soil Data
- Water Supply Data
- Hydrologic Data
- Plant varieties and properties
- Data on plant disease and pests
- Economic Data
- Sociological Data
- Information regarding interest groups

Source: *Development of Solutions Manual*, 1980

		Potential solutions: candidates for development				
		Solution 1	Solution 2	Solution 3	- - -	Solution n
First solutions/criteria matrix	Program priorities))) Program constraints)	(See tables II-1 and II-2				
	Time requirements					
	Interest groups affected					
	Uncertainties					
	Complementarities					
	Resource requirements					

Figure 2. First Solutions/Criteria Matrix

		Developed solutions: candidates for implementation		
		Solution 1	Solution 2	Solution 3
Final solutions/criteria matrix	Economic productivity effects Group 1 2 3 . . . m Total			
	Income effects Group 1 2 3 . . .			
	Resource conservation effects Group 1 2 3 . . . m			
	Uncertainities Group 1 2 3 . . . m			

Figure 3. Final Solutions/Criteria Matrix

Source: Development of Solutions Manual, 1980 which will fit well with other potential solutions. Figure 3 also suggests that the matrix exists to "zero-in" on four major dimensions which can be detailed. This is important as the team brainstorms and begins to reach some level of concensus on strategic considerations.

Under A(2) in Figure 1, the team using the matrix approach and objectives generates potential ideas for solutions. The objectives, constraints, and the strategic considerations help to set limits on the process. Under A(3) you utilize these limiting factors for screening-out implausible ideas about solutions. Each solution suggested should be examined in relationship to the matrix the team develops (see Figure 2). For example, a center pivot irrigation system may be an "ideal solution" for the problem of poor application rates due to unlevel topography and soils with high infiltration rates, but this irrigation system may not be plausible for small farmers in a developing nation.

Utilize Figures 2 and 3 for ranking all potential solutions and allocate the potential plausible solutions in relationship to the scarce resources under your command. Be realistic, as there are always constraints of scarce resources as suggested in Figure 3.

We will next have to set activities under B in Figure 1 for testing and adaptations of solutions. Remember that there are often direct solutions to priority problems where the solution passes the tests or criteria established. There are some direct solutions such as revised water revenue rates, changes in other policies such as water allocation procedures, incentives and services for farmers, etc. For these solutions, however, it would be difficult to design tests, demonstrations, or experiments for monitoring and evaluation. Therefore, such solutions can only be evaluated in an expost facto manner. In some places, however, these solutions can be evaluated in relationship to bench mark data about the change before it occurred.

B. Testing and Adaptation of Solutions

At stage B(5) in Figure 1, the team should set goals carefully, design tests to be conducted, specify deadlines, and establish feedback mechanisms to ensure good communication between farmers and researchers, and between those parties and government officials. Too often little attention is given to communication. Without this communication, creditability with farmers, between team members, and with relevant agencies is hard to develop. In terms of goals which seldom can be measured, you need to move to more specific objectives which describe what you intend to do. These objectives should also describe the observable actions to be measured and the standards or criteria which will help you establish the degree of success achieved. You can think in terms of Figure 4 below:

Under (1) in Figure 4 you can develop your criteria of success on the basis of quantity, quality, time or other standards which must be met. An example of such a criterion would be to reduce water losses in conveyance channels by 75% in one month in such a way that this level of performance is maintained by farmers. Note that each criterion added makes the activity or solution more difficult to measure in terms of established criteria.

Under (2) in Figure 4 the team must decide on the processes used to achieve the criteria and under (3) the specific measurements to be made. If the measurements show that you have not achieved the level of performance shown in your established criteria, go back and check the process to see what went wrong.

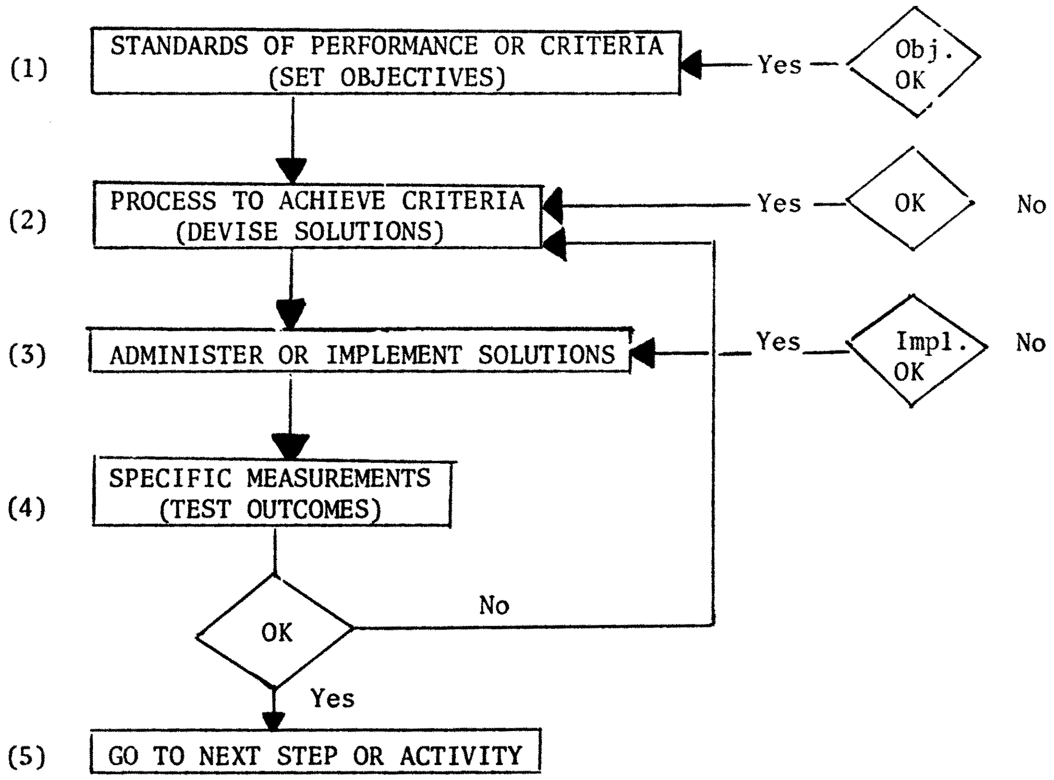

Figure 4.

Source: Pipe, Peter , Objectives - Tool For Change; Fearon Publishers, Inc. Belmont, California, 1975

Under B(6) in Figure 1, perform the tests you have established and with the farmer evaluate the results. If the solution proves useful to farmers, then work with the farmers to set-up demonstrations or field days where the farmers, not the team members, are on center stage. Let it be their field day and see that relevant government officials are there to interface with (not dominate) farmers. If the solution is useful to farmers, they can "sell" it to other farmers and officials better than the researcher can. Remember, "if the farmer can't sell it, we won't try." At B(8) work hard to get feedback from farmers, officials, and individuals who work both directly and indirectly with farmers (examples: extension, fertilizer, agents, credit or banking people).

At this point the feedback will help the team to refine the solutions (B[9]). This refinement process is critical for the adoption of the solutions by various classes of farmers who may not have the same conditions (soils, crops, etc.) as the original location where the solution was first developed. A key concept is adaptive research where findings developed under one set of conditions are modified for other conditions or areas.

In B(9) phased withdrawal of team and financial support is important. For too prevalent is the problem of "throwing too many resources" at a problem and then expecting that farmers can adapt. This is a major reason why farmers do not place much creditability on research station results, model farm results, and even extension demonstration results. They simply can never expect to command as many resources. This is why we stress "on-farm", farm and farmer conditions. My experience suggests that farmers use a discount factor when they observe results from experiment stations and projects because they know that they cannot command all those resources of scientific manpower and capital.

In Pakistan we often made this mistake and gave the mistaken impression that over time, farmers could adopt successfully certain improvement solutions developed by our team. At some point the team members must "move back," "Take hands off," and observe systematically whether or not the solutions will survive under farmer's conditions, especially considering the level of support the government can provide. Remember that the transfer of technology in low income nations repeatedly fails because it is not appropriate to the real world conditions.

C. Assessment, Refinement, and Scaling-Up of Solution Packages

Under C in Figure 1, Assessments, Refinements, and Scaling-Up of Solution Packages is the next set of activities. There are many types of assessments which include technical feasibility, economic feasibility, social impact and organizational feasibility, management feasibility, financial feasibility, and even political feasibility. Some of the methods of doing this will be discussed in the seminar. This is a new field which still needs more attention then it receives. Always the assessment is conducted in relationship to specific criteria and objectives which are both given to and derived by the team. This serves as a guidance mechanism for the DOS process and a way for delimiting and measuring the worth of the solutions evolved.

The concept of scaling-up in (C) Figure 1, refers to the assessment and refinement of solutions for a national program. Scaling-up means an examination of the resources needed for a project. The project could range from a pilot project to a full national project.

At this stage, C(12), if more information is needed for refinement of the solutions packages, then as Figure 1 indicates, you go back and locate the type needed. The assessment process often will provide the types of information needed. At any rate, the team may need to recycle some activities. If the objectives change, as is sometimes the case due to political forces, then each solution must be re-examined with the new criteria in mind. At C(11), if more information is needed you may need to conduct more tests (11a) or move back to check the designs to the tests already conducted at B(5).

If solutions have not been combined earlier in a complementary relationship, then such a synthesis will have to take place at C(13). For large improvement projects rarely will there be only single alternative solutions. The concept of complementarity is important here. For example, in the Pakistan project, water course rehabilitation, precision land leveling, and on-farm water management advisory services were chosen. Because a combination of these three solutions promised a reduction in conveyance losses, improved field application of water due to leveling fields, and improved water management and crop practices. All these factors assured increased crop production for small farmers. The technological and social solutions involved were tested in the Development of Solutions Phase. Further physical, social, economic, and other assessment results showed that these three components could be supported adequately within the context of Pakistan's resource constraints.

Finally, at C(14), reports are prepared and submitted for several audiences. First, a detailed technical report is made available for personnel who must develop proposals for local and foreign funding agencies. Secondly, a brief non-technical report is prepared for policy decision makers such as the Planning Commission. Third, a brief non-technical executive summary is needed for top officials such as busy ministers and their duputies.

There is a last caveat (warning) to remember. Once the alternative solutions have been made available through the DOS process, the decisions to be made are usually both technical and political, as a different process emerged for policy decisions on a project.

II. A Note on the Role of Objectives as Tools in Developing Solutions*

Throughout this brief overview of a systematic approach for DOS, stress has been given to the role of clear performance objectives. To sum up the use of objectives, we remind the reader that objectives

1. Describe the intent of what you expect to do.
2. Describe the conditions under which the action (trial, experiment, demonstration) is to be performed.
3. Includes an indication of the resources which are to be made available or withheld.
4. Establish the criteria in terms of quantity, quality, time limits, or other standards which must be met to judge success or failure.

An example of a performance objective related to improving delivery efficiencies is as follows:

Observable Action:	Reduction of conveyance effiencies on farm delivery systems
Conditions:	Earthen improved systems at farm level
Criteria:	Cost effective improvements over a ____________________ with delivery efficiencies of 70 percent.

If performance itself is important, then it should be specified in the objectives. Therefore, in the criteria, identify the minimum requirements which can be accepted for successful performance. Take heed, however, and remember real world conditions at the farm level.

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*Pipe, Peter, Objectives - Tool For Change, Fearon Publishers, Inc. Belmont, California, 1975

Often individuals who do not have adequate experience in the real world set unrealistic criteria which are impossible to meet. You need a rationale for establishing criteria related to time, quality, quantity, or other indications which will ascertain degree of success. Also, in setting objectives, isolate the desired action carefully and identify the conditions. This will force one to be specific. Remember that performance objective can be measured while a good is usually a description of an intent stated in terms which are not measurable. An objective, then, is a description of an intent stated in measurable terms. A performance objective is one that describes that intent of terms of observable performance. There are the types of objectives which would guide the DOS process and help to make it a systematic rather than a random process. It is a sad fact of life that much development research is characterized too often by "drift" rather than "direction", and "fuzziness" rather than "focus". The DOS process must have both focus and direction if it is to produce an ultimate result.

One conceptual method of attaining a useful ultimate product is to think in terms of process and product. Table 3 shows how this can be done. Assume that the general good is "the improvement of on-farm water management," and the performance objective is to "reduce conveyance losses by 75 percent."

Such an approach of separating the process from the product helps in developing clarity.

III. Rules for Brainstorming in Setting Performance Objectives Within the Ream Context

As is evident from the discussion on developing objectives and reaching concensus in the DOS process, it is important to develop rules for brainstorming and decision making. As suggested in other materials

TABLE 3.

GOAL: Improvement of OFWM

OBJECTIVE: Reduce Conveyance Losses by 75 percent

PROCESS	PRODUCT
A. Use Output of P.I. and examine causes vs. symptoms	A. Causes of problems documented
B. Divide plans for DOS	B. Clear performance objectives
C. Implement alternative solution	C. Receive data from monitoring and evaluation
D. Test alternative solutions	D. Conveyance loss reduced by 75 percent

presented in this seminary, team work is not easy and team building is an unending process. Several basic rules exits for gaining maximum team output from team sessions of brainstorming. A cardinal principle is that no one criticizes anothers idea or uses any means of intimidation. Such efforts stiffle creative thinking, sidetracks the creative process and causes individuals to remain silent. One productive approach[*] is as follows:

1. Write out the goal of DOS clearly so that it is visible to all.
2. Each team member is requested to work alone and answer the question "how will I know success when I see it?"
3. Working alone, each team member draws up a list of performance objectives which, when combined, will mean that the goal is reached.
4. At the end of 20-30 minutes each team member alone is asked to refine his or her performance objectives. (Be sure that the criteria for success can be measured by observable peformance).
5. Each team member alone identifies his or her top ten indicators which are the best predictors of success.
6. The team leader then asks each member in turn to state the top priority of his or her performance objectives which is written on a blackboard or flip chart. After each team member has provided his or her top objectives, then the leader goes around the group for the second best objective and so on until all 10 objectives of each member are recorded.
7. When the list is complete, it is revised in group discussion and refined. Each member of the team can defend his or her performance objective with rationale.

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[*] Adopted from Pipe, Peter, Objectives - Tool For Change, Fearon Publishers, Inc. Belmont, California, 1975

Conclusion

I have described the skeleton framework for a systematic DOS process and stressed the importance of several key concepts. More detailed information on procedures is available. The emphasis on performance objectives is to stress that all important concept: FOCUS.

As you read this, I would appreciate your comments and suggestions. We, as a team, must search for systematic DOS approaches which will provide useful results to small farmers around the world.

Staff Paper # 38

RESPONSE OF RICE, WHEAT AND FLAX TO ZINC APPLICATIONS ON THE SOILS OF THE NILE DELTA

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INTRODUCTION

The Egypt Water Use and Management Project objectives are primarily concerned with improving the social and economic welfare of the small Egyptian farmer by the application of viable on-farm management alternatives that would result in crop yield increases. There are four basic components in project activities in order to formulate and demonstrate on-farm management alternatives: 1. problem identification, 2. search for solutions, 3. testing of solutions to the problems identified and, 4. the diffusion of information.

Early in the problem identification phase micronutrient deficiencies were observed in many of the crops growing on the field sites that were selected as common study areas. A review of recent Egyptian literature indicated, that under experimental conditions, a marked increase in crop yields occured when micro-nutrients (zinc in particular) were added to the regular fertilizer program. This information was the basis for the field trials that were used as a solution testing program to the problems that were identified.

The greater majority of the alluvial soils of the Nile Valley and Delta owe their existence to the deposition of the suspended matter carried by the river from its source in the Ethiopian and Victorian plateaus and this parent material has a major influence on soil characteristics (9). Before construction of the High Dam a total of as much as 25 million tons were estimated to pass by Cairo during the month of September and eventually reaching a minimum of 0.5 million tons in May and June (9). The suspended matter contained from 55 to 65 percent clay with a silt content ranging from 25 to 30 percent and organic matter on the order to 2.3 to 4.5 percent. The composition of the suspended material of the Nile water has changed and the amount of sediment carried decreased markedly after construction of the High Dam. This change in composition could in part be one reason why many Egyptian soils are now deficient in micronutrients at the present time.

Another factor related to micronutrient deficiencies is the present allocation of fertilizers to Egyptian farmers. The practice of fertilization is mainly directed towards the addition of nitrogen and phosphorus and little account is taken of the variability in soils, cropping patterns and micronutrients. This system works fairly well but is seriously deficient when it comes to maximizing yields. The present productivity of Egyptian soils as determined by the yield of crops shows that the yield of the major crops are relatively high. Yields related to the world average, as 100 percent, ranged from 208 percent for cotton to 232 for rice (9). These are broad based averages indicating that crop production practices are relatively good but they can also be misleading. Recognizing that Egypt has fertile alluvial soils coupled with adequate water of good quality, ample sunlight, weather that permits year-round cultivation of the land and highly skilled farmers makes for an ideal combination for high levels of crop productivity.

Despite these unique favorable factors there remain several serious constraints to maximized crop production. A high water table, poor drainage, non-uniform water distribution on land, small land holdings, pest control, and minor soil element deficiencies are some of the major constraints to maximized crop production. Yields on farm fields are approximately 50 percent of the yields obtained on experimental stations in Egypt (9).

The purpose of this paper is to focus on the micronutrients constraint and present information obtained from field trials relative to the increase in productivity of various crops where micronutrients were added as part of the regular fertilizer program. Information of this type will also be a basis for the development of a soil testing program that will recommend the application of fertilizer by specific soil conditions rather than by area wide conditions.

REVIEW OF LITERATURE

The lack of micronutrients in many Egyptian soils is a rather recent and unexpected constraint to maximized agricultural production. Deficiencies in these minor elements are not generally visible to the eye but they do exert significant effects particularly in the lack of good response to the macro-nutrients such as nitrogen and phosphorus (6). These deficiencies can be attributed in part to each of the following factors: 1. The introduction of new high yielding crop varieties which generally have higher requirements for these micronutrients, 2. The use of high analysis fertilizers which contain no impurities as the older formulations had a significant amount of trace elements and 3. Prior to the building of the High Dam some minor elements were supplied to the soil in the form of sediment carried in the irrigation water from the Nile. This yearly replenishment no longer occurs due to the deposition of sediments in Lake Nasser.

To meet these changed conditions, expanded facilities for area soil testing and plant tissue analysis will be required as well as expanded demonstrations on farmers fields as a means of remedying trace element deficiencies. A good share of the agronomic work being carried on in Mansouria and Kafr El Sheikh is involved with the use of zinc sulphate and foliar fertilizers containing both macro and micronutrients applied to the major crops grown in both areas. In order to facilitate the discussion on literature this paper will deal with only 4 trace elements namely, zinc, manganese, copper and iron. The reader is referred to the following reference if more detail is required on other trace elements; Micronutrients in Agriculture, 1972. Edited by J. J. Mortvedt, P. M. Giordano and W. L. Lindsay, editors. Soil Sci. Soc. of America Monograph.

Zinc:

Of the six micronutrients that are of importance to crop production, zinc is among those found to have low concentration levels in soils (12). Krauskopf (12) points out that Zn, Mn, Cu and Fe are generally more abundant in basalts than in granites. Concentration in soils show wide variations since the raw material and the soil forming processes are so different from one climate to another. Kadi et al (7) in evaluating the zinc status in soils of Egypt showed that the total zinc content ranged from 18 to 156 ppm. They noted that the highest levels were found in heavy alluvial soils while moderate levels were noted in calcareous soils with sandy soils having the lowest levels of zinc. El Damaty et al (4) in evaluating 50 soils noted that the total zinc levels ranged from 3 to 195 ppm. They also noted that zinc generally increased with an increase in the silt and clay content. Positive significant correlations were found between Zn in plant and the amount extracted from soils. Soils from the Nile Delta, along the Mediterranean coast, Wadi el Natrun and Kharga oasis and treated with zinc, increased dry matter production of tomatoes by an average of 15%. The increase in production was exceptionally high on plants growing on Wadi el Natrun soils as an increase of 30% was obtained (21). This large increase was attributed to the inherent low level of zinc in these soils. El Sherif et al (8) measured the movement of zinc in some Egyptian soils having high pH values and noted that most of the applied zinc was retained in the surface 1-2 cm depth except for sandy soils from Wadi el Natrun where there was no restriction to movement. This fixation was, in part, attributed to the transformation from a positively charged zinc ion to a negatively charaged zincate ion in alkaline soils. The presence of the zincate complex in alkaline systems has been confirmed by Jurinak and Thorne (11).

Zinc deficiency of wetland rice has received more attention than any other nutritional problem in recent years. Zinc deficiency in rice was first reported as a field problem by Nene (17) and subsequently has been reported in Pakistan, India, Philippines, Japan, U.S., Chad, Nigeria, and Egypt. Next to nitrogen and phosphorus, lack of zinc is the most limiting factor in the production of wetland rice. Castro (1) in a comprehensive review on zinc deficiency in rice noted that this condition in soils was brought about by high pH, continuous waterlogging, low inherent zinc content of the soil, high organic matter content and high levels of fertilizers. He concluded that deficiency can be corrected by draining fields, dipping seedlings in a 2% suspension of zinc oxide in water before transplanting or by applying zinc sulphate to the rice nursery or field.

Manganese

The chemistry of manganese in soils shows that this micronutrient exists in different forms having widely divergent solubilities. Although positive responses of crops to the application of manganese have been reported, manganese deficiency in most crops has not been recognized in the field. However, it cannot be ruled out as it could occur on sandy soils, sodic soils and calcareous soils low in organic matter. These types of soil are characteristic of many of the soils found in the project work sites and particularly in the Abu Rayah and El Hammami areas.

El Damaty _et al_ (2) in examining the manganese status of seventy-four samples of soil, which as far as possible, represents most of the soils in Egypt, noted that the water soluble manganese form was completely absent in all soils. Alluvial soils were found to contain fairly high amounts of chemically available manganese which was sufficient to support normal growth. They also found that these alluvial soils were rich in total manganese and attributed this to the annual sedimentation of the solid matter transported by the Nile. However, since the high dam now stops this sedimentation from occuring in the valley and delta, possible deficiencies could occur particularly in sandy and calcareous soils as they are inherently low in manganese to begin with. In addition, waterlogging, as in the case of paddy rice production, causes an increase in concentration of water soluble manganese due to the reduction of the less available forms. The water soluble forms which were absent before waterlogging occured, reached 4 ppm in many soils. Dry matter yields of rice grown on continuously flooded soils was found to be higher than on unsubmerged soils. In addition, the reduction of MN^{++++} oxides also releases copper and zinc absorbed on them (10).

Copper:

A study (3) on the status of copper and its relationship with pH, % $CaCO_3$, % organic matter and the soil particle constituents was carried out on 75 samples that represented the main types of the soils of Egypt. The study revealed that alluvial soils contained high levels of chemically available copper compared with levels in calcareous soils. In addition, a sample taken from the Nile River suspended matter indicated that an average of 3.6 ppm of water-soluble copper was found in the suspended matter. Water soluble copper ranged from 0.6 ppm to 3.1 ppm while readily available copper fluctuates from 7.4 ppm to 19.7 ppm in the Nile mud.

In reduced environments such as rice paddies, copper may be present as Cu_2O, Cu, CuS, or Cu_2S and absorbed on soil minerals (10). The concentration of water-soluble copper in a soil decreases on flooding despite desorption from Fe^{+++} and Mn^{++++} oxide hydrates (20). This may be due partly to an increase in pH, for the solubility of copper decreases 100-fold for each unit pH increase (18).

Iron:

The concentration of water soluble iron is governed largely by the solubility of Fe^{+++} oxide hydrates. The low solubility of these oxides is of such a nature that concentrations in soils theoretically could not exceed .001 ppm. The higher concentration (0.1 ppm) found in soils are due to organic complexes and to colloidal Fe^{+++} oxide hydrates stabilized by organic matter.

Elgala and Hendawy (5) made a systematic study of iron in various soils of Egypt and found that the total iron content ranged from 5,400 ppm to 34,000 ppm but the water soluble content averaged around 2.7 ppm. Their results also indicated that the highest values of water-soluble iron occured in sandy and calcareous soils and the lowest values in alluvial soils. Although large amounts of total iron were found in some soils, there was a relationship between total iron and water-soluble iron indicating that the control of solubility of iron is due to factors such as pH and humus. Accordingly, the predominance of iron chlorosis in plants growing on sandy and calcareous soils could be attributed to the presence of more chelate forms of iron in alluvial soils due to their higher organic matter contents.

In paddy soils, reduction of Fe^{+++} compounds of Fe^{++} brings large amounts of iron into solution. During soil submergence, the concentration of water-soluble iron reaches a peak and then declines slightly or reaches a plateau (18). These changes vary with the pH and organic matter content of the soil.

The practice of fertilization of crops in Egypt which primarily deals with the application of high analysis nitrogenous and phosphatic fertilizers coupled with the introduction of new high yielding crop varieties that have higher requirements for micronutrients and the stopping of the annual deposition of Nile suspended matter will continue to cause deficiencies in micronutrients. Therefore, it becomes imperative that the micronutrient status of Egyptian soils be assessed either by soil fertility analysis or by field demonstration trials or by both methods.

METHODS AND MATERIALS

Information describing plant responses to environmental factors must be identified in order to chart a path of action to improve crop yields. A serious environmental constraint to improve crop yields was recently discovered as numerous Egyptian researchers (2,4,5,13 and 21) pointed out that many Egyptian soils were deficient in micronutrients.

In order to assess the nutrient status of the soils in the project work sites a soil fertility survey was conducted in Mansouria and Kafr El Sheikh. The Mansouria area was divided by locations where 12 samples were collected from El Hammami and 7 samples from Beni Magdoul. In addition to collecting zinc and iron data, information was also collected on pH, electrical conductivity, organic matter content, NO_3-N content, phosphorus levels, potassium levels and estimated lime levels. One hundred surface soil samples (0-20 cm depth) were taken from Abu Rayah and 9 other surrounding villages. Available phosphorus, potassium, zinc, copper, iron and manganese levels were determined along with pH, electrical conductivity, anion and cation content of the soil saturation extract (19 and 22).

Field trials were conducted in the Kafr el Sheikh (Abu Rayah) project work sites where 18 farm fields were selected to represent the average soil and environmental conditions of the whole area. Three field crops were involved and these crops are rice, wheat and flax. The response of rice to zinc was evaluated by using three treatments: 1) a control where normal management practices were used, 2) a practice where zinc sulphate at the rate of 10 kgs. per feddan was added to the field and 3) a treatment of where zinc sulphate at the rate of 20 kgs. per feddan was added to the nursery. The treated and untreated fields received approximately the same levels of nitrogen and phosphorus with the only difference being the addition of zinc sulphate to the treated fields. Rice seedlings prior to transplanting were weighed and at harvest time the height, the number of tillers, the number of effective tillers, grain and straw yields were obtained.

In the wheat demonstration study, 10 kg. of zinc sulphate per feddan was added during seedbed preparation stage to one-half of four farm fields. Phosphorus and nitrogen were applied at a constant recommended rate of 7.5 kg. of P_2O_5 and 45 kg. of nitrogen. Total plant, grain and straw yields were obtained at harvest.

In the case of flax, eight fields were selected where zinc sulphate at the rate of 10 kg. per feddan was added to one-half of each field. Nitrogen at the rate of 45 kg. per feddan was also applied to each field. At harvest, whole plant, seed and straw yields were obtained. In addition, weights of 50 flax seed capsules, number of seed in 50 capsules and the weight of 1,000 seed was also determined to see how the zinc sulphate treatments affected these components of yield.

The data obtained was treated statistically by using a one way analysis of variance to determine if significant differences existed between treatments.

RESULTS AND DISCUSSION

The soils of the project work sites at Abu Rayah and the surrounding areas have been classified as clay soils having clay percentages ranging from 45 to 60. With clay content on this order of magnitude cation exchange capacity (CEC) is high having mode values of 39.34 meq. per 100 g. of soil.

Table (2) Phosphorus, Potassium and available micronutrients values of the studied soil samples

	Location	Micronutrients (in PPM)				PPM	
		Zn	Mn	Fe	Cu	P	K
24		1.1	41.5	9.6	10.2	5.5	429.2
25		0.4	41.5	9.6	6.9	4.0	500.0
26		0.4	40.2	8.6	6.9	9.0	420.4
27		0.3	19.8	7.5	7.1	9.0	420.4
28		1.0	46.8	7.5	10.5	8.5	575.8
29		0.7	47.5	10.3	9.1	5.7	429.2
30		0.7	52.1	10.3	9.2	5.5	411.5
	E- El-Wezaria Coop						
32		0.4	48.8	8.6	6.3	5.0	500.0
33		0.3	37.6	6.8	7.3	6.0	349.6
34		0.6	34.9	6.8	7.1	7.0	278.8
35		1.0	36.9	5.1	6.7	5.7	420.4
36		0.6	38.2	10.3	7.8	3.5	327.4
37		2.7	50.8	12.7	8.2	7.0	385.0
39		0.8	44.2	12.7	8.1	10.0	385.0
40		1.4	62.7	12.7	9.0	5.0	385.4
41		0.6	38.3	5.1	5.6	5.5	367.3
	F- El-Ethad						
42		3.7	46.8	9.2	9.0	9.5	393.8
44		0.5	42.4	11.3	8.8	6.0	415.9
45		0.6	50.1	6.8	7.1	8.0	380.5
46		1.4	36.3	9.2	9.0	21.0	411.5
47		2.6	33.0	6.1	6.2	10.5	411.5
48		1.1	54.1	13.0	10.1	9.0	420.4
49		--	31.0	11.3	11.1	2.5	349.6
50		3.2	29.0	6.1	9.3	2.4	393.8
51		1.8	19.1	3.4	6.7	5.7	420.4
53		0.8	14.1	7.9	6.3	10.0	376.15

Table (2) Phosphorus, Potassium and available micronutrients values of the studied soil samples

	Location	Micronutrients (in PPM)				PPM	
		Zn	Mn	Fe	Cu	P	K
	G- El-Halafy Coop						
54		1.0	22.4	10.3	7.5	16.0	380.5
55		1.2	23.1	6.8	6.9	5.5	376.1
56		0.5	16.5	5.8	6.3	8.0	376.1
57		0.9	33.6	7.5	7.5	5.0	340.8
59		0.5	17.8	3.4	5.6	6.0	320.1
60		0.9	18.8	6.8	7.2	8.0	354.0
61		0.9	31.0	5.1	7.1	8.0	362.8
62		0.8	--	8.6	9.0	6.0	385.0
63		0.7	39.6	7.9	9.0	8.5	287.6
66		1.0	44.2	6.8	7.8	7.0	393.8
67		0.7	40.9	8.6	9.2	5.5	331.9
	H- Om-Sen Coop						
69		0.4	60.7	11.3	8.6	12.0	584.7
71		0.5	42.2	8.6	9.3	18.0	844.2
72		0.7	42.9	7.9	10.5	17.0	868.3
73		0.5	34.9	6.8	9.2	9.5	596.9
75		0.9	31.6	19.2		11.5	904.5
75		1.1	28.3	5.1	7.5	7.0	402.7
76		1.3	38.9	8.6	8.8	7.0	518.6
77		0.4	41.5	6.1	8.4	7.0	795.9
78		0.9	41.5	6.1	7.5	19.0	808.0
79		1.7	30.3	4.4	6.7	9.5	904.5
80		0.3	29.7	12.0	8.2	18.0	964.8
81		0.3	19.8	5.1	6.0	9.5	358.0
82		0.3	28.3	5.8	7.1	13.5	1097.4
84		0.4	35.6	8.5	8.6	12.0	856.2
85		0.6	47.5	8.5	7.5	13.5	795.9
86		0.8	51.4	8.6	9.3	11.0	506.5

Table (2) Phosphorus, Potassium and available micronutrients values of the studied soil samples

	Location	Micronutrients (in PPM)				PPM	
		Zn	Mn	Fe	Cu	P	K
87		2.3	36.3	9.6	9.0	8.0	560.8
88		1.5	10.8	4.4	9.3	16.0	856.2
	I- Dokmera Coop						
90		1.5	31.6	6.1	6.7	20.5	468.0
92		1.4	32.3	7.9	9.7	5.5	585.0
93		4.0	27.0	6.8	10.5	4.0	536.2
94		1.3	31.6	6.1	8.6	9.0	462.1
95		2.3	19.8	5.1	7.5	4.0	438.7
96		5.0	32.3	7.9	8.1	7.5	438.7
97		1.7	--	--	--	9.5	356.8
98		1.1	--	--	--	4.0	391.9
99		2.3	--	--	--	10.0	567.4

The majority of the soils sampled were found to be non-saline. There were exceptions as out of 120 sites sampled, three sites had electrical conductivity readings of 7.1, 5.4 and 5.1 mmhos cm which put them into a moderately saline category. Data from table 1 indicates that the sodium absorption ratios (SAR) vary greatly with soils and ranges from a low of 2.1 to a high of 14.6. From this analysis it is evident that none of the soils sampled are sodic in nature.

The amount of available potassium found in these soils indicates that this nutrient is not considered as a constraint to crop production. Due to the high clay content of the soils in this area the mode value of the available potassium is 394 ppm.

Available phosphorus levels however are significantly lower than those of potassium and in many cases could be considered as a constraint to crop production as levels ranged from 2.5 to 21.0 ppm. Approximately 55 percent of the sampled soils can be considered to be in low and medium range of phosphorus availability. These results point out the need for the development of a soil testing program based on individual soil sampling rather than on an area wide recommendation as now presently exists.

The micronutrient status as indicated in table 2 shows that adequate amounts of most micronutrients are present in these soils. According to Soltanpour and Schwab (22), Zn, Mn, Fe, and Cu levels in soils should not be less than 1.5, 1.8, 4.0 and 0.5 ppm, respectively. Zn levels are low with the exception of a few samples in most locations.

In the Mansouria area an examination of Table 3 reveals that most soils in the El Hammami area are non-saline. Only one soil sample had an electrical conductivity reading of 6.5 mmhos/cm which put it into the moderately saline category. In the Beni Magdoul area, approximately 30 percent of the soils sampled exhibited strongly saline characteristics. Phosphorus values ranged from 3 to 17 ppm in both sites and approximately

Table 3. Soil Fertility Report for El Hammami and Beni Magdoul 1978

Sample No.	pH Sat. Paste	Cond. mmhos/cm	o.m. %	Water ex. NO_3N ppm	$NAHCO_3$ P ppm	NH_4-AC K ppm	DTPA Zn ppm	DTPA Fe ppm	Lime EST.	Texture Feel
El Hammami										
1	7.9	6.5	0.3	79	6	87	0.6	6.1	med	sand
2	8.3	1.8	0.2	12	3	88	0.5	6.0	med	sand
3	7.9	3.6	0.5	90	13	91	0.7	6.6	High	L. sand
4	8.2	3.1	0.8	12	12	306	1.3	9.2	High	L. sand
5	8.5	0.9	0.2	1	4	80	0.6	7.6	High	L. sand
6	8.0	3.6	0.2	40	3	114	0.7	6.1	High	L. sand
7	8.0	3.2	0.2	13	3	85	0.6	6.8	High	L. sand
8	8.3	0.9	0.4	1	9	68	0.5	6.8	High	L. sand
9	8.4	1.9	0.7	1	6	198	0.7	7.1	High	L. sand
10	8.5	1.0	0.3	1	4	59	1.3	7.1	High	L. sand
11	8.5	0.9	0.2	1	5	126	0.8	6.8	High	sand
12	8.4	1.1	0.2	1	4	110	0.6	7.5	High	Sand
Beni Magdoul										
1	8.0	1.2	1.3	1	5	269	0.9	11.9	High	SCL
2	7.9	1.2	1.5	2	4	228	0.7	11.5	High	CL
3	7.9	1.8	1.4	3	5	312	0.8	10.5	High	CL

.../...

Cont.

4	7.9	1.5	1.4	16	6	322	0.8	10.0	High	CL
5	7.7	34.9	1.4	6	17	494	0.9	12.1	High	CL
6	8.0	3.0	0.8	33	4	220	0.8	10.3	High	SCL
7	7.4	75.5	1.5	73	6	500	1.3	7.9	High	C

42 percent of the soils could be considered at dangerously low levels from the standpoint of adequately supplying the needs of most crop plants. Potassium levels at both locations are more than adequate for good plant growth with the levels at Beni Magdoul almost twice as high as in El Hammami and this is primarily due to the higher clay content in the soils of Beni Magdoul. The micronutrient levels indicate that iron contents are adequate for all crop plants but zinc levels are low in most samples. Zinc levels tend to be lower in the El Hammami area than in Beni Magdoul and this may be possibly due to the higher organic matter and clay content of the Beni Magdoul soils. This is in agreement with the results obtianed by El Damaty et al. (4) and Kadi et al. (7) as they found that zinc generally increased with an increase in the silt, clay and organic matter content. Preliminary results from demonstration plots indicate that a positive response from zinc applications appears in certain crops.

Field Demonstration Studies

Rice

Rice is the second most important export crop of Egypt and as a summer crop it immediately follows winter crops in the cropping rotation. Due to its special irrigation regime, the rice growing area is restricted to the northern half of the Nile Delta. In general, the soils of this area are low to medium in fertility and in varying stages of reclamation. Abu Rayah is in the Kafr El Sheikh governorate which together with the governorates of Dakahlia, Beheria and Sharkia account for 83 percent of the rice growing area.

Next to nitrogen and phosphorus deficiencies, zinc deficiency is the most important nutritional factor limiting the growth of wetland rice in the rice growing areas of the world (1). A study was undertaken during the early summer of 1978 in the Abu Rayah site to see the response of rice applications of zinc sulphate. Since rice is generally

Table 4.

Effect of Zinc Sulphate on the Weight of 1,000 Rice Seedlings Collected from Nurseries in Abu Rayah, 1978

Treatment	Green Weight	Green Weight Difference		Dry Weight	Dry Weight Difference	
	- Grams -	- Grams -	%	- Grams -	- Grams -	%
No Zinc	500.4			115.0		
		38.0	7.5		20.8	18.1
Zinc applied in Nursery	538.4			135.8		

Table 5.

The Effect of Zinc Sulphate Applications on the Plant Height, Number of Tillers, Number of Effective Tillers and the yield of Grain of Rice Grown at Abu Rayah, 1978.

Factor	Control	Zn Added in Field	Zn Added in Nursery
Plant Height, cm.	93.9	105.2*	111.4*
Number of Tillers	31.6	31.7	38.2*
Number of Effective Tillers	29.0	29.4	35.1*
Grain Yield, Tons/hectare	5.4	7.5*	9.0*

* Significant at 5% Level

Plant height, number of tillers, number of effective tillers are the means of 18 counts. Yield of grain means of 9 counts.

transplanted, in order to save land and have better weed control, nurseries are established in late April and May and young seedlings are transplanted into the field about 1 month later. One feddan of nursery supplies enough rice transplants for 6 to 8 feddans. This arrangement allowed for the application of zinc to nurseries as well as to the field thus permitting an evaluation of the two methods of application in comparison with a no zinc application.

The first evaluation to be made was at the seedling stage when the plants were ready for transplanting. Table 4 shows the effect of zinc sulphate applied at the rate of 20 kgs per feddan on the weight of 1,000 rice seedlings. There was a 18.1% increase in the dry weight of seedlings due to the application of zinc. These nurseries were planted at the same time using the same variety and irrigated and flooded equally. Visual observations of the seedlings showed no difference in height or thickness or stems yet a significant weight increase was found. Based on this, one can assume that the zinc treated rice seedlings were in a more advanced stage of growth and probably took the shock of transplanting better than the control plants.

Table 5 summarizes the major findings of the study. The components of yield, plant height, number of tillers and the number of effective tillers showed significant increases due to zinc application in the nursery. A rather unexpected result occured in that there was no difference between the field application and the control in the number of tillers and the number of effective tillers. This may be due, in part, that the zinc taken up by plants in the field may have occured too late to cause an increase in tiller numbers. However, the zinc treated field did give an increase in grain yield over the control. The zinc treatment in the nursery gave the highest grain yield in comparison to the other two treatments.

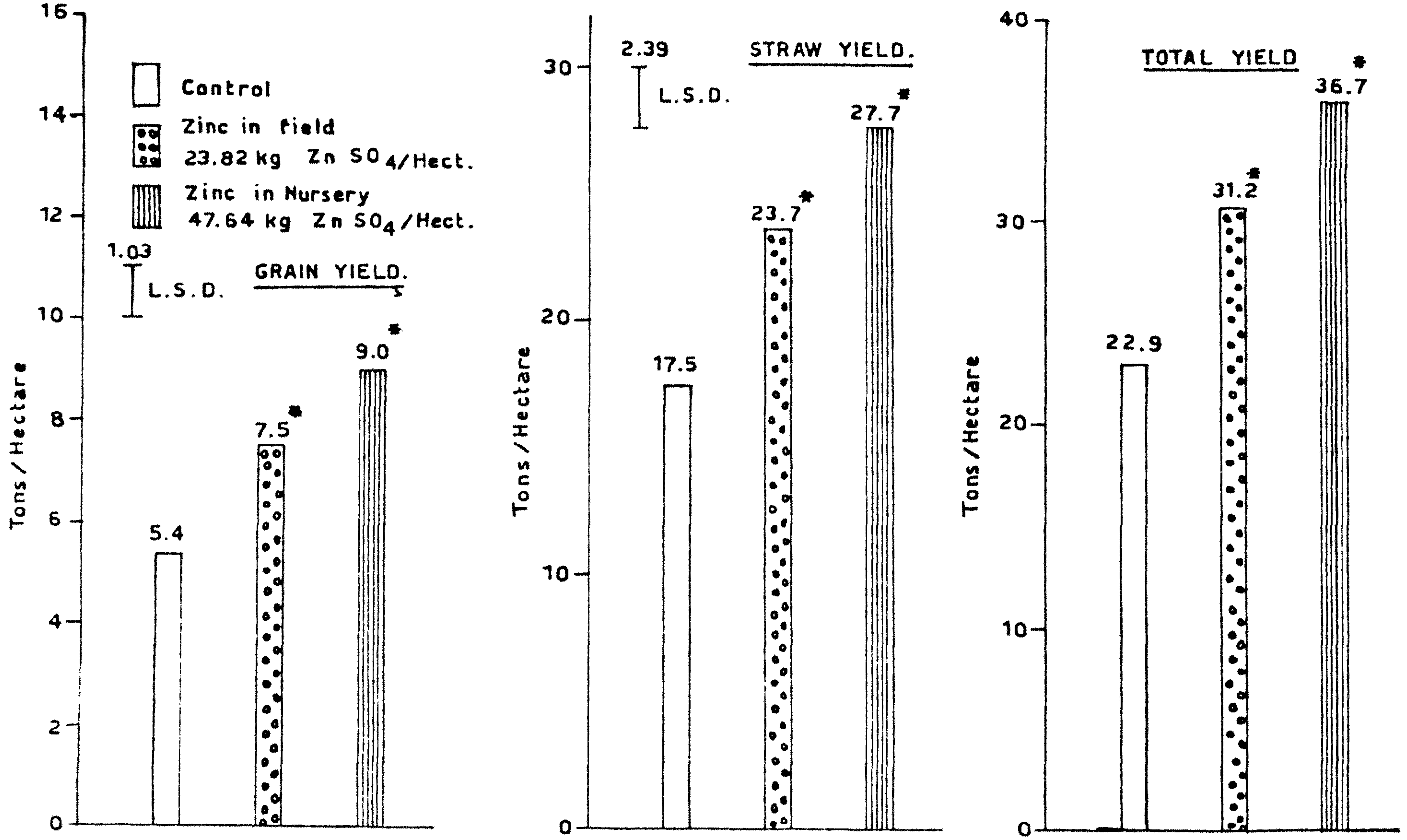

Fig . 4 Grain , straw and total yields of rice in tons/hectare as affected by different methods of zinc sulphate application (mean of 9 counts).

Figure 1 reflects not only the grain yield increase due to zinc applications but also depicts the increase in straw yields. Approximately 10 more tons of straw is produced by the zinc nursery treatment while 6 tons more straw is produced by the zinc field treatment in comparison to the control. The zinc application to the nursery is by far the cheapest and the best method of application based on grain and straw production.

Analyses of the plant and soil together with demonstrations on farm fields are the major tools in the diagnosis of a zinc deficiency problem. The level of available soil zinc below which deficiency might occur is 1.00 ppm. In a critical examination of the data from table 2 and 3 it becomes very evident that zinc concentrations generally fall below 1.00 ppm. In the El Hammami and Beni Magdoul areas approximately 83-86% of the soils sampled had levels of zinc below which a deficiency could occur. The incorporation of organic matter and the use of high levels of fertilizers can aggravate zinc deficiency in zinc deficient soils. Zinc availability in the Abu Rayah soils Table 2 shows that about 52% of these soils have less than 1.0 ppm. However, Castro (1) pointed out that in wetland rice production flooding can decrease the concentration of water-soluble zinc to values as low as 0.03 ppm. In calcareous and sodic soils, the decrease could be due to the precipitation of zinc sulphide as solubility data suggests the presence of insoluble zinc compounds in flooded soils. For rice production, several alternatives are available for combatting zinc deficiency. The fields can be drained and allowed to dry, or the seedlings dipped in a 2% zinc oxide solution before transplanting or zinc can be applied in the sulphate form to the field or nursery. Zinc applications to rice fields and nurseries seem to enhance the effect of nitrogen and phosphorus as the yield increases obtained cannot be attributed to zinc alone.

Table 6. The effect of zinc sulphate applications on wheat yields, 1978-1979

Component	Control	Zinc applied	Difference
Total plant yield, tons/fed	6.2	6.7	0.5 N.S.
Seed yield, tons/fed	2.1	2.4	0.3*
Straw yield, tons/fed	4.1	4.3	0.2 N.S.

* Significant at 5% level

N.S. Not significant

Wheat:

Wheat is the main winter crop and is grown throughout most of the country. It is usually planted in November and harvested late in May. This cereal is the major food crop of Egypt and since production in-country does not meet domestic needs, considerable amounts have to be imported. In addition, the straw is of great importance as a livestock feed at times when forages for animals is almost non-existent. From these facts, the importance of increasing yields of wheat is self-evident.

Table 6 summarizes the results obtained at Abu Rayah during the wheat growing season of 1978-79 evaluating the effect of zinc sulphate applications. Total plant yields and straw yields did not exhibit any significant difference due to the application of zinc. Grain yields on the other hand showed a significant small increase as an additional 0.3 tons of grain per feddan was produced on zinc treated fields.

Flax:

Flax is grown as a dual-purpose crop for fiber and oil and is the main source of an industrial oil for the paint industry. Flax is an important winter crop in the Abu Rayah area and considerable acreage is involved in its production.

Table 7 summarizes the various components of yield as well as the grain and straw yield relative to the application of zinc sulphate. The weight of 50 seed capsules, the number of seeds in 50 capsules and the weight of 1,000 flax seeds showed a significant response to zinc. Since these are the basic components in yield, one would expect the flax seed to respond by showing an increase in yield. Flax seed did respond as there was an increase of 151 kg/f due to the application of zinc. Since flax is a dual purpose crop it would have been ideal if the production of flax straw increased but zinc had no effect on this component. However, a 23.3% increase in

Table 7. The effect of zinc sulphate applications on flax yields in Abu Rayah, 1978-1979

Component	Control	Zinc applied	Difference
Wt. of 50 seed capsules, g.	3.2	4.4	1.2*
No. of flax seed in 50 caps.	313	394	81*
Wt. of 1,000 flax seed, g.	10.2	11.1	0.9
Total plant yield, tons/fed	3.4	3.7	0.3 N.S.
FlAx yield, kg/fed	648	799	151*
Flax straw yield, tons/fed	2.7	2.9	0.2 N.S.

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* Significant at 5% level

N.S. Not significant

seed yield even though there was no change in straw yield warrants the use of zinc for flax production.

Practical Implications

The occurrence of deficiencies of minor elements in Egyptian soils is likely to increase in the future because of:

1. Increased removal of nutrients due to the increase in the use of modern yield yielding varieties.
2. Depletion of micronutrients due to intensive cropping systems.
3. Increased use of concentrated and more pure forms of nitrogen and phosphorus fertilizers.
4. Agricultural fertilizer policy at the present time is mainly concerned with nitrogen and phosphorus fertilizers and not with micronutrients.

CONCLUSIONS

The results to date of micronutrient deficiency in Egyptian soils imply that water management, soil management, and the judicious use of fertilizers, both macro and micro, can overcome deficiency problems.

- Yield of rice on calcareous and alkali soils, on poorly drained soils and on soils with low inherent zinc content can be increased by the application of zinc sulphate to the field or nursery (20 kg/F in the nursery and 10 kg/F in the field).
- The water regime of the soil affects the zinc uptake and availability by the rice plant. Prolonged submergence reduces zinc availability whereas soil drying increases it markedly.
- Yield of grain in both wheat and flax are increased significantly by the application of zinc sulphate to fields at time of seedbed preparation)10 - 20 kg/F).
- More consideration should be given to the use of zinc sulphate as a source of zinc in rice, wheat and flax production as part of the A.R.E. Agricultural policy.

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Staff Paper #39

EVALUATION OF FURROW IRRIGATION SYSTEMS

Thomas W. Ley and Wayne Clyma

INTRODUCTION

Evaluation of the performance of furrow irrigation systems requires the collection and analysis of data relating to both the operation and management of the water application subsystem. The procedures suggested for the collection and analyses of data which follow can be used at two levels depending on the amount of detail desired. The less detailed approach provides satisfactory evaluation of system performance utilizing a suggested minimum number of analyses. The more detailed approach adds information on the operating aspects of the hydraulics of the system. Most often, the more detailed measurements are desired for an evaluation of some aspect of system design hydraulics. The less detailed approach provides fully the benefits of an evaluation of farmer practice. Discussion of the procedures for collecting and analyzing the more detailed types of data is provided in a later section. An equipment list and suggested data forms are provided later. The following subsections discuss the data to be collected, the chronological evaluation procedure and suggested analyses of the data for the evaluation of farmer practices.

REQUIRED DATA

Preliminary Data

There is a large amount of preliminary site data which should be collected and analyzed before the evaluation of an irrigation occurs.

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These data include physical information of the site and information from the farmer concerning his irrigation system and its operation. A list of suggested questions to direct to the farmer in order to obtain information in each of the following categories is included in Appendix A. Other more site specific questions should arise from the farmer's answers to these general questions.

1. Farmer operation and management.--Understanding why or how a farmer does certain things in managing and operating the irrigation system is vital. Often this aspect of evaluating irrigation performance may be overlooked and incomplete knowledge of the irrigation system state results. Farmer management may be constraining the level of performance which can be attained. The general level of knowledge of the farmer concerning irrigation principles and practices is evaluated. Other information discussed later will aid in determining if system management can be improved.

2. Water supply.--The farmer will know the available water supply, source, delivery, frequency, etc. He may have only a general knowledge of the flow rate and quality. These should be measured during the course of an evaluation. On-farm conveyance losses may be a big problem. The farmer may or may not know. Measure the losses if necessary.

3. Crop characteristics.--The crops grown and the planting dates of each must be known. Available data in the literature on crop seasonal water requirements, rates and stages of growth, maximum potential rooting depths, time from planting to effective cover, etc. This information along with climate data is used to estimate crop water use through the irrigation season. The crop root zone should be measured at each irrigation for crops with expanding root systems. The measured root

zone for a perennial crop (such as alfalfa) can often be assumed valid for the entire season unless a highly fluctuating water table is encountered. The crop root zone at each irrigation determines the available soil water reservoir at that time and is necessary to determine the soil water deficiency, the stress at the time of irrigation and performance parameters such as water application and water requirement efficiencies.

4. Physical characteristics.--Measure and record the field dimensions. Stakes should be driven into the ground at 25-m intervals along the length (adjust for size of field as necessary). Measure and record surface elevation at each stake (station) using a field rod and level. Plot the surface profile (elevation vs. length). Measure and record furrow spacings at several locations in the field. Determine if the downstream boundary condition is ponded or free outflow. Determine where and how to measure furrow inflow and runoff.

5. Soil survey.--If available, obtain information on soils in the area (on the farm), such as maps and classifications from a local or regional office (e.g., USDA Soil Conservation Service or similar government agency). Such information is very useful and aids the design of data collection procedures. Soil types and textures are known and maps usually depict the variation of surface textures in a field. If this information is not available, a soil survey is necessary to determine the soil types and uniformity in the field being studied. Soil samples should be collected in a minimum of ten locations in the field (i.e., at five locations along the length and two along the width). Samples should be taken from a minimum of four depths within the expected root zone, i.e., every 30 cm in an expected 1.2 m root zone (adjust as necessary). These samples should be analyzed to determine soil types.

Once soil types and variations through the field are known the apparent specific gravity of the soil (bulk density) and the field capacity and wilting point of the soil must be determined. Garcia (1978) presents procedures for these measurements. Depending on the results of the soil survey the sample collection procedure is defined. For a field with uniform soils it is necessary to collect data on the above soil properties in a minimum of three locations in the field to obtain a good average. For a field with nonuniform soils the above soil properties must be determined for each major soil type. A minimum of three replication of samples is necessary to obtain an average. In all cases, it is necessary to sample with depth. See Appendix B for further discussion.

Accurate definition of the above soil properties is necessary. The time and effort necessary to achieve this are well worth it and will eliminate having to repeat any sampling. These data are most easily collected before the crop is planted. Some change of apparent specific gravity of the plow layer with time may be expected. Sampling plans for soil water content and infiltration tests will be functions of soil type and uniformity. The results of the soil survey should thus be available in advance of the initial irrigation evaluation.

If soil salinity/alkalinity is expected to be a problem (indicated by maps, previous surveys, information from the farmer), samples should be analyzed to determine the salinity/alkalinity. Such a problem may also indicate the presence of a high water table.

6. Water table.--The farmer should have general knowledge of water table conditions in the area. Soil survey results may indicate a high water table. If the water table is high or expected to fluctuate

considerably (i.e., within the maximum potential root zone), it is desirable to monitor the ground water level through the irrigation season. This can be done with a series of grid of observation wells (EWUP, Vol. II, 1979).

A high water table can limit crop growth through water-logging. The groundwater quality can also seriously affect crop growth and should be measured.

Crop water use from the capillary fringe or the water table is possible. Estimates of crop consumptive use by evapotranspiration modeling techniques will not correspond with measured soil water deficits (by soil water content sampling) when the crop is using groundwater, assuming either method is yielding accurate results. This is significant if the water table rises during the season due to early overrigation. Water table fluctuations due to overririgation may also contribute to crop consumptive use and can affect root zone expansion. irrigated run. Samples should be taken from a minimum of five different depths within the root zone. Samples can be collected using a soil auger and should be placed in a partitioned box such that changes in soil texture and composition are immediately visible. Analysis of all the samples taken, for type and texture, is desirable. Soil textural change throughout the field is important information. Soil bulk density (apparent specific gravity) should be determined making at least three replications in one location (at different depths within the root zone) and in each area where soil texture was observed to be different. Garcia (1978) presents data collection and analysis procedures for determining soil bulk density. Representative soil samples should also be collected so that the field capacity and wilting point of the soil (or soils) can be determined (see Garcia, 1978).

On the Day Before Irrigation

Infiltration Data.--Blocked furrow infiltration tests should be conducted in at least four locations along the irrigated run when the field has a uniform soil. When non-uniform soils are present, a minimum of three replications of a test should be conducted on each soil type. There should be enough labor available so that each infiltrometer (Fig. 1) is manned throughout the test. The tests should last not less than seven to eight hours, and in some cases, as long as the duration of irrigation. Garcia (1978) presents procedures for the assembly and operation of the infiltrometers. Infiltration tests should be conducted in furrows other than those in which advance and recession data will be collected, but must be in furrows which will be irrigated. Further discussion of considerations of where to sample and how often is included in Appendix B.

Preirrigation Soil Water Content Data.--Garcia (1978) presents procedures for the collection and analysis of soil samples for determination of soil water content by the gravimetric method. In furrow irrigation, it is difficult to determine average water contents in the soil profile since the entire soil surface is not covered with water during irrigation and there may be significant lateral movement of water in the soil. In all instances, samples should be taken from each of several layers of the measured or expected maximum rooting depth of the crop (i.e., for a 1.2 m root zone, sample each 30-cm layer, and in the top 30-cm layer, collect samples from each 15-cm increment). If the water table is higher or near the expected maximum rooting depth, samples should be collected to near the water table. Each individual sample should be 150 grams or more. A problem arises in determining where to

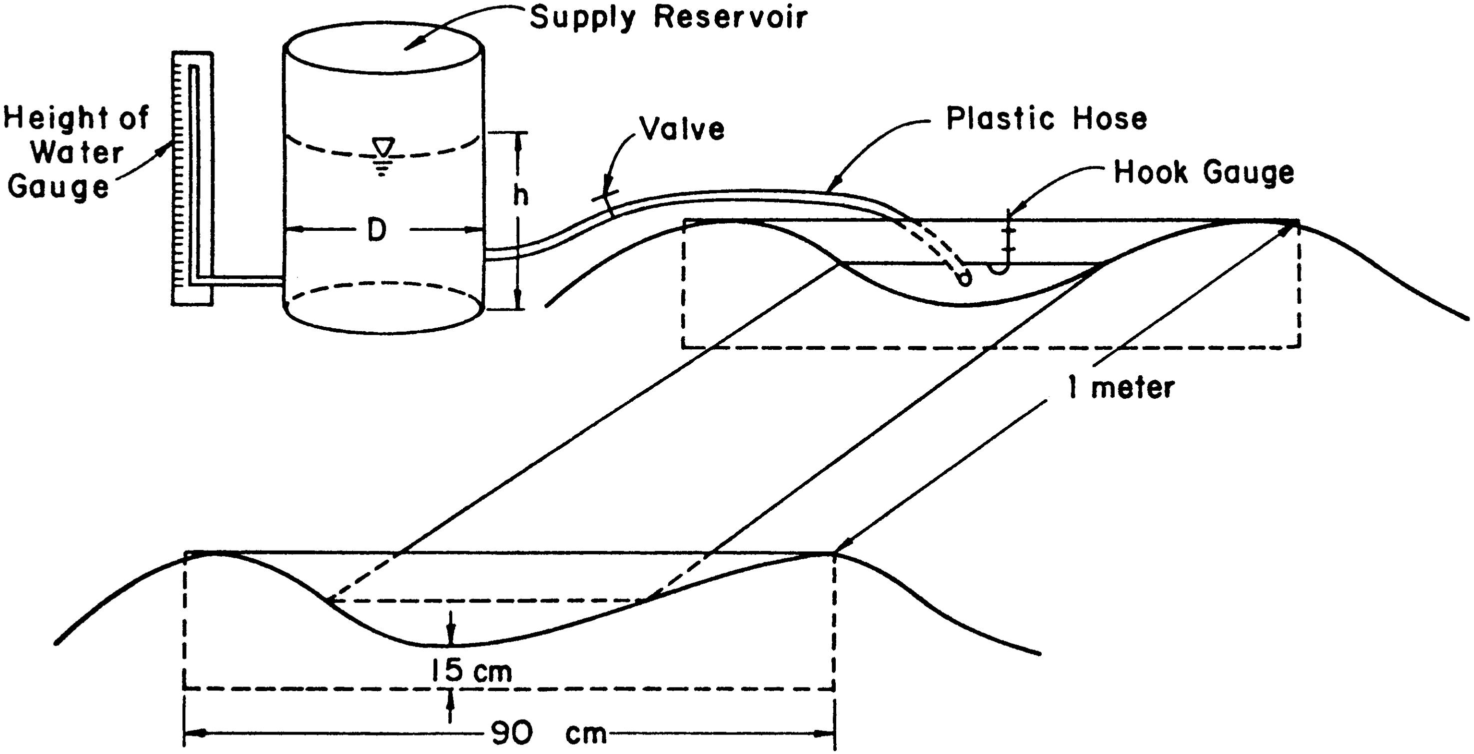


Figure 1. Blocked furrow infiltrometer.

sample at each location. When every furrow is irrigated, it is suggested that samples be taken from the bottom of the wet furrow and the middle of the furrow ridge (plant row) between furrows to get a representative average (Fig. 2a). When every other furrow is irrigated, it is suggested to take samples from the bottom of the irrigated furrow, the middle of the furrow ridge (plant row), and from the bottom of the non-irrigated furrow, in order to get a representative average of the water content below the ground surface and between wet furrows (Fig. 2b). For this case, an average water content for each layer sampled could be defined as:

$$P_{w,avg} = \frac{P_{w,1} + 2P_{w,2} + P_{w,3}}{4} \tag{1}$$

where $P_{w,avg}$ = average water content for the layer,

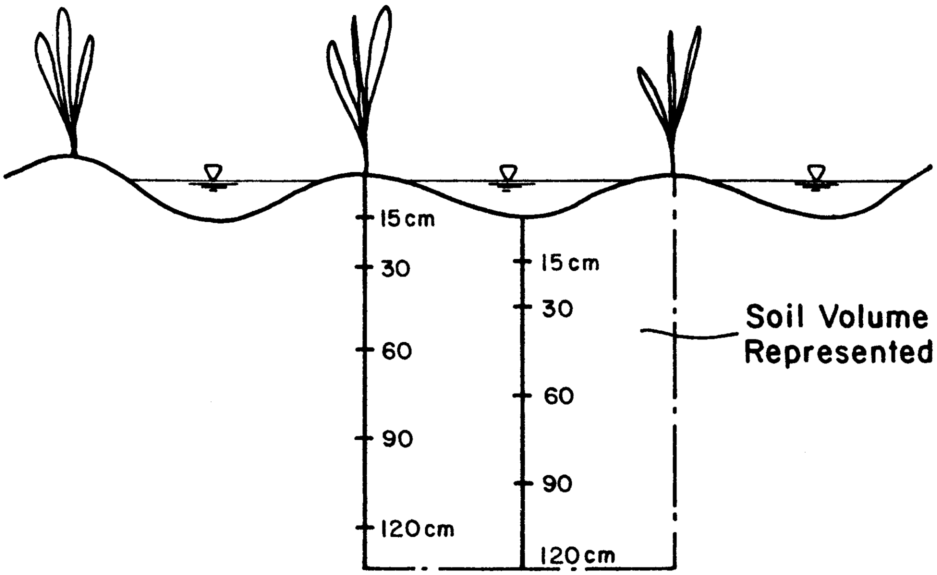
$P_{w,1}$ = water content for the layer in area 1 (see Fig. 2b),

$P_{w,2}$ = water content for the layer in area 2 (see Fig. 2b),

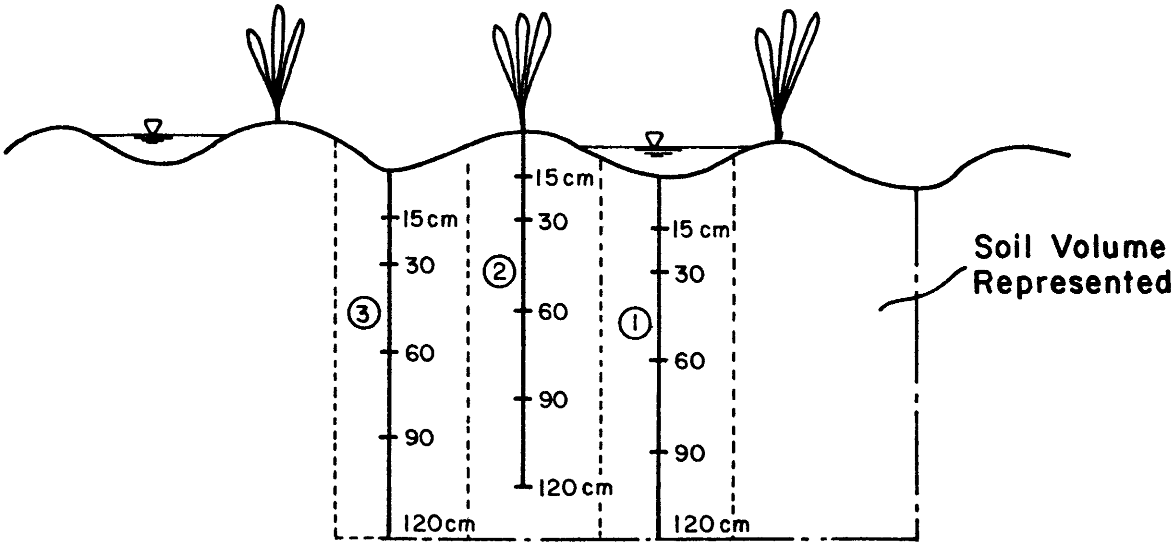
$P_{w,3}$ = water content for the layer in area 3 (see Fig. 2b).

It is pointed out that area 2 (Fig. 2b) receives twice the weight of the others in computing the average, since this area does in fact occur twice in the soil volume being represented.

Soil sampling locations in the field are determined by the results of the soil survey. If soils in the field are found to be uniform a minimum of three sampling locations in different parts of the field (along the furrow) should be selected to obtain an average for the field. If soils are non-uniform or if non-uniform water applications are expected, a minimum of three replications of samples in each representative area are necessary for computing an average. For instance, the distribution of applied water in many fields is non-uniform. A



a) Suggested Sample Holes when Every Furrow is Irrigated



b) Suggested Sample Holes when Everyother Furrow is Irrigated

Figure 2. Suggested soil water sampling locations across an irrigated furrow spacing.

sampling scheme to delineate the differences along the length might be three replications of samples at the head, middle and tail ends of a field. See Appendix B for further discussion of the considerations of sampling plans, numbers of samples to collect, etc.

It is recommended that evaluation data (inflow/runoff, advance/recession, etc.) be collected on a minimum of three furrows. Flumes or other flow measuring devices should be installed at the head and tail ends of each furrow to be evaluated. Care must be taken to ensure that the flumes (if used) are level, have no leaks around them, and that the furrow sides are built up in the approach to the flume to prevent overtopping. Since the flume, being a critical depth flow measurement device requiring a loss of head, water in the approach section of the furrow will back up. This effect is more pronounced on smaller slopes than steeper ones. Flow measuring devices should be installed on the day before irrigation.

On the Day of Irrigation

The following data are taken on a minimum of three furrows as the irrigation progresses. The clock time when water is introduced to each furrow being studied should be recorded.

Advance Data.--Record the clock time at which the water arrives at each station (i.e., every 25 m) as the waterfront moves down the furrow.

Inflow Data.-Periodically record the clock time or elapsed time from the beginning of irrigation and reading for each inflow rate measuring device.

Runoff Data.--Record the clock time when water reaches the point (usually near end of field) where the runoff rate measuring devices are located. It is suggested that runoff data be collected at 30 sec, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min and then every 1/2-hour from the time when runoff begins.

Recession Data.--Towards the end of irrigation, remove the flow measuring devices from the furrows. Record the clock time when water is shut off. Record the clock time at which water recedes from each station. The receding water edge is hard to define. Recession at a particular point is assumed to have occurred when approximately two-thirds of the furrow wetted perimeter is free of water. Very shallow flow conditions exist during recession. Small puddles and ripples in the furrow bottom further compound the problem. Consistency is of prime importance when taking recession data.

All flow measuring devices should be check during the irrigation for leaks and proper operating conditions. During the course of the evaluation any unusual factors or conditions should be noted. For instance, cracks in the soil significantly affect advance rate. Any erosion and sedimentation should be noted. Crop conditions (i.e., relative size, color, stand, wilting, etc.) throughout the section of the field being irrigated should be noted. Stunted growth may indicate salinity problems, poor infiltration rates (i.e., change in soil texture or plow pan layer which reduces infiltration) or other problems.

After Irrigation

Postirrigation soil water content samples should be collected anywhere from 1-1/2 days to 3 days after irrigation. This depends on the soil type and the time required for the soil to drain to field capacity. Garcia (1978) presents a field procedure for estimating when (after wetting) a soil has drained to field capacity. The same collection procedures as previously discussed apply.

Discussion and Recommendations

It is important to convey to the farmer what will be done during the evaluation. Crop damage and soil disturbance should be minimized. Cooperation of the farmer in all aspects of the evaluation is a necessity. It is important that nothing the investigators do before or during the evaluation cause the farmer to deviate from his normal irrigation practices.

It is important that preliminary data collected early in the season be good data. A careful, coordinated, determined effort here will save much time and eliminate problems and headaches later in the season. For instance, the soil water content of a field before the initial irrigation of the season may generally be assumed as uniform. Much effort in careful soil sampling and in collection of more samples (to increase the precision with which the mean soil water content is estimated) is recommended. The establishment of this initial condition serves an important purpose. It is the starting point for a root zone soil water budget.

From this initial condition, water added to the root zone of the crop by precipitation (measured by rain gages set up in several locations at the site) and by irrigation (measured by irrigation evaluations) is known. Crop use is estimated using climate data and crop stage and growth data in an accurate, calibrated evapotranspiration model. A root-zone soil water budget can thus be calculated through the season. Soil water content data collected at succeeding irrigations of the season are used as a check on the predicted soil water status when calibration of the ET model is necessary.

If there is a high water table in the area, crop use from the capillary fringe or the water table itself can be estimated. The difference between the calculated crop use and the measured soil water deficit (by sampling) during an irrigation interval is an estimate of the crop use from the water table during that interval. If there is no reason to believe that the crop is using water from a water table, then the computed difference indicates the accuracy of each method and possibly needed action to improve sampling or predictive techniques.

In some instances, collection of advance/recession data may not be necessary at each irrigation. For instance, a uniform application of water may be expected on a field with shorter lengths of run on a heavier soil. In this case, the distribution is assumed uniform and all that is required is the water on and water off to determine the water added to the soil. While this case may occur, it is advisable to collect advance and recession data when any non-uniformity of water application is suspected due to poor irrigation practices, non-uniform soils, non-uniform field slopes, etc. in order to know the distribution of applied water.

During the course of an actual irrigation evaluation, it is recommended that a partial evaluation of the data being collected be conducted. This is accomplished best by processing the data as it is collected in the field and interpreting the results. For instance, it is easy to evaluate inflow and runoff data and an obvious error is determined if the runoff is greater than the inflow. This check on data provides the investigator a means of eliminating wasted time and effort in the collection of erroneous data.

FIELD DATA ANALYSIS

Field data analysis provides a basis for understanding the performance of the irrigation system and how the system is being operated. The data may be analyzed through a number of procedures. Those presented here represent the minimum of analyses required to formulate an understanding of the system's performance resulting from a particular management scheme.

Infiltration Data.--The data collected during blocked furrow infiltration tests are generally of the form: total volume infiltrated per unit length vs. elapsed time. The data are plotted on log-log or rectangular grid paper. Garcia (1978) presents methods of analyzing the data such that an infiltration relationship of either of the following forms can be determined:

$$z = kt^a \,, \tag{2}$$

or

$$z = Kt^A + Ct \tag{3}$$

where z = cumulative volume infiltrated per unit length (L^3L^{-1}),

t = elapsed time (T),

C = steady-state or large-time infiltration rate $(L^3T^{-1}L^{-1})$,

k, a, K, A = empirical constants.

An infiltration function of either form (Eq. 2 or 3) should be found, and usually it is determined for the mean of the infiltration data collected at particular locations in a field. For instance, the mean would be determined for infiltration data on each major soil type or for each area where a sampling plan called for tests to be made.

Soil Water Content Data.--Procedures for determining the water content (dry weight basis) of each of the soil samples collected are presented by Garcia (1978). The depth of water in the soil profile is found using the following relationship:

$$d_m = \sum_{i=1}^{n} (P_{w,i} \times \gamma_{b,i} \times Y_i) \tag{4}$$

where d_m = water depth in the soil profile (L),

$P_{w,i}$ = water content (dry weight basis) of the ith layer of the profile (MM^{-1}),

$\gamma_{b,i}$ = soil bulk density in the ith layer of the profile $[ML^{-3}(ML^{-3})^{-1}]$,

Y_i = thickness of the ith layer (L).

n = number of root zone layers sampled.

The preirrigation water depths at each sampling location (i.e., position in the field) are averaged and compared to the water depth when the soil is at field capacity. This gives an estimate of the amount of water which needs to be applied during irrigation to bring the root zone to field capacity. This method for determining the soil water deficit at irrigation time is subject to the large degree of variability observed in soil water content sampling studies, and may give unreliable results. When reliable crop data and, climate data are available, another estimate of the soil water deficit can be obtained through the use of an evapotranspiration modeling procedure and soil water budgeting as discussed earlier.

Pre- and postirrigation water depths can be compared to obtain an estimate of the depth of water infiltrated (assuming there is no deep percolation of water past the lowest sampling depth) at each of the sampling locations. This is, of course, subject to the comment made previously concerning the reliability of soil sampling to determine water contents. The temporal and spatial variability in soil properties can be magnitudes and even orders of magnitude in just a small area of a field. Thus, the limitation on the reliability of results is imposed.

Advance/Recession Data.--Normally, these data are plotted on a rectangular grid with time as the ordinate and distance along the furrow as the abscissa (Fig. 3). The difference in time between the two curves is the infiltration opportunity time. The infiltration opportunity time at each station along the field should be determined. Often, the surface elevations are also plotted on the same sheet. Non-uniformity of slope along the run will usually show up in the advance and recession curves. A plot of the surface profile may often be very useful in helping to explain variations in advance and recession rates.

Inflow/Runoff Data.--The inflow and runoff data should be plotted vs. time (with inflow and runoff rates as the ordinates and time as the abscissa) on the same rectangular grid. These are the inflow and runoff hydrographs. The inflow hydrograph is plotted up to the time of shutoff. Graphical integration of the area under this curve represents the volume of water applied, W_a (L^3). The runoff hydrograph is also plotted up to the time of shutoff. After shutoff, the runoff rate is assumed to decrease linearly from the runoff rate at the time of shutoff to zero at the end of recession. Graphical integration of the entire area under this curve represents the total runoff volume, W_u (L^3). The difference between the volume of applied water and volume of runoff, as determined by this method, is the volume of water remaining in the field, or the total volume infiltrated during the irrigation, i.e.,

$$W_i = W_a - W_u \tag{5}$$

where W_i = total volume infiltrated (L^3).

The inflow-runoff method is assumed to be the most accurate for determining the total volume of infiltration. This is because it gives the average infiltration for the entire furrow length (as opposed to "point" type measurements from infiltration tests or soil water data), and because flow rates can usually be measured more accurately than infiltration or soil water content.

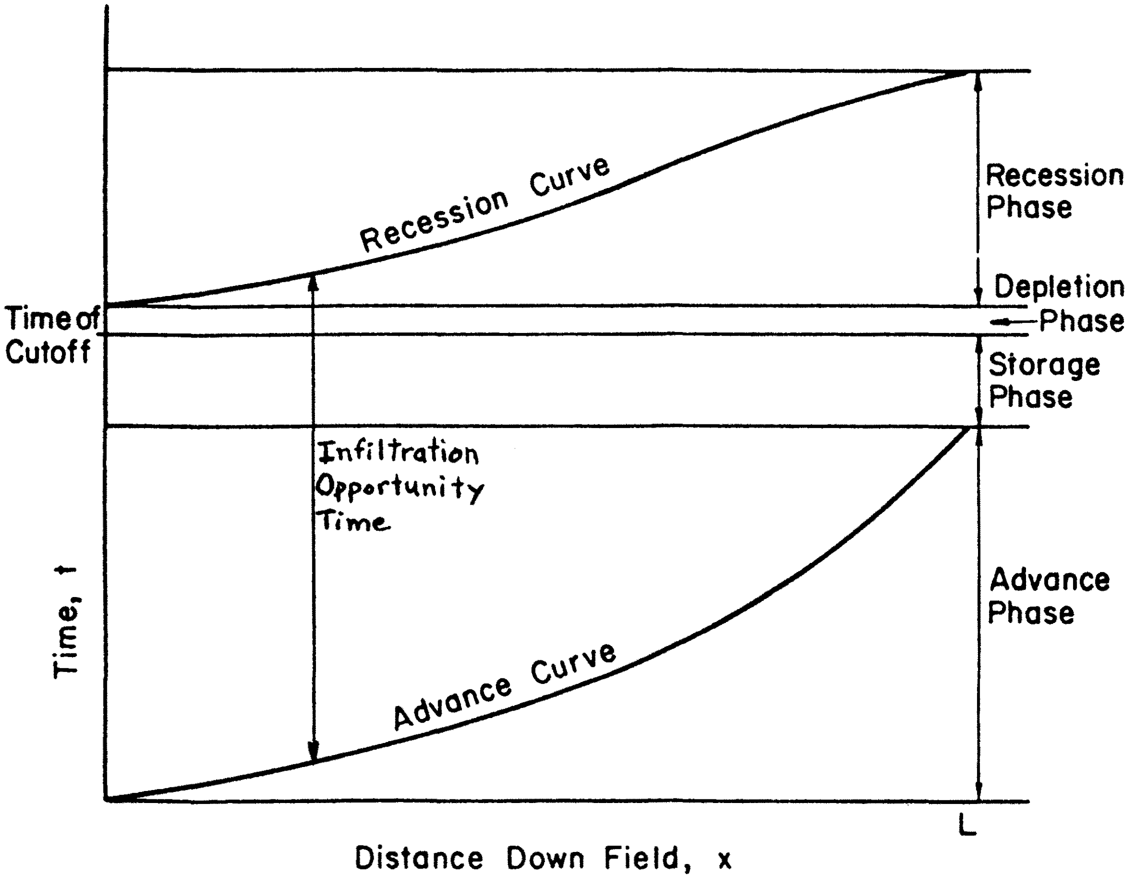


Figure 3. Simplified representation of advance and recession curves and phases of irrigation.

Subsurface Distribution of Applied Water.--The subsurface distribution of applied water in furrow irrigation can be determined when the following information is known.

1. A representative infiltration function(s) as determined above.
2. Infiltration opportunity times along the irrigated run, i.e., advance and recession times at points along the run.

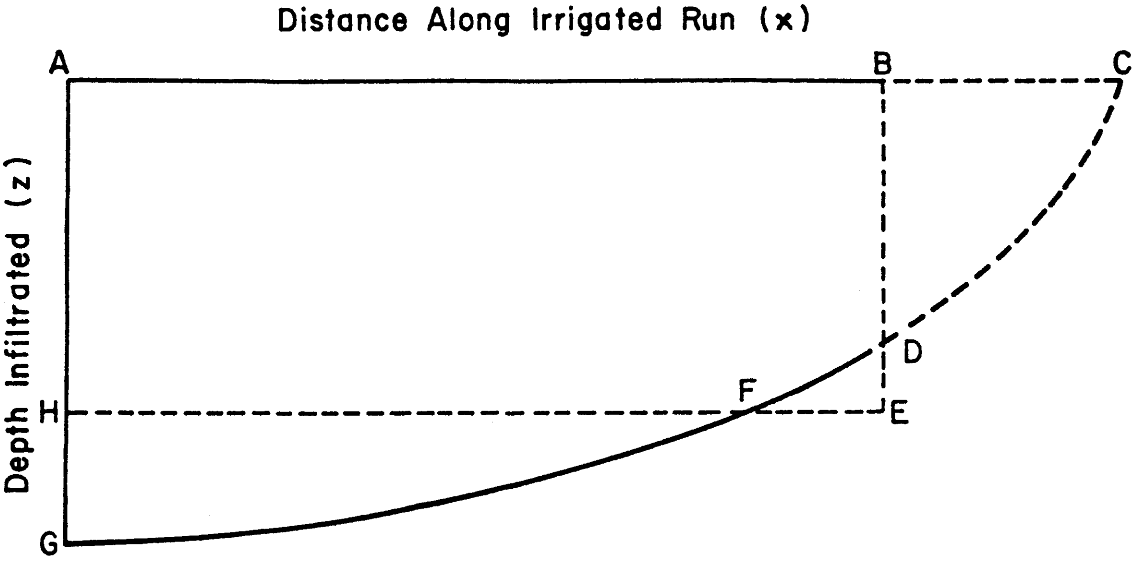
Upon construction of the subsurface profile, it is possible to characterize the performance of a particular irrigation. However, before irrigation performance parameters are defined it is necessary to define several related quantities upon which they depend.

Figure 4 represents an idealized profile of infiltrated water as a result of a furrow irrigation. The distance AB is the field length, and the line DFG is the boundary of the infiltrated water. If the downstream boundary condition is one of free outfall, then runoff water from the field can be assumed to extend to the imaginary field length C, and to infiltrate according to the profile CD. The water requirement depth at the time of irrigation is assumed uniform along the field length and is represented by line EFH. With these concepts in mind the following quantities with appropriate units shown in Figure 4 are defined.

1. Total volume of applied water, W_a (area ACDGA). This is the total volume of water introduced per furrow.

2. Total volume of water required in the root zone to reach field capacity, W_r (area ABEHA). This is the volumetric soil water deficit.

3. Total volume of water stored in the root zone, W_{rz} (area ABDFHA). This volume of water is dependent upon the field capacity of the soil and the available storage at the time of irrigation. The total volume of water available for plant use after the irrigation and drainage period equals the difference between the field capacity (FC)



AB	length of furrow (L)
ACDGA	total volume of applied water per furrow, $W_a(L^3)$
ABEHA	total volume of requirement per furrow, $W_r(L^3)$
ABDFHA	total volume of actual root zone storage per furrow, $W_{rz}(L^3)$
FGHF	total volume of deep percolation per furrow, $W_p(L^3)$
BCDB	total volume of runoff water per furrow, $W_u(L^3)$
DEFD	total volume of root zone deficit after irrigation per furrow, $W_{df}(L^3)$

Figure 4. Idealized subsurface profile of applied water in furrow irrigation.

and the permanent wilting point (PWP) of the soil, assuming the root zone is completely filled from the permanent wilting point to field capacity during irrigation [i.e., the total available water expressed as a depth, TAW = (FC - PWP) x (bulk density of the soil) x (rooting depth)].

4. Total volume of deep percolation, W_p (area FGHF). The volume of water which infiltrates past the lower boundary of the root zone. W_p may equal zero in some cases.

5. Total volume of tailwater or runoff, W_u (area BCDB). The volume of water which runs off the end of the field if free outfall conditions exist.

6. Total volume of root zone deficit after irrigation, W_{df} (area DEFD). W_{df} equals zero if the root zone is completely filled.

The infiltration relationship(s) as determined from infiltration tests and the infiltration opportunity times from advance/recession data are used to plot the subsurface distribution. The total infiltrated volume as predicted by the infiltration function(s) should be determined from this plot. Comparison of this value with that determined by the inflow/runoff hydrograph analysis is a check on the adequacy of the infiltration function(s) in predicting the total infiltrated volume. If there is significant deviation, the multiplicative constants of the infiltration function(s) should be adjusted by a trial and error volume balance procedure until the two values coincide. Once this is finished, the subsurface distribution, as predicted by the "adjusted" infiltration function(s), is plotted. The soil water deficit as estimated through soil water content analyses or evapotranspiration studies is also plotted on the same sheet.

Efficiency and Performance Parameters.--Graphical integration of each of the representative areas of the subsurface distribution is used to find each of the volumes as previously discussed. Values of volume applied, volume infiltrated and volume of runoff as determined by both the inflow/runoff analyses and by the subsurface distribution should correspond (assuming the infiltration function used to construct the subsurface profile is representative, i.e., yields good prediction of total infiltrated water volume).

Four irrigation performance parameters are defined as follows:

1. Water application efficiency, E_a, is the percent of the amount of water applied which is stored in the root zone for future use.

$$E_a = \frac{W_{rz}}{W_a} \cdot 100 \tag{6}$$

where

$$W_{rz} = W_i - W_p \tag{7a}$$

$$= W_r - W_{df}. \tag{7b}$$

2. Water requirement efficiency, E_r, indicates the percent of the amount of water required to refill the root zone which is supplied by an irrigation.

$$E_r = \frac{W_{rz}}{W_r} \cdot 100 \tag{8}$$

3. Runoff (or tailwater) ratio, R_t, represents the fraction of the total amount applied which is lost as runoff from the end of the field.

$$R_t = \frac{W_u}{W_a} \tag{9}$$

4. Deep percolation ratio, R_p, represents the fraction of the total amount applied which is lost as deep percolation past the bottom of the root zone.

$$R_p = \frac{W_p}{W_a} \qquad (10)$$

The sum of the deep percolation ratio, the runoff ratio and the water application efficiency (expressed as a fraction) is unity. Each of the above volumes can be treated as average depths when divided by the product of furrow length and irrigated furrow spacing.

EXAMPLE SYSTEM EVALUATION

The following discussion presents the results of an evaluation of a furrowed irrigation system using the procedures just discussed. A design of this field was formulated using the SCS furrow irrigation design procedure (USDA, 1978 draft). The results of this design are presented in a separate analysis of the design procedure ( ). Thus, it is possible to compare the current system operation and performance with the suggested design operation and performance. Ultimately, this allows for determination of possible system redesign and management changes such that improved system performance results. Recommended design parameters are repeated here for the reader's convenience.

$Q = 0.57 - 0.76$ ℓps/furrow (9-12 gpm/furrow)

$T_1 = 720$ min

irrigated furrow spacing = 1.12 m (3.67 ft)

design depth = 61 mm (2.4 in.)

The crop irrigated was sugar beets planted on a 0.56 m (1.84 ft) row spacing. Pre- and postirrigation soil water content samples were collected, however, analysis has proven them to be inadequate. At any rate, an average evapotranspiration rate for sugar beets was determined to be near 6 mm/day (0.24 in./day) in the general area. The elapsed time from the previous irrigation (when the root zone was last completely filled) to the time of the irrigation being evaluated was 12 days. The soil water deficit was thus estimated to be approximately 72 mm (2.8 in.).

The farmer was irrigating the furrows from a concrete-lined head ditch using 1 1/4-in. siphon tubes. Every other furrow was being irrigated so the irrigated furrow spacing was 1.12 m. The average furrow grade is 0.0098 m/m. The furrow length is 365 m. Inflow and runoff measurements were taken at the head of the furrow and at x = 350 m, respectively. Soils were found to be uniform areally, although there was some variation in texture with depth.

Five blocked furrow infiltration tests were conducted the day before irrigation at five locations along the length of run. The data, reduced to the form of volume infiltrated per unit length vs. time, are plotted in Figure 5. The mean infiltrated volume per unit length vs. time was found and is also plotted in Figure 5. A least squares regression procedure, outlined in Garcia (1978), was used to determine an empirical infiltration function of the form of Eq. (3) for the mean:

$$z = 2369.4\ t^{0.37} + 70\ t \qquad (11)$$

where z = cumulative volume infiltrated (cm^3/m),

t = time (min).

This function is also plotted in Figure 5.

Advance and recession data and surface elevation data are plotted in Figure 6. Infiltration opportunity times at stations along the furrow are included. The time of advance to the runoff measuring device (x = 350 m) was 180 min. The plot of the surface profile slope (Fig. 6) indicates the uniformity of slope is acceptable.

Normally, the farmer operates using a 12-hr inflow or set time. For this particular irrigation, however, a power failure caused pump

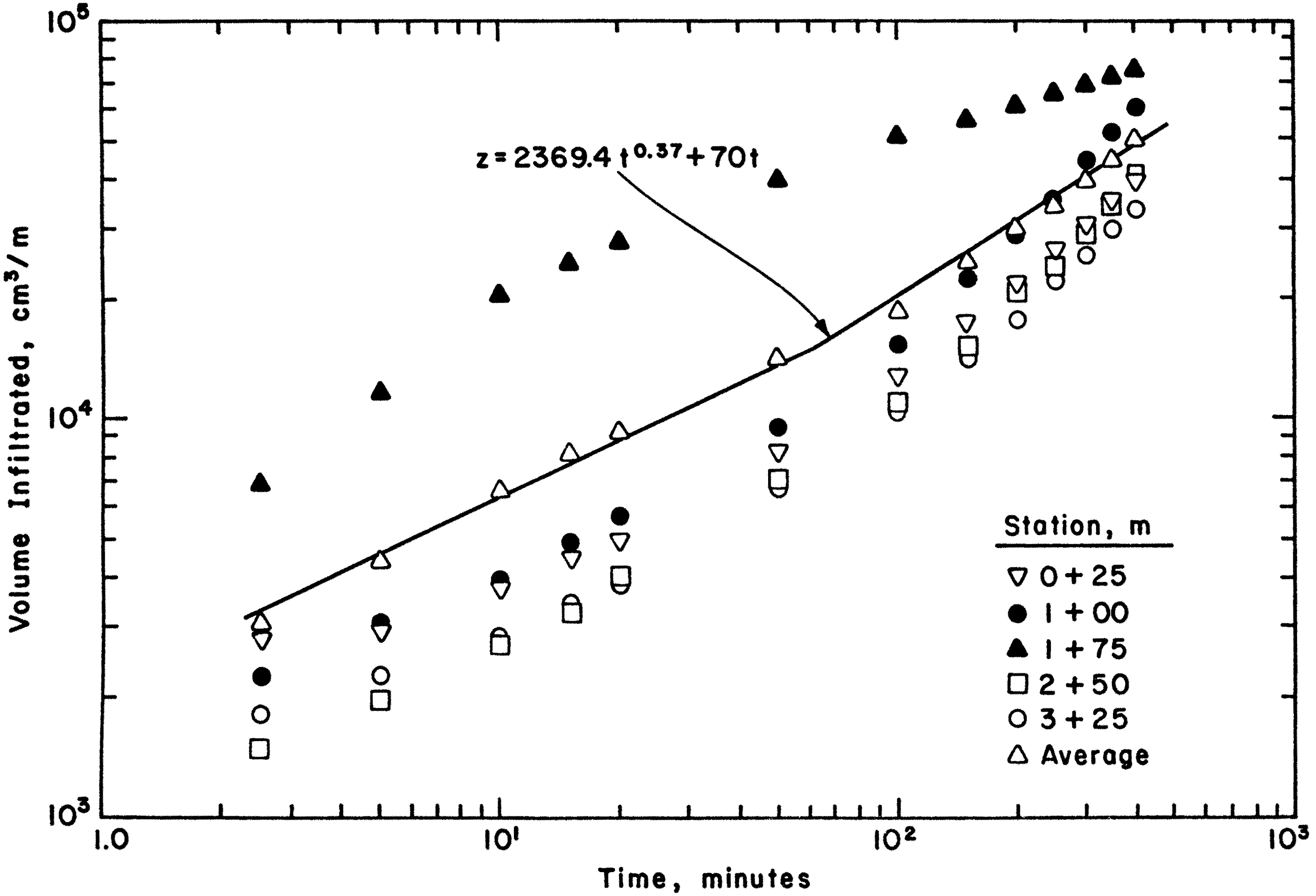
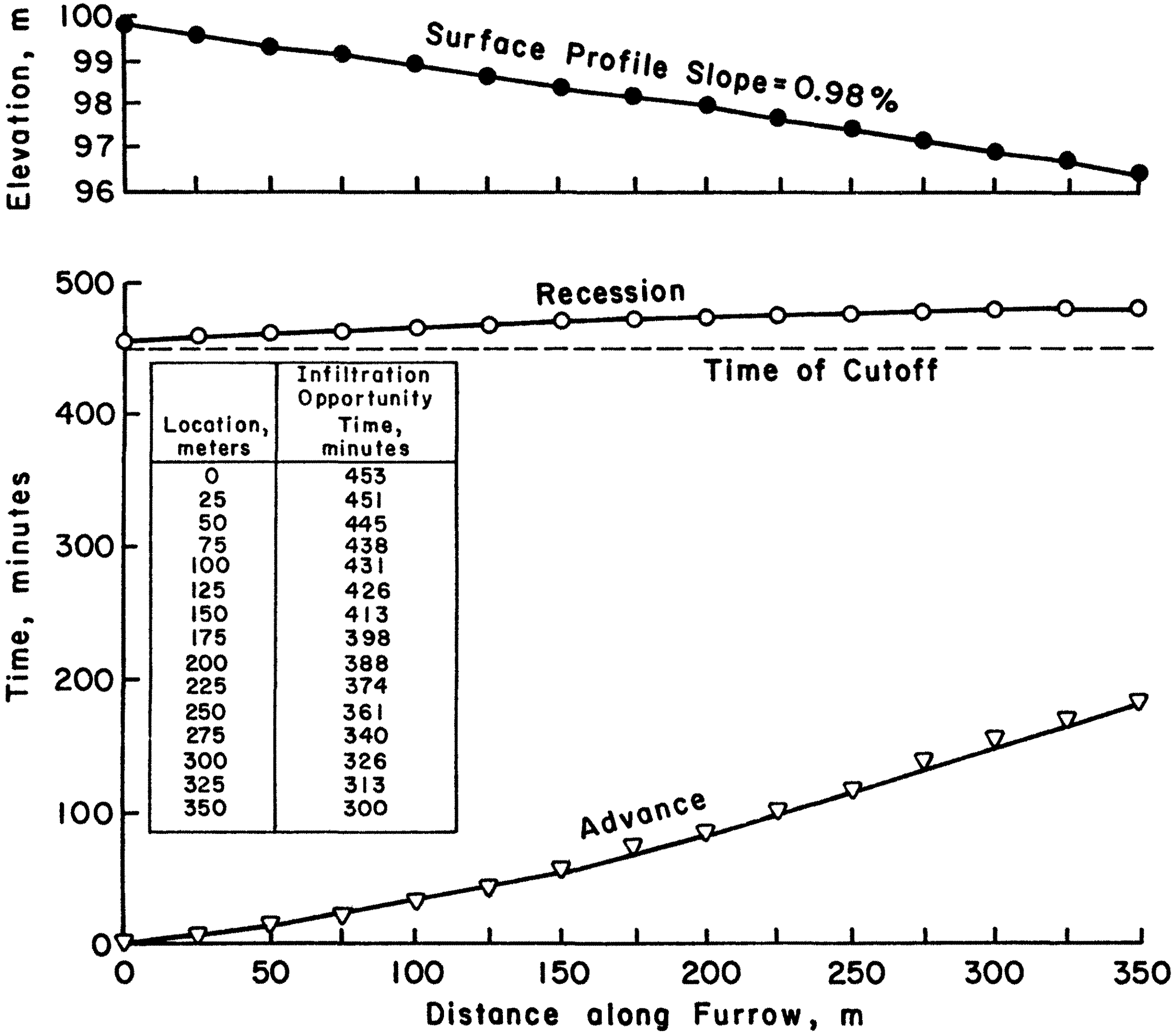


Figure 5. Blocked furrow infiltration test data.



Location, meters	Infiltration Opportunity Time, minutes
0	453
25	451
50	445
75	438
100	431
125	426
150	413
175	398
200	388
225	374
250	361
275	340
300	326
325	313
350	300

Figure 6. Advance/recession curves, surface profile slope and infiltration opportunity times.

shutdown and interrupted the irrigation. The inflow time over which measurements were taken was 7.5 hr. Inflow and runoff data for this time duration are plotted in Figure 7. Graphical integration of the area enclosed by each of these curves resulted in the following volumes:

Total volume applied, $W_a = 22.86 \text{ m}^3$
Total runoff volume, $W_u = 6.68 \text{ m}^3$
Total infiltrated volume, $W_i = W_a - W_u$
$= 16.18 \text{ m}^3$

An average infiltrated depth can be found by dividing by the furrow length and irrigated furrow spacing. In this case, a furrow length of 350 m is used since this is the distance over which infiltration occurred. The average infiltrated depth is:

$$\frac{16.18 \text{ m}^3}{(350 \text{ m})(1.12 \text{ m})} \left(\frac{1000 \text{ mm}}{\text{m}}\right) = 41.3 \text{ mm}$$

Infiltration opportunity times (from Fig. 7) are used in Equation (11) to plot the subsurface distribution (see Fig. 8). The ordinate in Figure 8 is actually an average infiltration depth in cm which is obtained by converting values obtained in Equation (11) from cm^3/m to m^3/m, then by dividing by the irrigated furrow spacing (m) and multiplying by 100 to obtain cm. Graphical integration of the area enclosed by this curve results in an estimate of total volume infiltrated per unit width as predicted by the blocked furrow infiltration function (Eq. 11). This estimate is:

$$W_i')_{\text{pred.}} = 15.19 \text{ m}^3/\text{m of width}$$

where $W_i')_{\text{pred.}}$ = estimated total volume infiltrated per unit width (L^3L^{-1}).

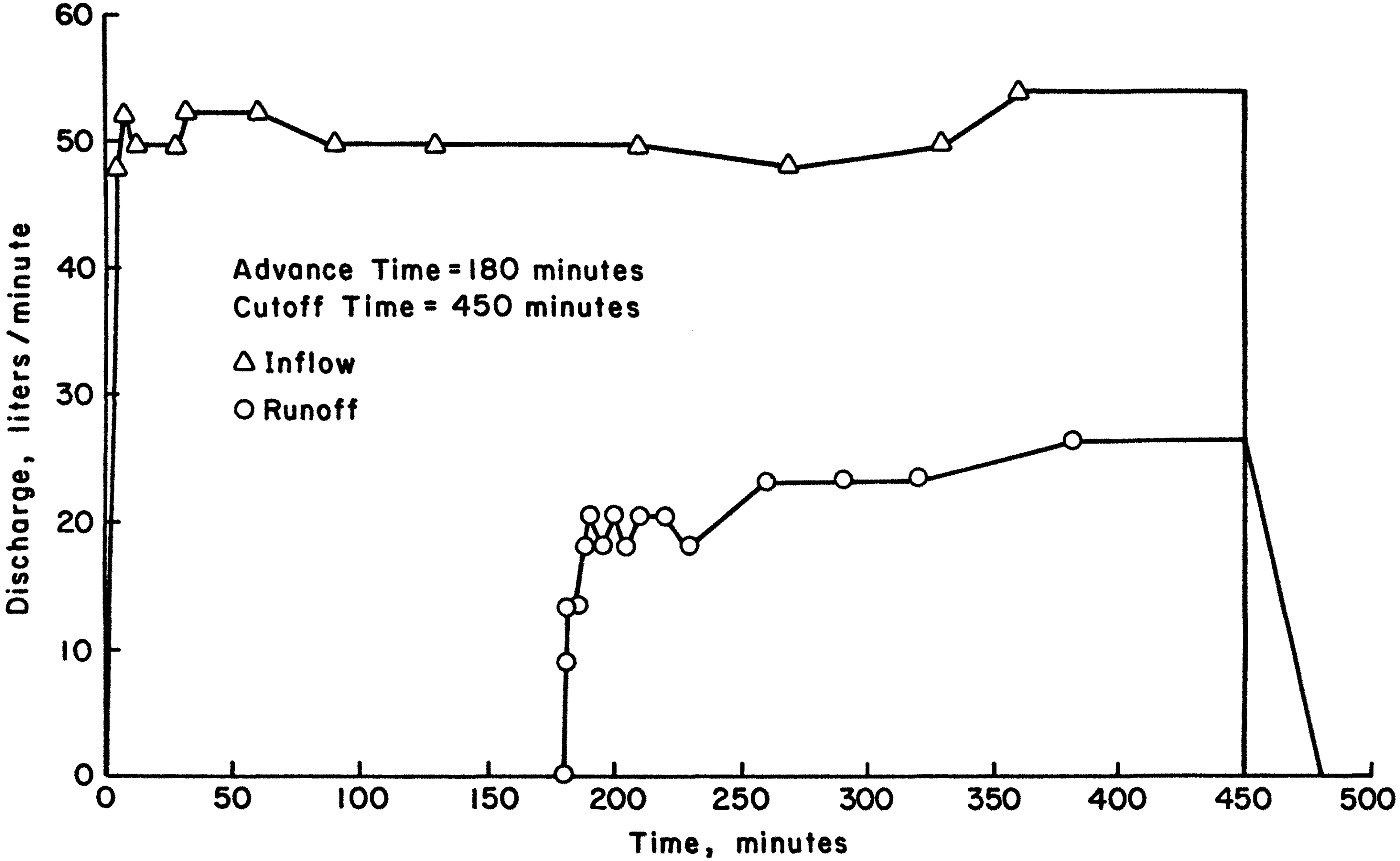


Figure 7. Inflow and runoff hydrographs.

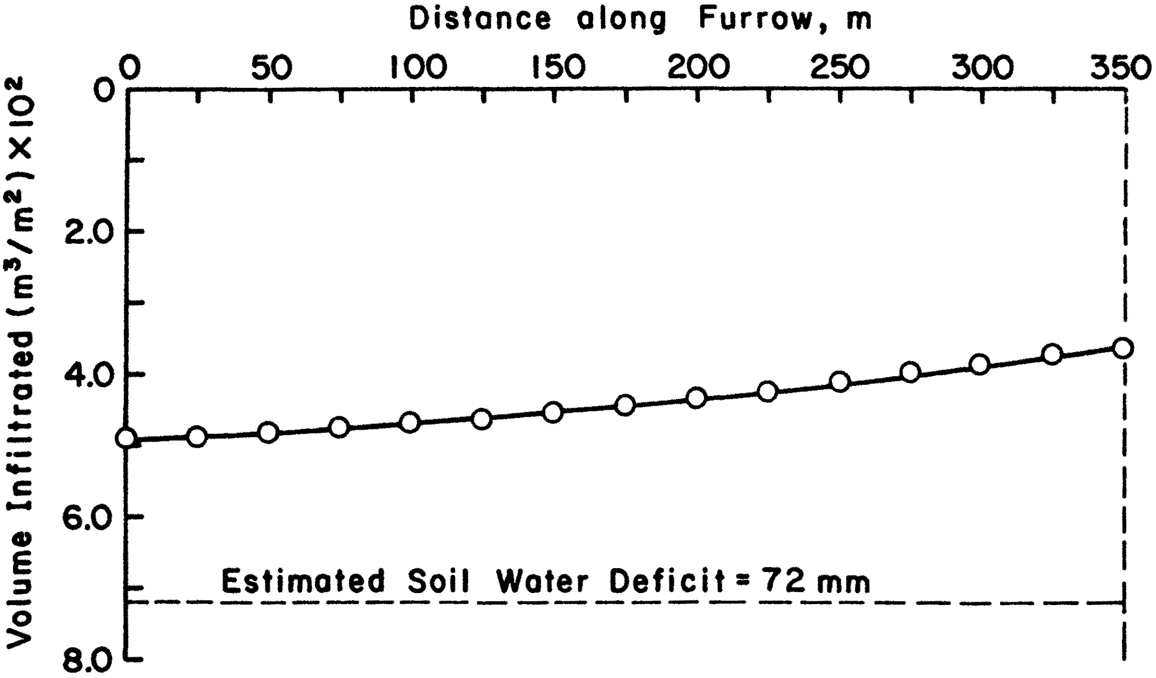


Figure 8. Subsurface distribution of applied water estimated from blocked furrow infiltration function, $z = 2369.4t^{0.37} + 70.0t$ (z-cm^3/m, t-min).

Multiplying by the furrow spacing (1.12 m) yields an estimate of the total volume infiltrated. Hence,

$$
\begin{aligned}
W_i)_{pred.} &= W_i')_{pred.} \times 1.12 \\
&= (15.19)(1.12) \\
&= 17.02 \text{ m}^3
\end{aligned}
$$

where $W_i)_{pred.}$ = estimate of total infiltrated volume (L^3).

An estimate of the average infiltrated depth as predicted by the blocked furrow infiltration function is:

$$\frac{17.02 \text{ m}^3}{(350 \text{ m})\ (1.12 \text{ m})} \left(\frac{1000 \text{ mm}}{\text{m}}\right) = 43.4 \text{ mm}$$

Comparison of the prediction of total infiltrated volume as obtained using the blocked furrow infiltration function with the value obtained by inflow/runoff hydrograph analysis shows the following deviation:

$$\left(\frac{17.02 - 16.18}{16.18}\right) 100 = + 5.2\%$$

This deviation is acceptable, considering the accuracy with which data can be collected in the field. Had the deviation been unacceptable (i.e., greater than 10 - 15 percent), then adjustment of the multiplicative constants in the infiltration function would have been necessary (by a volume balance trial and error procedure or graphical procedure, see example border irrigation evaluation by Ley and Clyma, 1980) until the deviation was within an acceptable range.

Results.--Each of the volumes associated with performance parameters can be determined with the results of the inflow/runoff hydrograph analysis and the subsurface distribution plot. For this case, the inflow/runoff hydrograph results are used. The volumes are as follows:

Total volume applied, $W_a = 22.86\ m^3$

Total runoff volume, $W_u = 6.68\ m^3$

Total volume infiltrated, $W_i = 16.18\ m^3$

Total volume required, $W_r = (72\ mm)\ (\frac{1\ m}{1000\ mm})(350\ m)(1.12\ m)$

$= 28.22\ m^3$

Total volume stored, $W_{rz} = 16.18\ m^3$

Total volume deep percolated, $W_p = 0.0\ m^3$

Total deficit volume, $W_{df} = 28.22 - 16.18$

$= 12.04\ m^3$

Each volume can be converted to an average depth by dividing by the product of furrow length and irrigated furrow spacing. The performance parameters for this irrigation are determined using Equations (6) through (10).

Water application efficiency, $$E_a = \frac{W_{rz}}{W_a} \cdot 100 \qquad (6)$$

$$= \frac{16.18}{22.86} \cdot 100$$

$$= 70.8\%$$

Water requirement efficiency, $$E_r = \frac{W_{rz}}{W_r} \cdot 100 \qquad (8)$$

$$= \frac{16.18}{28.22} \cdot 100$$

$$= 57.3\%$$

Tailwater ratio, $$R_t = \frac{W_u}{W_a} \qquad (9)$$

$$= \frac{6.68}{22.86}$$

$$= 0.292$$

$$\text{Deep percolation ratio, } R_p = \frac{W_p}{W_a} \tag{10}$$

$$= \frac{0.0}{22.86}$$

$$= 0.0$$

Since the irrigation was interrupted by a power failure, it is not possible to compare the design with the results of this evaluation. However, it is known that the farmer normally uses a 12-hr set time and that he makes no adjustment to the furrow inflow rate once the siphon tubes are set. Hence, referring again to Figure 7, it is possible to estimate what the volumes for a 12-hr inflow time would have been. This is done by extrapolating both the inflow and runoff curves out to 720 minutes at a discharge rate equal to their averages for the last half of the 450 minute irrigation. Changes will occur in W_a, W_u, W_i, W_{rz} and possibly W_p. Estimates of what the volumes and performance parameters for the 12-hr set might have been are as follows:

$W_a = 36.40\ m^3$
$W_u\ \ 13.32\ m^3$
$W_i = 23.08\ m^3$
$W_{rz} = 23.08\ m^3$
$W_p = 0.0\ m^3$
$E_a = 63.4\%$
$E_r = 81.8\%$
$R_t = 0.366$
$R_p = 0.00$

Table 1 provides a summary of the evaluation and a comparison with the design.

Table 1. Summary of evaluation and comparison with design.

Parameter	Evaluation (measured)	Evaluation (estimated)	Design[1]
Inflow time, min	450	720	720
Average furrow inflow rate, ℓps	0.847	0.843	0.57-0.76 (9-12 gpm)
Design depth or requirement, mm	72	72	61 (2.4 in.)
Average depth applied, mm	58.4	93.0	70.0 (2.76 in.)
Average infiltrated depth, mm	41.4	58.9	56.5 (2.22 in.)
Water application efficiency, %	70.8	63.4	81.4
Water requirement efficiency, %	57.3	81.8	92.7
Tailwater ratio, dec.	0.292	0.366	0.186
Deep percolation ratio, dec.	0.00	0.00	0.00

[1] Values for average depth applied, average depth infiltrated and design performance parameters are averages for the 0.57-0.76 ℓps (9-12 gpm) range of furrow inflow rates.

Conclusions

1. It is obvious that the interrrupted irrigation was inadequate. However, the uniformity of application was good.

2. Extrapolation of flow rates on the inflow/runoff hydrographs (to 720 min) yields an estimate of what the system performance would normally be under the farmer's current (12-hr set) operation. Assuming these results valid, the farmer would be doing only a fair job of replenishing the needed soil water and would have a large amount of runoff loss. Comparison with the suggested design parameters indicates why this happens. First, the farmer's average furrow inflow rate for the irrigation is well above the suggested range. This would be a major reason for the high amount of runoff losses as compared to design. Second, the farmer irrigated at a higher soil water deficit than suggested by design analyses. This factor contributes to the under-irrigation which is occurring with his current management.

3. The initial design for this field was formulated for a design depth of 72 mm (2.8 in.), the approximate operating soil water deficit for the farmer. Only marginally acceptable levels of design performance could be obtained for these design conditions. Iterations of the design procedure for smaller design depths were carried out and a feasible design determined for a design depth of 61 mm (2.4 in.). The farmer could significantly improve system performance by altering his system management to apply a smaller amount (61 mm) on a more frequent basis. i.e., reducing the design depth from 72 mm (2.8 in.) to 61 mm (2.4 in.) shortens the irrigation interval by 1 to 2 days.

Recommendations

1. The farmer should consider altering his system management to the smaller design application depth as discussed. Given the range of furrow inflow rates suggested from the design, 0.57 to 0.76 ℓps (9 to 12 gpm), acceptable levels of system performance can be achieved.

2. Further evaluations of the irrigation system are necessary. If the farmer accepts the above design parameters then an evaluation of the new design and management is desired. Also, seasonal changes in factors and conditions which affect the system performance must be evaluated so that an efficient operation can be implemented throughout the season. The example presented has only illustrated the many factors and conditions to be considered for one irrigation of the season.

COLLECTION AND ANALYSIS OF MORE DETAILED DATA

Data Collection

When it is desirable to obtain more detailed information on the physical operating aspects of the irrigation system, the following measurements should be made in sequence with the procedures described previously.

Furrow Cross-section Data.--An estimate of the furrow cross-sectional area can be obtained through the use of the device shown in Figure 9. The furrow profilometer is placed in the furrow with the sliding rods just resting on the furrow bottom. An identification marker of the location is placed next to the profilometer and a photo of them is taken. This should be done in several (at least three) pre-selected points along each of the furrows in which other measurements are made (i.e., advance/recession, inflow/runoff, etc.). Furrow cross-section data should be collected both before and after the irrigation; it is suggested that these data be collected at the same time soil water content samples are collected. Care and good judgement should be exercised in the placement of the profilometer, making sure to place it in a representative section of the furrow without disturbing the soil.

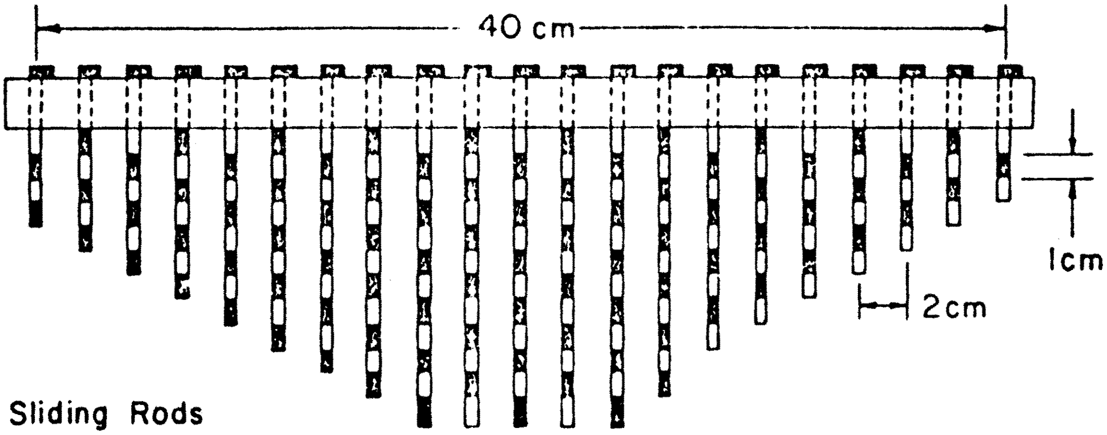


Figure 9. Furrow profilometer.

Flow Depth and Top Width Data.--The flow depth and top width are measured in each of the furrows in which inflow/runoff and advance/recession data are taken. Measurements should be made at several points along these furrows several times during the irrigation. These measurements should be taken at approximately the same location each time. When these data are collected, it is desirable to make the measurements as often as possible during the advance, and may be spaced out at 30 to 60-minute intervals during the rest of the irrigation.

Furrow Infiltration Data.--Another method for determining infiltration during furrow irrigation is the inflow-outflow method presented by Criddle, et al. (1956). Small flumes or other flow measuring devices are placed in the furrow at some spacing, i.e., anywhere from 25 m to 75 m. The inflow and outflow rates vs. time are recorded for each section. Flow depth and top width measurements are also taken in these sections. A volume balance procedure (discussed shortly) is used to determine an infiltration relationship. When these data are collected the measurements should be made in furrows other than those in which advance and recession data are collected.

Data Analyses

Furrow Profiles and Surface Storage.--Once the furrow cross-section photos are ready, the data is transcribed to the appropriate data form. These data can then be analyzed, and in general, an empirical power relationship between center depth and cross-sectional area found:

$$A_f = ARy^{BR} \tag{12}$$

where A_f = furrow cross-sectional area (L^2),

y = center depth (L),

AR, BR = empirical constants.

The constants AR and BR can be found using a least squares technique. Usually a mean relationship for the entire furrow length is determined as follows:

a. Graphically estimate the area of each cross section at depths of 1, 2 and 3 cm from the furrow bottom at the furrow centerline.

b. Calculate the mean area for the furrow sections of each furrow at each depth.

c. Perform a logarithmic transformation of Equation (A-1) and a least squares regression of the transformed variables to determine the constants AR and BR.

Assuming the empirical relationship for the furrow cross-sectional area (as just derived) is valid for the entire furrow length; flow depth data are used to find flow areas at each of the points where the flow depth is measured. Since flow depth data are available through the advance phase and the remaining phases of irrigation, an average cross-sectional flow area for the entire furrow length can be found for each of these phases. In turn, an estimate of the total volume of water in the furrow (surface storage) for a particular length, can be found by multiplying the average flow area by the furrow length being considered. The volume of surface storage may be necessary in certain volume balance analyses.

The cross-sectional flow area relationship and flow depth data are also used in estimating the furrow roughness in a relationship such as Manning's formula:

$$Q = \frac{C_u}{n} S_o^{1/2} R^{2/3} A_f \qquad (13)$$

where Q = flow rate at a particular section (L^3T^{-1}),

n = Manning's roughness factor,

S_o = bed slope ($L\ L^{-1}$),

R = hydraulic radius (L),

A_f = cross-sectional flow area (L^2),

C_u = constant dependent on units (1.0 for metric, 1.486 for English).

For such an analysis steady uniform flow in a prismatic channel of uniform slope is assumed. This allows usage of Manning's formula with the energy gradient equal to the furrow bed slope. The condition of steady uniform flow in furrow irrigation is approximated at the time when the soil has reached its basic intake rate. Thus, flow depth data only for about the last half of the irrigation should be used. The flow rate at any particular section along a furrow is assumed to decrease linearly from the inflow rate to the runoff rate when the soil is at its basic intake rate. Hence, Equation (A-2) can be solved for Manning's n since the other variables can be estimated (i.e., R and A_f are found from the furrow cross-section relation and flow depth data). Point estimates of n will result, which are averaged to find the mean furrow roughness.

Furrow Infiltration by Inflow-Outflow.--Criddle, et al. (1956) present a complete method for analyzing data collected in the inflow-outflow procedure. It involves a volume balance procedure using the inflow-outflow rate measurements to determine the furrow infiltration vs. time. Since flow depth data are available for the sections of furrow being evaluated, the volume of surface storage for those sections can be found as described previously. These estimates of surface storage volume are time distributed as are the inflow rate and outflow rate measurements. A volume balance as follows results in a time distribution of the volume infiltrated.

$$VINF(t) = VIN(t) - [VOUT(t) + VSS(t)] \tag{14}$$

where

$VINF(t)$ = total volume infiltrated at time t, (L^3),

$VIN(t)$ = total volume of inflow to furrow section at time t, (L^3),

$VOUT(t)$ = total volume of outflow from furrow section at time t, (L^3),

$VSS(t)$ = volume of water in surface storage at time t, (L^3).

In general, a functional relationship for infiltration can be determined for the data: volume infiltrated vs. time. More complete discussion of the method is found in Criddle, et al. (1956).

EQUIPMENT LIST AND SUGGESTED DATA FORMS

Equipment

The following list of equipment necessary for the evaluation of three furrows is suggested.

1. Six flow measurement devices (i.e., small cutthroat flumes with 1-in. throats).
2. Engineer's level, field rod, chain or tape, orange flagging.
3. Wood stakes and lathe for station markers, crayon for marking and hatchet for driving them into ground.
4. Soil sampling equipment:
    a. soil auger or tube sampler
    b. soil sample cans with tight fitting lids (up to 200, 2-in. diameter cans)
    c. box for carrying cans
5. Small carpenter's levels for leveling flumes, etc.

6. Blocked furrow infiltration equipment (up to 10 sets, see Figure 1) plus plastic sheeting.
7. 50 small wire stakes with orange flagging.
8. Bulk density equipment.
9. Instruments for measuring time (stop watch, wrist watch with second hand).
10. Buckets for hauling water.
11. Shovels, sledge hammers.
12. Soil uniformity box (partitioned box).
13. Pencils, clipboards and data forms.

For the more detailed measurements include:

14. Device for measuring flow depth and top width.
15. Furrow profilometer (see Figure A1).
16. Camera, film and identification marker.
17. Small flow measurement devices for furrow infiltration by inflow-outflow method.

Data Forms

Data forms for the following data sets are provided:

Soil Water Content Data
Bulk Density Data
Blocked Furrow Infiltration Data
Water Advance/Recession Data
Flow Rate Data
Farm and Field Data
Flow Depth and Top Width Data
Furrow Cross-sectional Area Data
Furrow Infiltration Data (Inflow-Outflow Method).

Each form includes a special code for identification of the evaluation site:

Ident (R_E, F_A, F_I, I, F_u),

where the data are identified by the letters in parenthesis.

R_E--Region

F_A--Specific Farm

F_I--Field Number on Farm

I--Irrigation Number (starting from the first irrigation at that location)

F_u--Furrow Number

Acknowledgements

Substantial support for the formulation of this paper was provided by the Egypt Water Use and Management Project, Agency for International Development Contract No. AID/NE-C-1351.

FLOW RATE DATA

IDENTIFICATION______________ OBSERVER________________ DATE_________

CROP_________ LENGTH_________ INFLOW________ or RUNOFF___________

FURROW/BORDER NO._______ FURROW SPACING/BORDER WIDTH______________

MEASURING DEVICE______________ START TIME_________ STOP TIME_______

COMMENTS:

Clock* Time (1)	Elapsed Time (min) (2)	ΔT (min) (3)	Reading ( ) (4)	Flow Rate ( ) (5)	Average Flow Rate ( ) (6)	Volume ( ) (6) x (3) (7)	Σ Volume ( ) Σ (7) (8)

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*All clock times are on 24-hour basis.

FARM AND FIELD DATA

IDENTIFICATION________________ OBSERVER_______________ DATE___________

FARMER_________________________ ADDRESS__________________________________

(Sketch the farm and on-farm water delivery system noting pertinent roads, boundaries, field boundaries, locations of pumps, open drains, etc.)

FLOW DEPTH AND TOP WIDTH DATA

Ident (R_E,F_A,F_I,I,F_u):_____ Length:______ Observer:_________ Date:______

Crop:____________________ Furrow Spacing (m):______________________

Remarks:

d - Flow depth (cm)
w - Top width of flow (cm)

	Start	End	Start	End	Start	End	Start	End
Time								
Station d/w								

	Start	End	Start	End	Start	End	Start	End
Time								
Station d/w								

APPENDIX A RECONNAISSANCE QUESTIONNAIRE

1. Farmer operation and management

How does the farmer decide when to irrigate?
What is his irrigation frequency? How does it change during the season?
How does he decide how to irrigate?
How does he decide how much water to apply?
Does the farmer know the total flow rate available to him?
What are the farmer's operating hours?
Does he irrigate at night?
How does he decide how long to irrigate a field?
How long does he irrigate a field?
Does the farmer have any problems with the system?
What are his cultivation and tillage practices?
Does he irrigate every furrow or alternate furrows?
How many furrows does he irrigate in one set?
How many sets does it take to irrigate the field?
Does he try to compact the furrows equally?

2. Water supply

What are the sources of available water?
Is the delivery station (point of diversion to farm) a problem, i.e., high losses, etc.?
Is the on-farm distribution system a problem (i.e., too many in-field channels, high losses, etc.)?
What is the flow rate of each source of water?
When is each source available and for how long?
Is the frequency of delivery and available head a problem?
What is the water quality?
How is the water delivered to each field?

3. Crop characteristics

What are the crops being grown?
What are the respective planting dates?
What cropping patterns, if any, have been followed?
Does the farmer have any major problems in crop production?
What are the major inputs? Potential yield?
What is his expected yield? Average yield in area?
Any obvious physical symptoms of problems?

4. Physical characteristics

Does the farmer know the field dimensions?
Does he know the slope and cross-slope (if any)?
Has the field been leveled to a uniform slope?
If yes, when? If no, why not?
What provisions, if any, are made for surface runoff?
Does runoff leave the farm or is it used again somewhere on the farm?
What is the border spacing and how did the farmer decide on that spacing?
What is the furrow spacing?
What is the method of diverting water into each furrow?

5. Soil survey

Does the farmer know the soils on his farm?
Does he know of any trouble spots (i.e., very light or heavy soils or salinity problems)?

6. Water table

Does the farmer know the groundwater level?
Does he feel it is a problem?
Is surface/subsurface drainage provided? If so, where?

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Staff Paper #40

EVALUATION OF GRADED BORDER IRRIGATION SYSTEMS

Thomas W. Ley and Wayne Clyma

INTRODUCTION

Data collection and analysis procedures for evaluating the performance of graded border irrigation systems are presented. Information is collected on both the physical and managerial aspects of operational systems. Basic data reduction procedures define the state of the irrigation system. A list of suggested equipment and data forms are included.

REQUIRED DATA

Preliminary Data

The evaluation of any irrigation system necessarily requires the collection and analysis of a large amount of data Not the least of which are basic preliminary site data which can be obtained through interviews with the farmer and by performing several basic physical measurements. Basic site information must be known before the evaluation of an irrigation occurs. It is also desirable to obtain as much information as possible from the farmer concerning his operation and management of the irrigation system before an irrigation is evaluated. A list of suggested questions is found in Appendix A for each of the following categories of information. The list, is by no means exhaustive, and often the farmers answers to some of the questions will lead the trained person to other more site specific questions.

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1. Farmer operation and management.--Understanding why or how a farmer does certain things in managing and operating the irrigation system is vital. Often this aspect of evaluating irrigation performance may be overlooked and incomplete knowledge of the irrigation system state results. Farmer management may be constraining the level of performance which can be attained. The general level of knowledge of the farmer concerning irrigation principles and practices is evaluated. Other information discussed later will aid in determining if system management can be improved.

2. Water supply.--The farmer will know the available water supply, source, delivery, frequency, etc. He may have only a general knowledge of the flow rate and quality. These should be measured during the course of an evaluation. On-farm conveyance losses may be a big problem. The farmer may or may not know. Measure the losses if necessary.

3. Crop characteristics.--The crops grown and the planting dates of each must be known. Available data in the literature are needed on crop seasonal water requirements, rates and stages of growth, maximum potential rooting depths, time from planting to effective cover, etc. This information along with climatic data is used to estimate crop water use through the irrigation season. The crop root zone should be measured at each irrigation for crops with expanding root systems. The measured root zone for a perennial crop (such as alfalfa) can often be assumed valid for the entire season unless a fluctuating water table is encountered. The crop root zone at each irrigation determines the available soil water reservoir at that time and is necessary to determine the soil water deficiency, the stress at the time of irrigation and performance parameters such as water application and water requirement efficiencies.

4. Physical characteristics.--Measure and record the field dimensions. Stakes should be driven into the ground at 25-m intervals along the length (adjust for size of field as necessary). Measure and record surface elevations at each stake (station) using a field rod and level. Plot the surface profile (elevation vs. length). Measure and record the cross-slope and border spacing at each station. Determine if a ponded or free outflow boundary condition exists at the downstream end. Determine where and how to measure border inflow and runoff.

5. Soil survey.--If available, obtain information on soils in the area (on the farm), such as maps and classifications from a local or regional office (e.g., USDA Soil Conservation Service or similar government agency). Such information is very useful and aids the design of data collection procedures. Soil types and textures are known and maps usually depict the variation of surface textures in a field. If this information is not available a soil survey is necessary to determine the soil types and uniformity in the field being studied. Soil samples should be collected in a minimum of ten locations in the field (i.e., at five locations along the length and two along the width). Samples should be taken from a minimum of four depths within the expected root zone, i.e., every 30 cm in an expected 1.2 m root zone (adjust as necessary). These samples should be analyzed to determine soil types.

Once soil types and variations through the field are known the apparent specific gravity of the soil (bulk density), the field capacity and wilting point of the soil must be determined. Garcia (1978) presents procedures for these measurements. Depending on the results of the soil survey the sample collection procedure is defined. For a field with uniform soils it is necessary to collect data on the above soil properties in a minimum of three locations in the field to obtain a good average. It is necessary to sample with depth. For a field with non-uniform soils the above soil properties must be determined for each major soil type. A minimum of three replications of samples is necessary to obtain an average. Sampling with depth is required. See Appendix B for further discussion.

Accurate definition of the above soil properties is necessary. The time and effort necessary to achieve accurate data will eliminate having to repeat any sampling. These data are most easily collected before the crop is planted. Some change of apparent specific gravity of the plow layer with time may be expected. Sampling plans for soil water content and infiltration tests will be functions of soil type and uniformity. The results of the soil survey should thus be available in advance of the initial irrigation evaluation.

If soil salinity/alkalinity is expected to be a problem (indicated by maps, previous surveys, information from the farmers), samples should be analyzed to determine the salinity/alkalinity. Such a problem may also indicate the presence of a high water table.

6. Water table.--The farmer should have general knowledge of water table conditions in the area. Soil survey results may indicate a high water table. If the water table is high or expected to fluctuate considerably (i.e., within the maximum potential root zone), it is desirable to monitor the ground water level through the irrigation season. This can be done with a series or grid of observation wells (EWUP, Vol. II, 1979).

A high water table can limit crop growth through water-logging. The groundwater quality can also seriously affect crop growth and should be measured.

Crop water use from the capillary fringe or the water table is possible. Estimates of crop consumptive use by evapotranspiration modeling techniques will not correspond with measured soil water deficits (by soil water content sampling) when the crop is using groundwater, assuming each method is yielding accurate results. This is significant if the water table rises during the season due to early overirrigation. Water table fluctuations due to overirrigation may also contribute to crop consumptive use and can affect root zone expansion.

On the Day before Irrigation

Preirrigation Soil Water Content Data.--Garcia (1978) presents procedures for the collection and analysis of soil samples for determining water content by the gravimetric method. Depending on the results of the soil survey (which should be available by this point in time), the sampling plan is devised. If the soil survey results show the soils to be uniform, a minimum of three locations in different parts of the field are selected for sampling to obtain an average for the field. However, if certain variations are expected (non-uniform water applications, etc.) or if soils are non-uniform a minimum of three replications of samples should be collected where the non-uniformities are or where variations are expected. For instance, non-uniform water applications along the length of run is common and collection of a minimum of three replications of samples at a minimum of three representative locations along the length is suggested. See Appendix B for further discussion on sampling and how often to sample.

In all cases, samples should be collected from each of several layers of the measured or expected maximum rooting depth of the crop (i.e., for a 1.2 m root zone, sample each 30-cm layer, and in the top

30-cm layer collect samples from each 15-cm increment). If the water table is higher than the expected maximum rooting depth, samples should be collected to the water table. Each individual sample should be 150 grams or more.

Other preparations for the evaluation should be made on the day before irrigation such as installation of flow measuring devices and cylinder infiltrameters. Contact the farmer and find out the time he expects to start irrigating. Plan to arrive in sufficient time to complete all preparations for the evaluation(s) such as preparation of data forms and assignment of duties.

On the Day of Irrigation

Infiltration Data.--For uniform soils at least three and preferably a total of six cylinder infiltration tests should be conducted in three locations along the length. For non-uniform soils three replications of tests should be made in each area where a different soil texture exists. If non-uniformity in distribution along the length of run is anticipated, then three replications for each representative length of the field is necessary to delineate these differences. During the season differences in soil water content will accentuate the differences in infiltration and the distribution of water. See Appendix B for further discussion of considerations of where to sample and how often.

The infiltrometer measurements should be started as the water arrives at each infiltrometer and the ponded depth maintained the same as the depth of flow of the irrigation water. If the tests cannot be conducted during irrigation, they should be conducted on the day before irrigation and a buffer ring should be used. Garcia (1978) presented procedures for installing the infiltrometers and conducting the tests.

Inflow/Runoff Data.--Flow measurement devices to determine inflow to and runoff from the border should be properly installed before the irrigation. The clock time[1] at which water is first introduced to the border should be recorded. A measurement of the initial inflow rate should be taken. Periodically during the irrigation record the inflow rate and clock time of the observation. When the water reaches the runoff measurement device begin making runoff rate vs. time measurements. A suggested pattern for taking runoff data from the time runoff starts is to take a reading at 30 sec/min, 2 min, 4 min, 8 min, 15 min, 30 min, and then every 1/2 hour. Record the clock time when water entering the border is terminated.

Advance/Recession Data.--The rate of waterfront advance should be observed and recorded. When the moving stream front is irregular, record the time when an "average" front reaches each station (see Fig. 1). After the inflow is terminated, record the rate of recession. Ideally, this would be the time when water disappears from each station. It is difficult to determine the location of the receding water edge. When water has disappeared from 50 percent of the grid surface area represented by each station, recession is assumed to have occurred at that station. Consistency is of primary importance in taking recession data.

After Irrigation

Postirrigation soil water content samples should be collected anywhere from 1-1/2 days to 3 days after irrigation. This depends on the soil type and the time required for the soil to drain to field

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[1] Clock times should be on a 24-hour basis (military time).

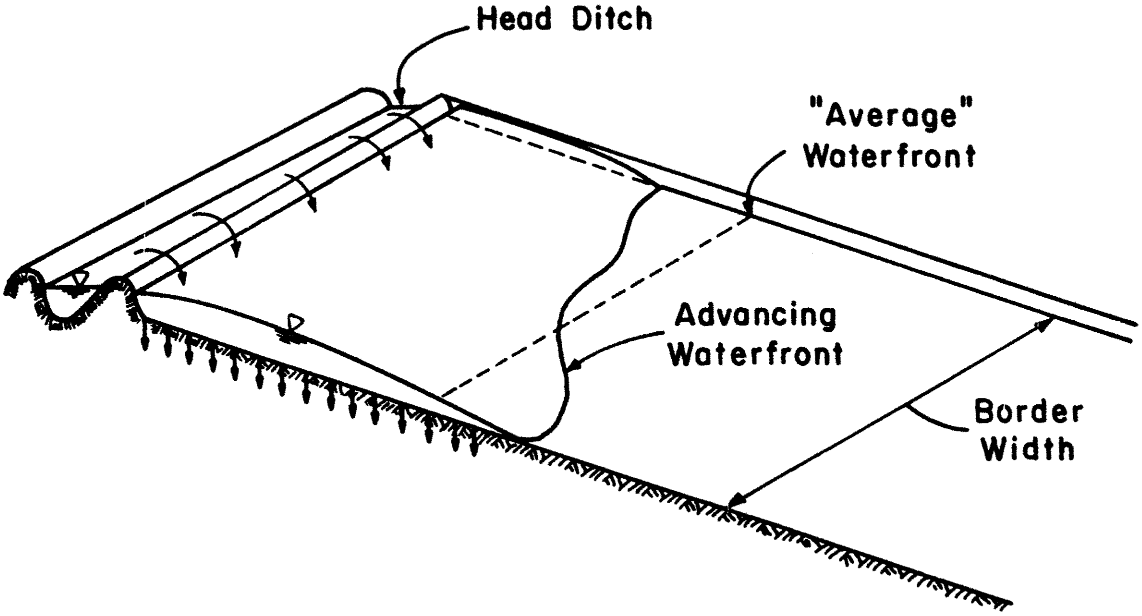


Figure 1. Illustration of irregular waterfront advance and location of "average" waterfront.

capacity. Garcia (1978) presents a field procedure for estimating when (after wetting) a soil has drained to field capacity. The same collection procedures as previously discussed apply.

Discussion and Recommendations

To ensure cooperation of the farmer during the evaluation, describe exactly what will be done. Minimize crop damage and soil disturbance. Be sure the farmer will operate his system as he usually does. Avoid remarks which may influence his management decisions. The purpose of the evaluation is to determine the system performance and evaluate the system operation as the farmer currently manages it.

It is important that preliminary data collected early in the season be good data. A careful, coordinated, determined effort here will save much time and eliminate problems and headaches later in the season. For instance, the soil water content of a field before the initial irrigation of the season may generally be assumed as uniform. Much effort in careful soil sampling and in collection of more samples (to increase the precision with which the mean soil water content is estimated) is recommended. The establishment of this initial condition serves an important purpose. It is the starting point for a root zone soil water budget.

From this initial condition, water added to the root zone of the crop by precipitation (measured by rain gages set up in several locations at the site), and by irrigation (measured by irrigation evaluations) is known. Crop use is estimated using climate data and crop stage and growth data in an accurate, calibrated evapotranspiration model. A root zone soil water budget can thus be calculated through the season. Soil water content data collected at succeeding irrigations of the season are used as a check on the predicted soil water status when calibration of the ET model is necessary.

If there is a high water table in the area, crop use from the capillary fringe or the water table itself can be estimated. The difference between the calculated crop use and the measured soil water deficit (by sampling) during an irrigation interval is an estimate of the crop use from the water table during that interval. If there is no reason to believe that the crop is using water from a water table, then the computed difference indicates the accuracy of each method and possibly needed action to improve sampling or predictive techniques.

In some instances, collection of advance/recession data may not be necessary at each irrigation. For instance, a uniform application of water may be expected on a field with shorter lengths of run on a heavier soil. In this case, the distribution is assumed uniform and all that is required is the water on and water off to determine the water added to the soil. While this case may occur, it is advisable to collect advance and recession data when any non-uniformity of water application is suspected due to poor irrigation practices, non-uniform soils, non-uniform field slopes, etc. in order to know the distribution of applied water.

During the course of an actual irrigation evaluation, it is recommended that a partial evaluation of the data being collected be conducted. This is accomplished best by processing the data as it is collected in the field and interpreting the results. For instance, it is easy to evaluate inflow and runoff data. An obvious error is determined if the runoff is greater than the inflow. This check on data provides the investigator a means of eliminating wasted time and effort in the collection of erroneous data.

FIELD DATA ANALYSIS

Field data analysis provides a basis for understanding the performance of the irrigation system and how the system is being operated. The data may be analyzed through a number of procedures. Those presented here represent the minimum of analyses required to formulate an understanding of the system's performance resulting from a particular management scheme.

Soil Water

The soil water content may be estimated by two methods: 1) gravimetric method, and 2) feel method. The soil water content expressed as a depth of water per unit depth of root zone can be estimated using the results of the gravimetric soil water analyses in the following equation:

$$d_m = \sum_{i=1}^{n} (P_{w,i} \cdot \gamma_{b,i} \cdot y_i) \tag{1}$$

where d_m = the soil water content expressed as a depth (L) for the entire depth investigated,

$P_{w,i}$ = dry weight soil water content for the ith layer of the root zone (MM^{-1}),

$\gamma_{b,i}$ = soil bulk density in the ith layer $[(ML^{-3})(ML^{-3})^{-1}]$,

y_i = thickness of the ith soil layer (L),

n = number of layers in the root zone which were sampled.

The pre-irrigation soil water content data are checked with the soil field capacity to estimate the soil water deficit (available root zone storage) at the time of irrigation. As previously discussed, crop water use and root zone soil water budgeting also provides a check on the soil water deficit at irrigation time. The pre- and post-irrigation soil water data can also be useful in analyzing depths infiltrated and adequacy of irrigation along the border assuming there is no deep percolation of water below the lowest depths investigated.

The feel method for estimating soil water content is largely subjective since it is dependent upon visual inspection of certain characteristics of the soil sample. The method should be used only when the investigator has a large amount of experience and even then only for a rough estimate of soil water content. Table 1 describes the relationship between soil physical appearance and soil water content for varying soil types.

Advance and Recession

The advance and recession data are plotted on coordinate paper as shown in Figure 2. The advance curve is a plot of the time the waterfront advances along the border vs. the length of the border. The recession curve is a plot of the time the waterfront recedes from the surface vs. the border length. The intake opportunity time is the difference between the advance and recession time as shown in Figure 2. Intake opportunity times represent the amount of time water has the opportunity to infiltrate at points along the border. Surface elevation data are often plotted on the same graph as an aid in explaining variations in advance and recession rates, and resultant effects on infiltration opportunity time.

Infiltration Relationship

The data from cylinder infiltration rests are reduced to the form of cumulative depth of infiltration vs. time. The reduced data are then plotted on log-log paper (Garcia, 1978). In general, the data plot as straight lines, but may slightly curve and often will "dogleg." Some

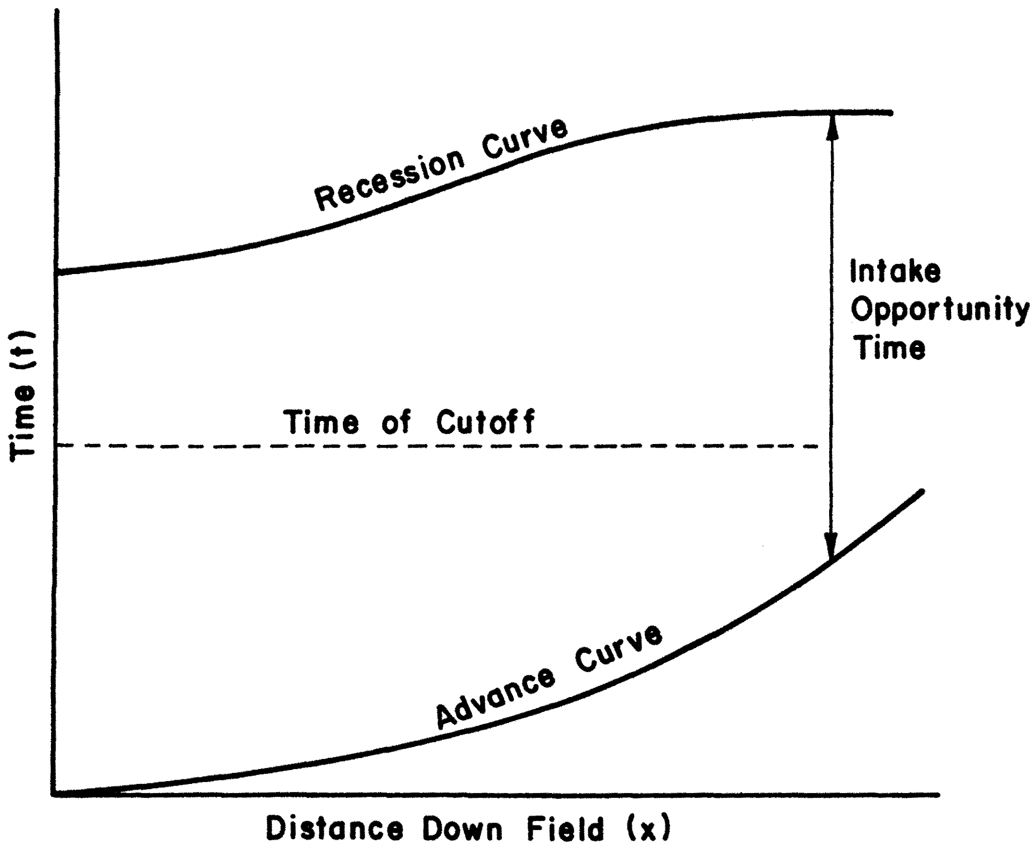


Figure 2. Typical advance and recession curves for border irrigation.

Table. 1. Soil moisture deficiency and appearance relationship chart (after Merriam and Keller, 1978). (This chart indicates approximate relationship of soil moisture deficiency between field capacity and wilting point. For more accurate information the soil must be checked by drying samples.)

Moisture Deficiency (in./ft)	Soil Texutre Classification				Moisture Deficiency (in./ft)
	Coarse (loamy sand)	Sandy (sandy loam)	Medium (loam)	Fine (clay loam)	
0.0	Leaves wet outline on hand when squeezed	Appears very dark, leaves wet outline on hand, makes a short ribbon	Appears very dark, leaves wet outline on hand, will ribbon out about one inch	Appears very dark, leaves slight moisture, on hand when squeezed, will ribbon out about two inches	0.0
0.2	Appears moist makes a weak ball	Quite dark color, makes a hard ball			0.2
0.4	Appear slightly moist sticks together		Dark color, forms a plstic ball, slicks when rubbed	Dark color, will slick and ribbons easily	0.4
0.6		Fairly dark color, makes a good ball	Quite dark, forms a hard ball		0.6
0.8	Dry, loose, flows thru fingers. (wilting point)	Slightly dark color, makes a weak ball	Fairly dark, forms a good ball	Quite dark, will make thick ribbon, may slick when rubbed	0.8
1.0		Lightly colored by moisture, will not ball	Slightly dark, forms weak ball	Fairly dark, makes a good ball	1.0
1.2					1.2
1.4		Very slight color due to moisture (wilting point)	Lightly colored, small clods crumble fairly easily	Will ball, small clods will flatten out rather than crumble	1.4
1.6			Slight color due to moisture, small clods are hard (wilting point)	Some darkness due to unavailable moisture, clods are hard, cracked (wilting point)	1.6
1.8					1.8
2.0					2.0

Field Method of Approximating Soil Moisture (Deficiency) for Irrigation; Transactions of the American Society of Agricultural Engineers, Vol. 3, No. 1, 1960; John L. Merriam, Professor, California Polytechnic State University, 1975, San Luis Obispo, California.

curves steepen after a few minutes either because of release of trapped air (usually in sandier soils) or because the cylinders were not driven deeply enough. Soils which have cracks, into which water disappears quickly, often exhibit curves which are initially steep and then flatten. Plow pans may cause a similar, but usually delayed effect. The average infiltrated depth vs. time should be computed using the data from each area where soil properties were found to be uniform (Merriam and Keller, 1978). The average infiltrated depth vs. time should then also be plotted on the same log-log graph as the individual data sets for these areas. A least squares regression technique (see Garcia, 1978) is often used to find an infiltration function of the following form for the average infiltrated depth vs. time:

$$z = kt^a \tag{2}$$

where z = cumulative depth infiltrated (L),

t = time (T)

k,a = empirical constants.

This type of infiltration function is usually considered representative in border irrigation. In most cases, the infiltration relationship resulting from ring infiltration tests is inadequate in predicting the actual infiltration which occurs during the irrigation. The <u>actual average</u> infiltrated depth can be found using inflow and runoff data (discussed later) for the irrigation. The following procedure is used to find the <u>predicted average</u> infiltrated depth (as predicted by the infiltration relationship).

1. Using intake opportunity times (from advance/recession data) for stations along the border and the infiltration relationship, find the predicted infiltrated depth at each station.

2. Determine the average infiltrated depth for each reach (distance between stations) by averaging the predicted infiltrated depths of successive stations.
3. Determine the predicted average infiltrated depth for the entire border by summing the reach averages (found in 2) and dividing by the number of reaches. Keep in mind that this value is an estimated or predicted value resulting from the use of the empirical infiltration function.

Inflow and Runoff

Inflow and runoff data provide a simple means of determining the actual average infiltrated depth. The inflow and runoff hydrographs are constructed on the same rectangular grid by plotting inflow and runoff rates vs. time. An estimate of the total volume of water applied, $W_a(L^3)$, is found by graphically integrating the area under the inflow hydrograph. An estimate of the total runoff volume, $W_u(L^3)$, is found by graphically integrating the area under the runoff hydrograph. An estimate of the total infiltrated volume, $W_i(L^3)$ is found by taking the difference as follows:

$$W_i = W_a - W_u \tag{3}$$

The actual average infiltrated depth can then be determined by dividing W_i by the product of the border width and length.

Adequacy of Infiltration Relationship

Once both the predicted average infiltrated depth and the actual average infiltrated depth have been found they are compared. This is a check on the adequacy of the empirical infiltration function in predicting the average infiltrated depth. If the two values are not approximately equal (i.e., less than 5 to 10 percent difference), then the infiltration relationship should be adjusted accordingly until the predicted value is approximately equal to the actual value. The adjustment procedure is done either graphically or numerically and involves finding a new value for the multiplicative constant in Equation (2), while the value of the exponent remains the same (Merriam and Keller, 1978). On the log-log plot, this implies the slope of the curve remains constant and the curve is either shifted upwards or downwards. Both the graphical and numerical procedures are much more fully and easily explained in the example evaluation presented later.

Runoff Data Not Available.--When runoff data are not available, then the adequacy of the infiltration function must be checked using a different method (Merriam and Keller, 1978). In this case, the checkpoint is the actual average *applied* depth rather than the actual average infiltrated depth. The method requires the extrapolation of the advance and recession curves to their intersection. This provides an estimate of how far the water would have spread if the downstream boundary condition at end of the border was an imaginary extended border length, and is a means of accounting for all of the water applied. The predicted average *applied* depth is found by utilizing intake opportunity times in the infiltration relationship as previously discussed. Now, however, the opportunity times for the imaginary extended length must be included in the anaylsis. The actual average *applied* depth is found by dividing the total applied volume by the imaginary wetted area (i.e., the product of border width and total imaginary extended length). Comparison of the *predicted average* and *actual average applied* depths indicates if adjustment of the infiltration relationship is necessary. This procedure is obviously not as accurate as that used when runoff data are available due to the errors introduced in extrapolation of the advance and recession curves.

Subsurface Distribution

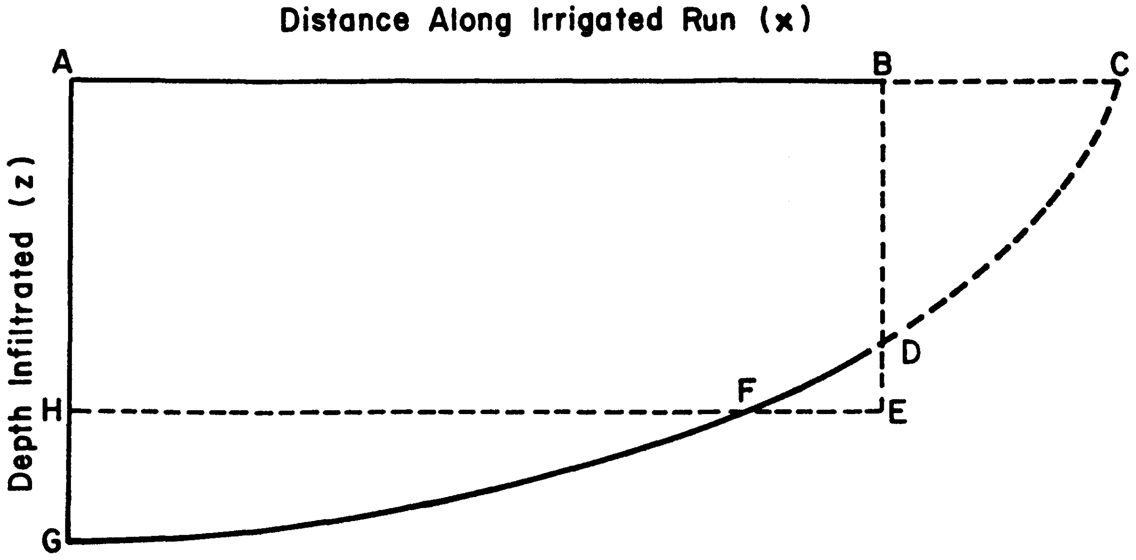
The subsurface distribution of applied water in border irrigation can be determined when the following information is known.

1. A representative infiltration function (as determined above).
2. Infiltration opportunity times along the irrigated run, i.e., advance and recession times at points along the run.

Upon construction of the subsurface profile, it is possible to characterize the performance of a particular irrigation. However, before irrigation performance parameters are defined it is necessary to define several related quantities upon which they depend.

Figure 3 represents an idealized profile of infiltrated water as a result of border irrigation. The distance AB is the border length, and the line DFG is the boundary of the infiltrated water. If the downstream boundary condition is one of free outfall, then runoff water from the field can be assumed to extend to the imaginary field length C, and to infiltrate according to the profile CD. The water requirement depth at the time of irrigation is assumed uniform along the border length and is represented by line EFH. With these concepts in mind the following quantities with appropriate units are defined in Figure 3.

1. Total volume of applied water, W_a (area ACDGA). This is the total volume of water introduced per unit width of border.
2. Total volume of water required in the root zone to reach field capacity, W_r (area ABEHA). This is the volumetric soil water deficiency.



AB	length of border (L)
ACDGA	total volume of applied water per unit field width, $W_a (L^3 L^{-1})$
ABEHA	total volume of requirement per unit field width, $W_r (L^3 L^{-1})$
ABDFHA	total volume of actual root zone storage per unit field width, $W_{rz} (L^3 L^{-1})$
FGHF	total volume of deep percolation per unit field width, $W_r (L^3 L^{-1})$
BCDB	total volume of runoff water per unit field width, $W_u (L^3 L^{-1})$
DEFD	total volume of root zone deficit after irrigation per unit field width, $W_{df} (L^3 L^{-1})$

Figure 3. Idealized subsurface profile of applied water in border irrigation.

3. Total volume of water stored in the root zone, W_{rz} (area ABDFHA). This volume of water is dependent upon the field capacity of the soil and the available storage at the time of irrigation. The total volume of water available for plant use after the irrigation and drainage period equals the difference between the field capacity (FC) and the permanent wilting point (PWP) of the soil, if the root zone is completely filled during irrigation [i.e., the total available water expressed as a depth, TAW = (FC - PWP) x (bulk density of the soil) x (rooting depth)].
4. Total volume of deep percolation, W_p (area FGHF). The volume of water which infiltrates past the lower boundary of the root zone. W_p may equal zero in some cases.
5. Total volume of tailwater or runoff, W_u (area BCDB). The volume of water which runs off the end of the field if free outfall conditions exist.
6. Total volume of root zone deficit after irrigation, W_{df} (area DEFD). W_{df} equals zero if the root zone is completely filled.

The total volume of water applied and the total volume of runoff an be cross-checked with the hydrograph analyses discussed earlier, when such data are available. Volumes can be converted to average depths by dividing by the product of border width and border length.

Irrigation Performance Parameters

Four irrigation performance parameters are discussed and may be defined using either volumes or depths.

1. Water application efficiency, E_a, is the percent of the amount of water applied which is stored in the root zone for

future use. It is a measure of the effectiveness of the irrigation in storing water.

$$E_a = \frac{W_{rz}}{W_a} \cdot 100 = \frac{D_{au}}{D_a} \cdot 100 \qquad (4)$$

where W_{rz} and W_a are as defined previously, and D_{au} and D_a are the corresponding average depths (L) associated with these volumes, respectively.

2. Water requirement efficiency, E_r, indicates the percent of the amount of water required to refill the root zone, which is supplied by an irrigation. It is a measure of the effectiveness of the irrigation in meeting the crop requirement.

$$E_r = \frac{W_{rz}}{W_r} \cdot 100 = \frac{D_{au}}{D_u} \cdot 100 \qquad (5)$$

where W_{rz} and W_r are as defined previously, and D_{au} and D_u are the corresponding average depths (L) associated with these volumes, respectively.

3. Tailwater ratio, R_t, represents the fraction of the total amount applied which is lost as tailwater or runoff from the end of the border.

$$R_t = \frac{W_u}{W_a} \qquad (6)$$

where W_u and W_a are volumes (L^3) as previously defined.

4. Deep percolation ratio, R_p, represents the fraction of the total amount applied which is lost as deep percolation past the bottom of the root zone.

$$R_p = \frac{W_u}{W_a} \qquad (7)$$

where W_p is as previously defined.

It is pointed out that the sum of the water application efficiency (expressed as a fraction), the tailwater ratio, and the deep percolation ratio is unity.

Another performance parameter often used describes the uniformity of water application. It may be unnecessary, however, when a plot of the subsurface distribution of applied water (as discussed earlier) is available. This parameter is a measure of the uniformity of the spatial distribution. Several techniques for characterizing the spatial distribution of infiltrated water have been developed. One of the more common and more easily calculated parameters is UCH, the Hawaiian Sugar Planter's Association uniformity coefficient (Hart, 1961):

$$UCH = 1 - \sqrt{\frac{2}{\pi}}\ \frac{s}{\bar{x}} = 1-0.798\ \frac{s}{\bar{x}} \qquad (8)$$

where $\bar{x}$ = the mean infiltrated depth (determined from several observations),

s = the standard deviation of the observations.

EXAMPLE SYSTEM EVALUATION

The following discussion presents the results of an evaluation of a graded border irrigation system as the farmer was currently operating it. The original data are taken from Merriam and Keller (1978). The value of being able to describe system operation and performance through an evaluation, and then comparing the results to an appropriate design is illustrated. A design for the field was formulated using the SCS border irrigation design procedure (USDA, 1974). The results of this design are presented in a seperate analysis of the design procedure ( ). Changes in system operation and management for improved water application are more easily recognized when compared to the design.

Unfortunately, for this particular evaluation, runoff data and postirrigation soil water content data are not available. The preirrigation soil water status was evaluated using the feel method previously discussed. Recommended design parameters are repeated here for the reader's convenience.

Q_u = 4.31 ℓ/s-m (0.0464 cfs/ft)
T_a = 118 min
strip width = 7.9 m (26 ft)
design depth = 114 mm (4.5 in.)

The farmer was operating the system using the full available stream of 34 ℓps (1.2 cfs) on a border strip width of only 7 m (23 ft) and border length of 210 m (700 cfs). This gives a unit width stream of 4.83 ℓ/s-m (0.052 cfs/ft) (which is larger than the design value due to smaller border width). Due to harvest operations, the farmer scheduled a more frequent water application. The application time was 88 minutes and the soil water deficit at the time of irrigation was estimated to be 74 mm (2.9 in.).

Four cylinder infiltration tests were conducted during the evaluation in four locations along the length since the soil was found to be fairly uniform. These data, in the form of cumulative depth infiltrated versus time, are plotted in Figure 4. A wide range of initial intake rates is observed. However, after approximately 30 minutes, the data curves have nearly the same slope. The average cumulative intake vs. time was determined from the four sets of data and is also plotted in Figure 4 (as the curve labeled "average"). As can be seen, there is a significant dogleg in this curve (Merriam and Keller, 1978). Since all of the data plots exhibit nearly the same slope after

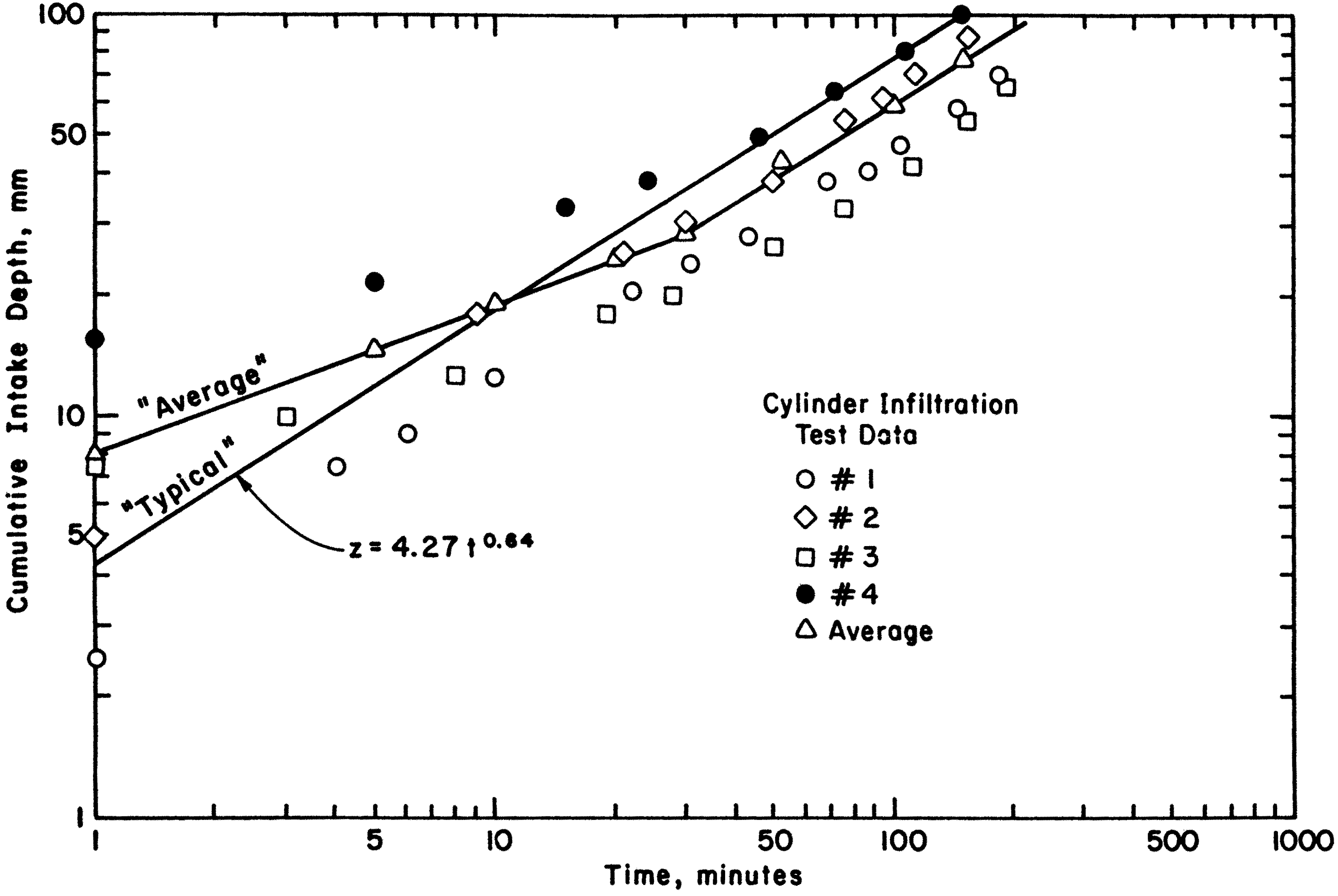


Figure 4. Cylinder intake data.

30 minutes, it was decided a straight line typical of this condition but also typical of the wide range of initial rates was most representative. The curve labeled "typical" is the result. It is felt that the "typical" curve provides adequate representation of the intake data, and is easier to describe functionally. The infiltration function defining the "typical" curve is:

$$z = 4.27\ t^{0.64} \quad , \tag{9}$$

where z = depth infiltrated (mm)

t = intake opportunity time (min).

Equation (9) was also used to develop the initial design results presented earlier.

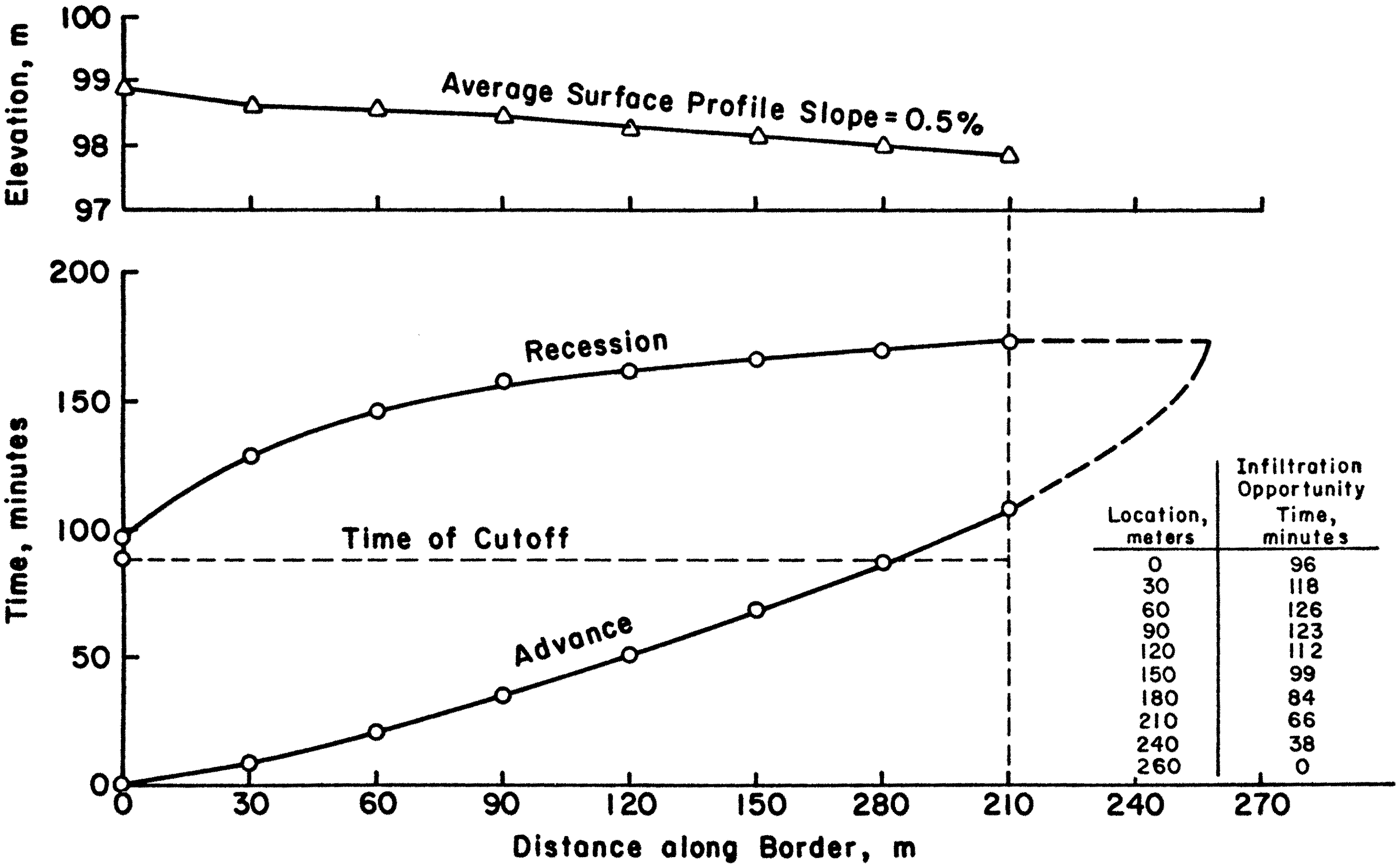
Advance and recession data were collected at 30-m stations along the irrigated run. These data along with infiltration opportunity times and the surface profile slope are presented in Figure 5. Since runoff data are not available, the advance and recession curves were extrapolated to their intersection in Figure 5. The imaginary extended length is seen to be about 260 m. Intake opportunity times for the imaginary extended length are included. An estimate of the actual average applied depth can now be determined. The inflow rate of 34 ℓps (1.2 cfs) was constant for the entire 88-min. duration. Therefore:

$$D_a = \frac{W_a}{WL} = \frac{QT}{WL} \tag{10}$$

$$D_a = \frac{(34\ \ell ps)(88\ \text{min})(60\ x/\text{min})\left(\frac{1\ m^3}{1000\ \ell}\right)}{(7\ m)\ (260\ m)} \left(\frac{1000\ mm}{1\ m}\right)$$

$$D_a = 99\ mm$$

This value can be used as a checkpoint for testing the adequacy of the infiltration function previously determined in predicting the <u>average</u>



Location, meters	Infiltration Opportunity Time, minutes
0	96
30	118
60	126
90	123
120	112
150	99
180	84
210	66
240	38
260	0

Figure 5. Advance/recession, surface profile curves and infiltration opportunity times.

applied depth. The procedure is illustrated in Table 2. Equation (9) and infiltration opportunity times from Figure 6 are used to find infiltrated depths at stations along the run (actual plus extended length). The average depth for each 30-m reach is found. The last reach was only 15 m, thus the average depth there was determined proportionately to its length. The average applied depth for the entire wetted length as predicted by Equation (9) is calculated as 76.9 mm. This does not correspond with the actual average depth applied of 99 mm, as found earlier.

Adjustment of the infiltration function is necessary. The procedure for doing this is illustrated graphically in Figure 6. The "typical" curve represented by Equation (9) is shifted upwards in Figure 6 keeping the slope of the curve constant. The "adjusted" curve should have a slope equal to the "typical" curve and should pass through the point, where the depth equals 99 mm and the time equals the time at which the "typical" curve has a depth of 76.9 mm infiltrated. This time (using Equation (9)) is approximately 92 minutes. The intercept at unit time for the adjusted curve is approximately 5.48 mm. A numerical procedure for determining the functional relationship of the "adjusted" curve involves finding a new value for k in Equation (2), such that with $a = 0.64$ and $t = 92$ min, z will equal 99 mm:

$$k = z \div t^a$$

$$k = 99 \div 92^{0.64}$$

$$k = 5.48$$

Thus, the "adjusted" infiltration curve is represented by:

$$z = 5.48\ t^{0.64} \tag{11}$$

Table 2. Check on infiltrated depths and total applied depth predicted by "typical" infiltration function and "adjusted" infiltration function (after Merriam and Keller, 1978).

Station (m)	0	30	60	90	120	150	180	210	240	260
Opportunity Time (min)	96	118	126	123	112	99	84	66	38	0
				Infiltration Depths (using Equation (9))						
Depth (mm)	79.3	90.5	94.3	92.9	87.5	80.8	72.8	62.4	43.8	0.0
Average Depth (mm)	84.9	92.4	93.6	90.2	84.2	76.8	67.6	53.1	0.5(21.9)	
Average Depth on 260 mm = 653.7/8.5 = 76.9 mm										
				Infiltration Depths (using Equation (11))						
Depth (mm)	101.7	116.1	121.1	119.2	112.3	103.7	93.4	80.0	56.2	0.0
Average Depth (mm)	108.9	118.6	120.2	115.8	108.0	98.6	86.7	68.1	0.5(28.1)	
Average Depth on 260 mm = 838.8/8.5 = 98.7 mm										

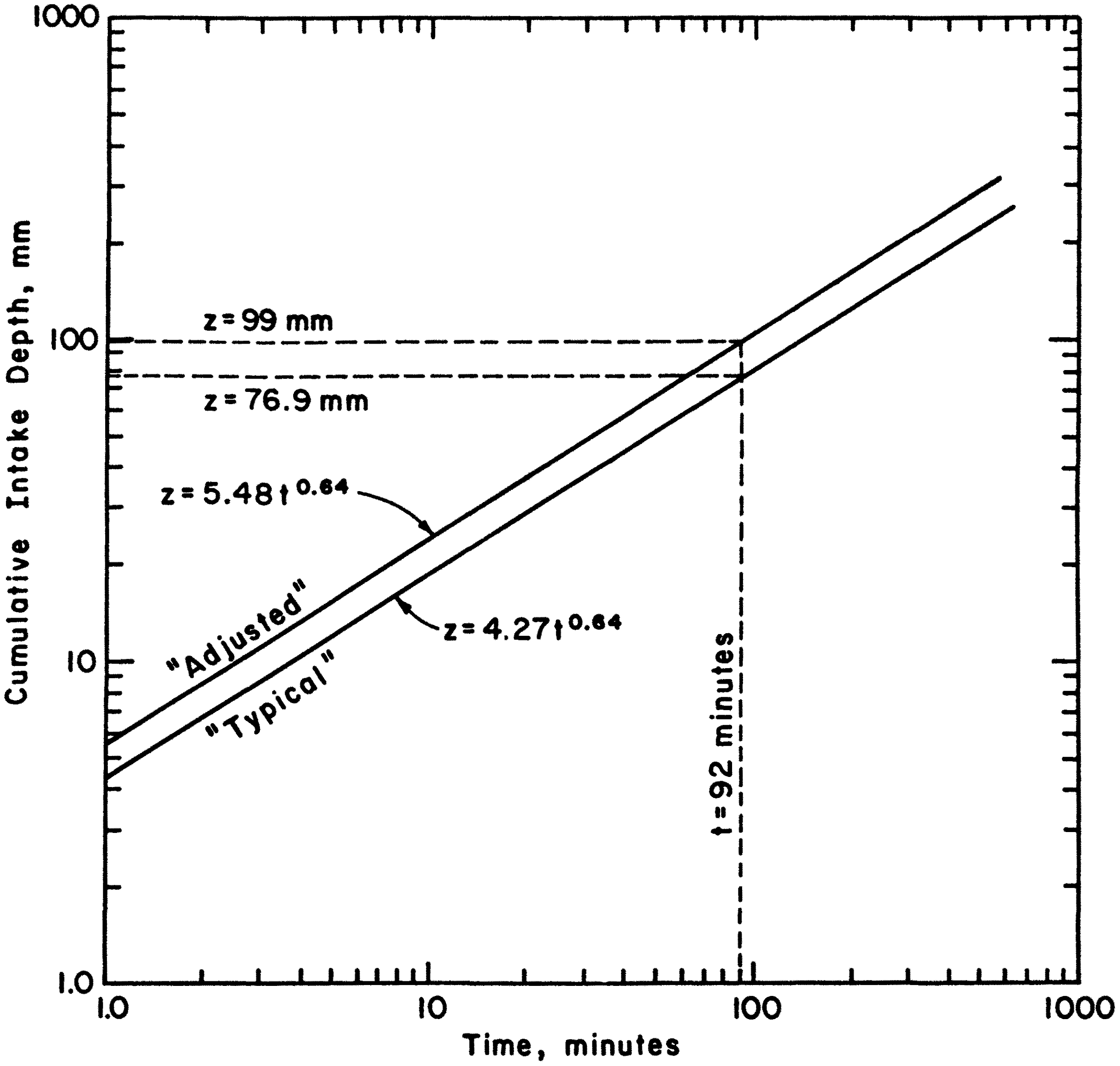


Figure 6. Illustration of adjustment of infiltration function.

where z = cumulative infiltrated depth (mm)

t = time (min).

A check on the adequacy of the "adjusted" curve is provided in the lower section of Table 2 using the same procedure as before. It is seen that Equation (11) adequately predicts the total average applied depth.

Results

The subsurface distribution of applied water as predicted by Equation (11) is plotted in Figure 7.

Each of the volumes associated with Figure 7 (as previously discussed) can be found by graphical integration of related areas of Figure 7. On a unit width basis (for border width of 7 m), they are as follows:

Volume applied, $W_a = 25.6\ m^3/m$

Volume runoff, $W_u = 2.7\ m^3/m$

Volume infiltrated, $22.9\ m^3/m$

Volume required, $W_r = 15.7\ m^3/m$

Volume stored, $W_{rz} = 15.7\ m^3/m$

Volume deep percolated, $W_p = 7.2\ m^3/m$

Volume deficit, $W_{df} = 0.0\ m^3/m$

Each of these volumes can be converted to an average depth by dividing by the border length of 240 m. Utilizing the above volumes, the performance parameters for this irrigation are determined using Equations (4) through (7).

$$\text{Water application efficiency, } E_a = \frac{W_{rz}}{W_a} \cdot 100 \qquad (4)$$

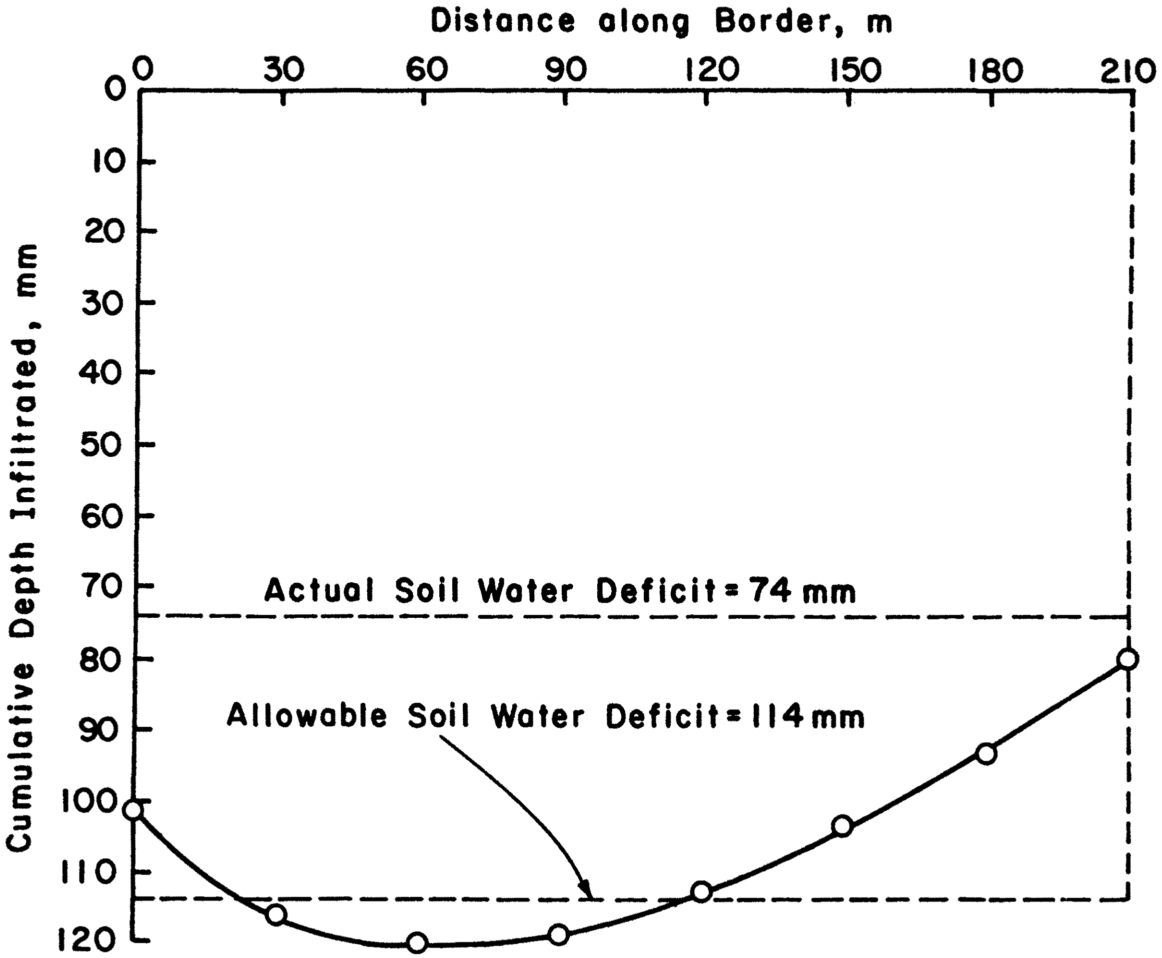


Figure 7. Subsurface distribution of applied water.

$$= \frac{15.7}{25.6} \cdot 100$$

$$= 61.4\%$$

Water requirement efficiency, $$E_r = \frac{W_{rz}}{W_r} \cdot 100 \quad (5)$$

$$= \frac{15.7}{15.7} \cdot 100$$

$$= 100\%$$

Tailwater ratio, $$R_t = \frac{W_u}{W_a} \quad (6)$$

$$= \frac{2.7}{25.6}$$

$$= 0.11$$

Deep percolation ratio, $$R_p = \frac{W_p}{W_a} \quad (7)$$

$$= \frac{7.2}{25.6}$$

$$= 0.28$$

The uniformity of water application is illustrated in Figure 8.

Table 3 presents a comparison of the suggested design with the system as it was operated for this irrigation. The expected runoff and deep percolation for the design are not available.

Table 3. Comparison of design and current operation.

Parameter	Design	Current Operation
Unit width stream, ℓ/s-m	4.31 (0.0464 cfs/ft)	4.83
Time of application, min	118.0	88.0
Border strip width, m	7.9 (26.0 ft)	7.0
Design depth or requirement, mm	114.0 (4.5 in.)	74.0
Average depth applied, mm	142.5 (5.61 in.)	119.9
Water application efficiency, %	80.0	61.4
Water requirement efficiency, %	--	100
Tailwater ratio, dec.	--	0.11
Deep percolation ratio, dec.	--	0.28

Conclusions

As a result of the evaluation, and comparison of the results to the suggested design, the following conclusions are made:

1. Obviously, the farmer irrigated too soon, i.e., at a smaller requirement than suggested. Although he was aware of this and was trying to apply a lighter amount, he still overirrigated the entire field.

2. Using the entire available flow on a smaller strip width, the farmer was using a larger unit width stream. The smaller application time used must be an attempt at reducing the amount applied. At 80% design efficiency and a requirement of 74 mm (2.9 in.), design equations yield an application time of approximately 68 minutes for this larger unit width stream. For the given field length this may be too short, since the distance of advance for this time if about 150 m (Figure 5). Poor distribution and underirrigation of the lower end would probably result.

3. The anticipated advance curve for the design should be only slightly steeper than in Figure 5 due to the offsetting effects of greater application time, but higher initial intake rate of the drier soil. The anticipated recession curve should be slightly steeper at the lower end and shifted upwards by an amount equal to the increase of application time, compared to Figure 5. Thus, the expected result if the system were operated according to design would be a more uniform application of water, with the upper end being slightly overirrigated and the lower end being slightly underirrigated.

4. For the border strip width currently in use, the farmer could use the larger unit width stream and decrease the application time to

around 106 minutes and expect a value of E_a near 80%. The resulting irrigation would most likely be less uniform, however.

5. The nonuniformity in slope for the first 90 m probably causes the recession curve to be steeper in that section. The first 30 m, being much steeper, would cause a short lag time; and then the next, flatter 60-m section would cause the recession to slow down. The advance is also slowed down in the 30-m station to 90-m station section (refer to Figure 5). If this section were graded to the slope of the remainder of the field, the advance and recession curves should be more "parallel" and the amount of overirrigation in that section reduced.

6. The large amount of deep percolation is a result of irrigating too soon. The amount of runoff is about right, however, indicating the farmer had about the correct inflow time. An efficient irrigation would most likely be impossible for the 210 m border, the given soil water deficit and the available stream. Either a very nonuniform irrigation would result, with the requirement at the upper end just being met; or there would be a large amount of runoff on what have to be very narrow borders (so that the unit width stream would be large enough for the desired advance time).

Recommendations

1. The farmer should attempt to adhere to an irrigation schedule in which the design depth of 114 mm (4.5 in.) is applied at each irrigation. Obviously, however, seasonal changes in crop requirement and infiltration rate would have to be taken into account.

2. Land leveling to obtain a more uniform grade in the direction of irrigation would increase the uniformity of the water application. In particular, the overirrigation occurring at the upper end of the border would be reduced.

3. The combined effects of the first two recommendations would yield high values for E_a and E_r. Also, it is pointed out, that runoff losses from the border could be effectively reduced through the use of a tailwater reuse system.

4. The farmer should not deviate from an irrigation schedule in which he applies 114 mm (4.5 in.) at each irrigation. The implication of operating at lower values of design depth for the given available flow rate and border dimensions is that the efficiency and uniformity of water application would be reduced. Otherwise, increased flexibility in the timing and rate of water delivery is necessary to obtain a specific unit width stream for a particular design depth, design efficiency and application time.

5. Using the 7-m (23-ft) width borders rather than the design recommended 7.9-m (26-ft) width results in a larger unit width stream when the full available flow is utilized. Assuming the other design parameters had been used with this unit width stream, a reduction in efficiency from the design efficiency is expected. The farmer could use a slightly smaller application time than the design and still achieve good results since the deviation in border widths was small.

EQUIPMENT LIST AND SUGGESTED DATA FORMS

Equipment

The equipment needed for a detailed evaluation of a border irrigation system is:

1. Engineer's level and rod for reading ground surface elevations.
2. A measuring tape for locating stations and measuring border dimensions.
3. Laths or stakes, hatchet and crayon for marking stations.

4. Instrument for measuring time (wristwatch with a second hand).
5. Equipment for collecting soil samples to determine water content.
    a. Soil auger or probe to take soil samples.
    b. Soil cans with tight-fitting lids.
6. Equipment for determining bulk density.
7. Cylinder infiltrometers (up to 6 sets).
8. Device for measuring the water level in cylinder such as a hook or staff gauge.
9. Equipment for installing cylinders.
    a. Metal plate or a heavy timber.
    b. Sledge hammer.
10. 3-mil plastic sheeting or other waterproof membrane.
11. Buckets for hauling water.
12. Shovels.
13. Devices for measuring flow such as Parshall or cutthroat flumes, calibrated siphons, weirs or flow meters.
14. Pencils, clipboards and data forms.

Data Forms

Data forms for the following data sets are provided:

Soil Water Content Data
Bulk Density Data
Cylinder Infiltrometer Data
Water Advance/Recession Data
Flow Rate Data
Farm and Field Data

FLOW RATE DATA

IDENTIFICATION______________ OBSERVER________________ DATE_________

CROP_________ LENGTH_________ INFLOW________ or RUNOFF__________

FURROW/BORDER NO._______ FURROW SPACING/BORDER WIDTH_____________

MEASURING DEVICE______________ START TIME_________ STOP TIME_______

COMMENTS:

Clock* Time (1)	Elapsed Time (min) (2)	ΔT (min) (3)	Reading ( ) (4)	Flow Rate ( ) (5)	Average Flow Rate ( ) (6)	Volume ( ) (6) x (3) (7)	Σ Volume ( ) Σ (7) (8)

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*All clock times are on 24-hour basis.

FARM AND FIELD DATA

IDENTIFICATION________________ OBSERVER_______________ DATE___________

FARMER________________________ ADDRESS__________________________________

(Sketch the farm and on-farm water delivery system noting pertinent roads, boundaries, field boundaries, locations of pumps, open drains, etc.)

APPENDIX A

RECONNAISSANCE QUESTIONNAIRE

1. Farmer operation and management

How does the farmer decide when to irrigate?
What is his irrigation frequency? How does it change during the season?
How does he decide how to irrigate?
How does he decide how much water to apply?
Does the farmer know the total flow rate available to him?
What are the farmer's operating hours?
Does he irrigate at night?
How does he decide how long to irrigate a field?
How long does he irrigate a field?
Does the farmer have any problems with the system?
What are his cultivation and tillage practices?
Does he irrigate more than one border strip at once?

2. Water supply

What are the sources of available water?
Is the delivery station (point of diversion to farm) a problem, i.e., high losses, etc.?
Is the on-farm distribution system a problem (i.e., too many in-field channels, high losses, etc.)?
What is the flow rate of each source of water?
When is each source available and for how long?
Is the frequency of delivery and available head a problem?
What is the water quality?
How is the water delivered to each field?

3. Crop characteristics

What are the crops being grown?
What are the respective planting dates?
What cropping patterns, if any, have been followed?
Does the farmer have any major problems in crop production?
What are the major inputs? Potential yield?
What is his expected yield? Average yield in area?
Any obvious physical symptoms of problems?

4. Physical characteristics

Does the farmer know the field dimensions?
Does he know the slope and cross-slope (if any)?
Has the field been leveled to a uniform slope?
If yes, when? If no, why not?
What provisions, if any, are made for surface runoff?
Does runoff leave the farm or is it used again somewhere on the farm?
What is the border spacing and how did the farmer decide on that spacing?
What is the method of diverting water into each border?

5. Soil survey

Does the farmer know the soils on his farm?
Does he know of any trouble spots (i.e., very light or heavy soils or salinity problems)?

6. Water table

Does the farmer know the groundwater level?
Does he feel it is a problem?
Is surface/subsurface drainage provided? If so, where?

APPENDIX B

SOIL MOISTURE MEASUREMENT CONSIDERATIONS

Basic guidelines to aid the evaluator in establishing procedures for sampling (where to samples, how many samples, etc.) are discussed. Plans will be needed to determine when, where and how much to sample for soil parameters such as field capacity, wilting point, bulk density, water content and infiltration as discussed in the text. It is recalled that a minimum of three replications of samples is called for in all cases to obtain a simple average. The following discussion is intended to provide a means of determining when more samples should be collected (and how many more) to increase the precision of the results and also to illustrate simple tests which can be used to interpret the results. Garcia (Appendix A, 1978) has presented a basic treatment of the statistical analyses of measurements. These include measures of central tendency, such as the mean; measures of variability, such as the standard deviation; and simple statistical inference based on these population parameters such that for a given level of probability an interval of values which encloses the true value of a parameter is estimated.

Several studies have focused on determining the variability of soil sampling for water content (Black et al., 1965; Reuss et al., 1975; Staple and Lehane, 1962; Hewlett and Douglass, 1961). Each of these studies presents results of site studies including means and standard deviations of sampling and extrapolation of these results to methods of estimating numbers of samples required for given levels of precision. The problems with such approaches is that it is necessary to know beforehand the variability of water contents to be expected in a field such that the number of samples or replicated samples to collect to obtain a confidence interval for the mean at a given precision (level of probability) can be determined. It is difficult to estimate the combined effects of sampling errors, possible sampling bias, and the variation of soil properties in a field (let alone the individual effects). At any rate, generalizations are made such as: requiring 30 or more samples per treatment to provide fair assurance that the least significant difference between the means of two treatments be less than 0.5 inch of water (Staple and Lehane, 1961). It should be obvious that given a certain level of variability in a given sampling plan, the precision with which a true value is estimated will increase as the number of samples taken increases. However, this is even further magnified where one is trying to estimate the difference between two true values. For instance, Reuss et al. (1975) presented results which showed that 95% confidence intervals for before and after irrigation water contents in a profile could be estimated as 9.50 ± 0.37 inches and 12.00 ± 0.61 inches, respectively. These were quite acceptable for the number of cores taken: five. However, for the difference of 2.5 inches the precision is ±0.71 inches or approximately ±28% of the value which was being estimated. This was unacceptable, and to increase the precision with which the difference is estimated the number of samples to collect both before and after irrigation is more than 60. This assumes the variability or error variance of sampling is a constant.

Two useful tools for analyzing sets of samples for significant differences are one-way and two-way analysis of variance tests. For instance, if a soil survey shows nonuniform soils in the field being studied, but significant differences in infiltration rates through the field are not suspected, a one-way analysis of variance of several sets of replicated tests would statistically determine if significant differences between locations are present. Similarly, a two-way analysis of variance can be used to check on differences between replications at a sampling location and on differences between sampling locations.

In all instances, it should be remembered that replications (minimum of three) are required to establish an average. If soils are uniform, three cores in the entire field may be all that are necessary, however, more may be desired to increase precision. When soils are nonuniform, replications (minimum of three) in each major soil type are necessary to establish the mean for that soil type. More samples will increase the precision. A one-way analysis of variance will determine if significant differences between the estimated means exist. Tradeoffs in precision and costs (time and effort of the evaluator) occur. In general, the best design to use is the one that provides the maximum precision at a given cost (effort) or that provides a specified precision (error) at the least cost (Black et al., Chap. 5, 1965).

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